RECORD OF DECISION

OHIO RIVER MAINSTEM SYSTEM STUDY
System Investment Plan/Programmatic Environmental Impact Statement
ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

I have reviewed the final integrated System Investment Plan/Programmatic Environmental Impact Statement (SIP/PEIS) for the Ohio River Mainstem System Study (ORMSS), as well as all comments received in response to final agency review. I find the recommended plan addresses the serious structural condition of the locks on this economically vital waterway and is therefore in the public interest. Thus, I approve the plan for use in scheduling future Federal navigation studies and maintenance on the mainstem Ohio River. Further, I approve pursuit of planning and implementation of measures to improve environmental sustainability of the Ohio River.

The basic authority for the ORMSS, is contained in a resolution adopted by the Committee on Public Works of the United States Senate dated 16 May 1955. Further authority was provided through a resolution adopted by the U.S. House of Representatives Committee on Public Works and Transportation adopted 11 March 1982. The ORMSS does not recommend any projects or programs for authorization by Congress. Rather, the primary purpose of the ORMSS is to develop the best System Investment Plan (SIP) for maintaining safe, environmentally sustainable, and reliable navigation on the mainstem Ohio River over a 60-year period from 2010 to 2070. In response to stakeholder input, the study purpose was modified to include identification of high priority needs to improve ecological sustainability and provide a balance between economic and environmental improvements.

The study evaluated the operation and maintenance, rehabilitation, and construction reinvestment needs at the 19 navigation lock and dam sites on the Ohio River Mainstem, with needs determined by the structural condition of each lock and the economic consequence of outages. The ORMSS SIP primarily focused on the long-term needs associated with the locks since the performance of these structures is the principal driver of lock closure. The dams were not part of this study since improvements or modifications to the dams would not alter lock capacity or performance. The magnitude of economic consequences is directly related to the likelihood of a lock outage and the level of waterway traffic. Given uncertainty with regard to future traffic growth, five alternative traffic demand scenarios were developed. These scenarios were based upon three competing outlooks for clean air regulations affecting electric utility output and fuel choices and upon two economic growth outlooks. Risk-based projections of structural condition at each lock throughout its life cycle provided an indication of the likelihood and duration of lock outages due to component failures. Alternative investment options were examined for each lock site within the context of the entire system in order to find the investment option that maximized system benefits net of costs. The SIP/PEIS does

not identify a most likely scenario, nor recommend any of the five system plans; it presents an optimum system investment plan under each scenario.

The final SIP/PEIS recommends the following:

- Increase Operation and Maintenance (O&M) investments to maximize economic efficiency by pursuing the replacement and major rehabilitation of major components when economically justified.

- Complete all authorized navigation improvements as soon as possible at Olmsted, J.T. Myers, McAlpine, Greenup, Lower Monongahela, Kentucky Lock, and Chickamauga.

- Provide optimal funding for the Upper Ohio River Feasibility Study currently underway in order for this project to be included in a WRDA in or around the FY 2012 time frame.

- Initiate main chamber rehabilitation studies as soon as possible for Meldahl, Hannibal, and J.T. Myers.

- Initiate a main chamber rehabilitation study for Pike Island in the near term (before 2015).

- Pursue planning and implementation of measures to improve environmental sustainability in collaboration with other interests.

- Complete the Endangered Species Act, Section 7 consultation process for the Operation and Maintenance of the Ohio River Corps facilities and incorporate all Reasonable and Prudent Measures identified, if any.

- Complete on-going work on the Markland gates as soon as possible.

- Evaluate site-specific impacts for follow on studies and other actions and tier from the ORMSS SIP/PEIS in accordance with the President's Council on Environmental Quality Regulations for Implementing NEPA, 40 C.F.R. 1502.20.

- Implement the recommendations of the Ohio River Basin Comprehensive Study in order to assess water resource opportunities throughout the basin in collaboration with other interests. Planning efforts include identification and evaluation of opportunities to improve environmental sustainability throughout the basin including the tributaries.

- Establish a standalone program (Ohio River Navigation System Investment Program) to update the data and models used in preparing the System Investment Plan. Expand the program capability to include the Ohio River dams and include tributary (Allegheny, Monongahela, Kanawha, Green, Tennessee, and

Cumberland Rivers) locks and dam structures to support navigation investment decisions and manage future system risk. Use these tools in annual budget formulation.

- Use the Ohio River Navigation System Investment Program to reexamine the medium and long term needs identified in the SIP to optimize investments on these projects.

- The System Investment Plan was not developed considering a constrained federal budget or considering the total Ohio River System. Follow on actions need to be conducted to analyze investment strategies with a constrained Federal budget and expanded to include all navigation locks, dams, and channels on the Ohio River and its navigable tributaries.

OHIO RIVER LOCK INVESTMENT ALTERNATIVES

The vast majority of Ohio River locks are between 25 and 50 years of age, whereas by 2015, 40% of Ohio River locks will be over 50 years old. As locks age and their reliability decreases, closures of main chambers for repair become more likely. When these closures occur, smaller auxiliary lock chambers must carry the entire traffic burden. Because these chambers are smaller, tows must be uncoupled and moved through in multiple lockage operations (usually two lockage cuts, up to five at Emsworth, Dashields and Montgomery) rather than a typical single cut lockage operation used at a main chamber.

For navigation investments, the No Action Alternative (Without Project Condition or WOPC) was continuance of a reactive maintenance strategy. Alternatives considered in the final array of With Project Conditions (WPC) for navigation investment consisted of:

- The Advanced Maintenance Alternative (AMA) which allows for scheduled replacement of any critical lock component when economically justified,
- The Major Rehabilitation Alternative (MRA) which allows both component replacement and bundling of component replacements into major rehabilitation packages that meet Corps criteria for that program when economically justified, and
- The Lock Modernization Alternative (LMA) which allows proactive maintenance and major rehabilitations as well as lock modernization (i.e., extension or replacement) options.

Measures eliminated from detailed consideration in the WOPC are in Section 8.4, and the alternative of Federal Disinvestment in the system is in Section 8.6.1 of the SIP/PEIS. Measures eliminated from detailed consideration in the WPC are in SIP/PEIS Sections 9.2.2.3 for maintenance, 9.2.3.3 for operations, and 9.3.5 for modernization.

MEASURES FOR OHIO RIVER ECOSYSTEM SUSTAINABILITY

Significant degradation of aquatic and riparian/floodplain resources have occurred as a result of human activities throughout the Ohio River region. These include, but are not limited to, water pollution from municipalities and industries; acid mine drainage; in-stream extraction of sand and gravel; construction and operation of high-lift locks and dams; loss of shallow water habitat due to maintenance of the navigation channel; disruptions to mussel beds due to barge fleeting areas, tow queuing, disposal of dredged materials, and conversion of habitat for agriculture, residential, commercial, and industrial uses. Habitat conversions are expected to continue in the future as development in or adjacent to the river continues to occur.

A total of 26 high priority ecosystem sustainability measures were identified through an Expert Elicitation Process and were considered in Section 9.4 of the SIP/PEIS. The No Action Alternative included 14 types of measures that could be implemented through a variety of existing Corps authorities, such as the Ohio River Ecosystem Restoration Program, the Ohio River Basin Comprehensive Study, and Water Resources Development Acts Sections 206 and 1135, especially in collaboration with other agencies and interests including non-Federal sponsors, as appropriate. The two ecosystem sustainability alternatives in the WPC were the Moderate and Maximum Ecosystem Sustainability Plans. These were developed based on approximate costs, need for modified or additional authority, complexity, and several scientific, policy, funding, and timing uncertainties. The Moderate Plan includes five specific types of measures in addition to the 14 from the WOPC, while the Maximum Plan consisted of all 26 measures identified.

RECOMMENDED PLAN

The recommended plan for navigation investment is the LMA. This plan includes component replacements as in the AMA as well as bundling of component replacements as in the MRA, when and where these are economically justified. It also provides for lock replacements or extensions where needed and justified. The LMA includes elements of the No Action Alternative in those instances where a reactive maintenance strategy is the best solution. Individual measures, as well as the mixture of actions, are optimized to provide the greatest benefit from Federal investment. The LMA is the National Economic Development (NED) Plan. The LMA is also the Environmentally Preferred Alternative because it provides the greatest reduction in total transit days on the Ohio River mainstem. Reducing total transit days translates into substantially less time that tows are in queue in environmentally sensitive tailwater areas. Tailwaters downstream of locks and dams on the Ohio River provide habitats that most resemble pre-impoundment riverine conditions important to numerous species of fish, mussels, and other aquatic life.

The recommended plan for ecosystem sustainability is the Moderate Plan. This plan includes all elements of the No Action plan and adds five other types of measures to improve ecosystem sustainability. While the Maximum Plan would be environmentally preferable to either No Action or the Moderate Plan, uncertainties surrounding individual

restoration project implementation or program development identified in the Maximum Plan led to recommendation of the Moderate Plan. As opportunities arise, especially during planning for site-specific navigation improvements, however, individual measures contained in the Maximum Plan will be pursued in conjunction with non-Federal sponsors.

PUBLIC/AGENCY COMMENTS IN THE FINAL SIP/PEIS

The public/agency comment for the final SIP/PEIS was open from February 25, 2011 to March 28, 2011. The comment period was extended an additional 15 days to accommodate a request from a commenter to provide additional time to review the document. A total of 49 comments were received during the review period. A summary of the specific comments is attached to this Record of Decision (ROD). Seven groups, representing Federal and state agencies and non-governmental environmental organizations, provided comments. Commenter's included the U.S. Environmental Protection Agency (EPA), Indiana Department of Natural Resources, the Kentucky Department of Environmental Protection, the Kentucky Resources Council, the Ohio River Foundation, Oxbow Inc., and The Nature Conservancy. Many of the comments from the non-governmental organizations were either recommendations or were identical to comments provided for the initial public review conducted in 2006, which had been previously addressed. Other comments provided by the NGOs were addressed in the report. Some technical comments provided by The Nature Conservancy provided new information on natural resources and were incorporated into the report. Comments from resource agencies were generally supportive, questioned some of the methodologies utilized in the ORMSS analyses, or provided specific recommendations for future studies and language for the ROD. Comments provided during the final public review did not affect study analyses or conclusions and consequently warranted no major revisions to the ORMSS SIP/PEIS.

COMMITMENTS

Foremost of commitments toward mitigating systemic environmental impacts is adoption of sustainability-focused mitigation measures for future actions. Sustainability-focused mitigation differs from traditional replacement-in-kind mitigation in that it includes measures directed toward those high priority ecosystem needs identified through the Expert Elicitation Process. In addition, to address systemic issues related to the navigation system, the Corps will incorporate the following environmental components into future site-specific studies:

- Evaluation, and if feasible construction, of native fish passage strategies at each lock and dam along the Mainstem during studies for lock modernization and major rehabilitation. These strategies will be developed to benefit not only native fish populations but other valued aquatic ecosystem components such as freshwater mussels.

- Continuance and expansion, as needed, of the Interagency Working Group to participate in and to review and comment on studies as they progress.

- Identification, description, and quantification of riverine habitat within the individual project's area of influence.

- Incorporation of sustainability planning within each individual project's area of influence.

- Development of a National Environmental Restoration (NER) Plan that will become part of the Combined NED/NER Plan for authorization of each site-specific project if all policy conditions are met. All separable ecosystem restoration costs, including feasibility study costs, will require a non-Federal cost sharing partner in accordance legislation and policies of the time.

Although the selected plans do not include specific recommendations for monitoring of mitigation commitments, it will be necessary for the Corps of Engineers, in cooperation with stakeholders (i.e., Federal, State, and local agencies, along with non-governmental entities) to maintain awareness and communication of economic and ecological conditions and issues in order to make necessary adjustments to the selected plans.

It is my decision that the LMA for Federal navigation investment and the Moderate Plan for ecosystem sustainability will be pursued. These plans as detailed in the ORMSS SIP/PEIS include sufficient flexibility for revision and update as conditions indicate the necessity to do so. The public interest will best be served by implementing these plans for improving and balancing economic and environmental sustainability of the Ohio River mainstem. Thus, I approve the Lock Modernization and the Moderate Ecosystem Sustainability Plans for the Corps of Engineers to use in planning and budgeting Federal investments in and along the mainstem Ohio River.

JOHN W. PEABODY
Major General, U.S. Army
Division Engineer

8 July, 2011
DATE

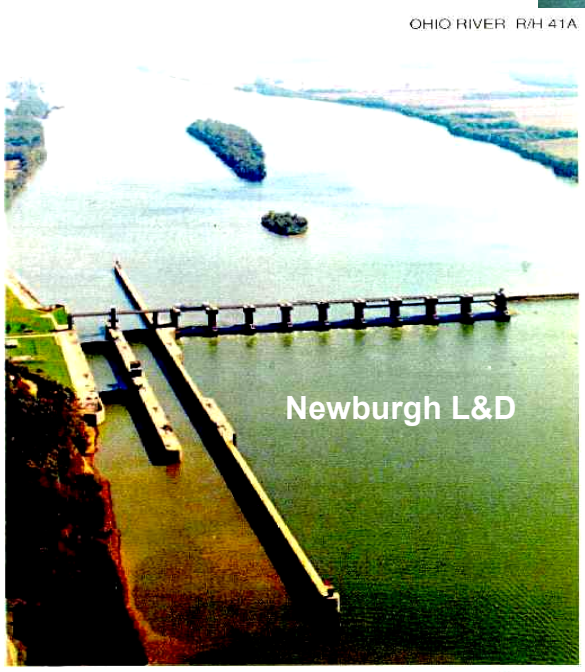
US Army Corps
of Engineers
Great Lakes and Ohio River Division
LOUISVILLE DISTRICT / HUNTINGTON DISTRICT / PITTSBURGH DISTRICT

Ohio River Mainstem Systems Study (ORMSS)

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Integrated Main Report



July 2011

US ARMY CORPS OF ENGINEERS, GREAT LAKES AND
OHIO RIVER DIVISION
OHIO RIVER MAINSTEM SYSTEM STUDY
INTEGRATED SYSTEM INVESTMENT PLAN AND
PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT
JULY 2011
Illinois, Indiana**,** Kentucky, Ohio, Pennsylvania, Kentucky

Abstract: The primary purpose of the Ohio River Mainstem System Study (ORMSS) was to develop the best System Investment Plan (SIP) for maintaining safe, environmentally sustainable, and reliable navigation on the 981 mile long Ohio River over the period 2010-2070. The SIP is intended to serve as a long term planning tool for decision makers in the budgeting and asset/infrastructure management process and does not recommend any specific projects for authorization or construction. This study evaluated system-wide impacts through a Programmatic Environmental Impact Statement (PEIS). Navigation investment alternatives were formulated based on five possible scenarios associated with utility coal, air quality compliance policy, and economic growth. Navigation infrastructure recommendations in the SIP serve to reduce expected maintenance and repair costs and associated delays to navigation due to lock closures. The SIP includes a mix of investments ranging from reactive maintenance (replacement of lock components as failure occurs) to advance maintenance (replacement of lock components before failure) to major rehabilitations (bundling of multiple component replacements into a rehabilitation) to lock modernization on the upper Ohio River. Recommendations for new lock construction will require justification through follow-on detailed feasibility study. Identification of measures to improve ecological sustainability was included as a study purpose to provide a balance between economic and ecological development. Recommendations for ecosystem sustainability alternatives were formulated from measures identified during facilitated group discussions that focused on highest priority needs to enhance aquatic and riparian ecosystem sustainability. Ecosystem related recommendations included measures to improve ecosystem sustainability in collaboration with other interests. A major focus of the PEIS was the comprehensive Cumulative Effects Assessment (CEA) that evaluated impacts from past, present, and reasonably foreseeable future actions on ten categories of Valued Environmental Components. For many of the recommended actions, future site-specific studies will be required prior to project approval or recommendation for authorization.

This document is an integrated report wherein the PEIS is embedded within the planning report. Table 2-2 in Section 2 identities locations of discussions required to be included in the PEIS.

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System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Integrated Main Report

July 2011

Ohio River Mainstem System Study Integrated Main Report
(Programmatic Environmental Impact Statement Included)

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LIST OF ACRONYMS
OHIO RIVER MAINSTEM SYSTEM STUDY/PROGRAMATIC ENVIRONMENTAL IMPACT STATEMENT

AES —Analysis of Environmental Sustainability

AM – Adaptive Management

AMD – Acid Mine Drainage

AR – Advanced Replacement of Lock Component(s)

ARA – Advanced Replacement Alternative

AWO – American Waterways Operators

BCERE – Baseline Cost Estimate for Real Estate

BEA —Bureau of Economic Analysis

BOD – Biological Oxygen Demand

BMP – Best Management Practices

CE – Cumulative Effect

CEA – Cumulative Effects Assessment

CEQ – President's Council on Environmental Quality

CG – Construction General Funding Account

CO Carbon Monoxide

CS – Clear Skies

CSO – Combined Sewer Overflows

CSw/o Hg – Clear Skies without Mercury Limits

CWA Clean Water Act

DINAMO – The Association for Development of Inland Navigation in America's Ohio Valley

DO – Dissolved Oxygen

LIST OF ACRONYMS
OHIO RIVER MAINSTEM SYSTEM STUDY/PROGRAMATIC ENVIRONMENTAL IMPACT STATEMENT

EDM — Emsworth, Dashields, and Montgomery Locks and Dams

EIS — Environmental Impact Statement

EJ — Environmental Justice

EmSh — Emerald Shiner

ENGO — Environmental Non-Governmental Organization

ERDC — U.S. Army Corps of Engineers Research and Development Center

EO — Executive Order

EOP — Environmental Operating Principles

EP — Engineer Pamphlet

ER — Engineer Regulation

ERNS — Emergency Response Notification System

ERP — Ohio River Ecosystem Restoration Program

ES — Environmental Sustainability

FAF - U.S. Department of Transportation's Freight Analysis Framework

FONSI — Finding of No Significant Impact

GSA — General Service Administration

H&S — Health and Safety

HQUSACE — U.S. Army Corps of Engineers Headquarters

HSI — Habitat Suitability Indices

HU — Habitat Unit

IAIA — International Association for Impact Assessment

LIST OF ACRONYMS
OHIO RIVER MAINSTEM SYSTEM STUDY/PROGRAMATIC ENVIRONMENTAL IMPACT STATEMENT

ITR — Independent Technical Review

IWG — Interagency Working Group

JTU — Jackson Turbidity Unit

L/D — Locks and Dams or Lock and Dam

LM — Lock Modernization

LMA— Lock Modernization Alternative

LPMS — Lock Performance Monitoring System

LRD — Great Lakes and Ohio River Division

LRN — U.S. Army Engineer Nashville District

m^2 — square meters

MIwb — Modified Index of Well Being

MGQCS — Miter Gate Quick Changeout System

MR — Major Rehabilitation

MRA — Major Rehabilitation Alternative

MRER — Major Rehabilitation Evaluation Report

MS — Marginally Sustainable

MSA — Metropolitan Statistical Area

NAAQS — National Ambient Air Quality Standards

NAVPAT — Navigation Predictive Analysis Technique

NED — National Economic Development

NEPA — National Environmental Policy Act of 1969

LIST OF ACRONYMS
OHIO RIVER MAINSTEM SYSTEM STUDY/PROGRAMATIC ENVIRONMENTAL IMPACT STATEMENT

NES — National Environmental Sustainability Plan

NGO — Non-Governmental Organizations

NHL — National Historic Landmarks

NOx — Nitrous Oxides

NPDES - National Pollutant Discharge Elimination System

NR — National Register of Historic Places

NRC — National Research Council of the National Academy of Sciences

NS — Not Sustainable

NSP — Navigation Stewardship Program

NTU — Nephalometric Turbidity Unit

NGO — Non-Governmental Organizations

03 — Ozone

O&M — Operations and Maintenance

ODNR — Ohio Department of Natural Resources

OHDW — Ohio Department of Natural Resources, Division of Watercrafl

ORFIn — Ohio River Fish Index

ORThJWR - Ohio River Islands National Wildlife Refuge

ORNIM — Ohio River Navigation Investment Model

ORS — Ohio River Navigation System

ORSANCO — Ohio River Valley Sanitation Commission

ORV — Ohio River Valley

LIST OF ACRONYMS
OHIO RIVER MAINSTEM SYSTEM STUDY/PROGRAMATIC ENVIRONMENTAL IMPACT STATEMENT

OSB — Oversight Board

OSU - Ohio State University

P&G - Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies

PCBs — Polychlorinated Biphenyls

PDT — Product Delivery Team

PED — Preconstruction Engineering and Design

PEIS — Programmatic Environmental Impact Statement

PGN — Planning Guidance Notebook

pH - A measure of acidity and/or alkalinity

PM - Particulate Matter

QC — Quality Control

RCRA — Resource Conservation and Recovery Act

REDM — Real Estate Design Memorandum

REP - Real Estate Plan

RFFA — Reasonably Foreseeable Future Action

RFR — RiparianlFloodplain Resources

rm — River Mile

RM — Reactive Maintenance

RMA — Reactive Maintenance Alternative

ROD — Record of Decision

SHPO — State Historic Preservation Officer

LIST OF ACRONYMS
OHIO RIVER MAINSTEM SYSTEM STUDY/PROGRAMATIC ENVIRONMENTAL IMPACT STATEMENT

SIP — System Investment Plan

SO_2— Sulfur Dioxide

TES — Threatened and Endangered Species

TMDL — Total Maximum Daily Load

TSS — Total Suspended Solids

UB — Utility Based

UBH — Utility Based High

ug/L — Micrograms per Liter

USACE — U.S. Army Corps of Engineers

USEPA — U.S. Environmental Protection Agency

USFWS — U.S. Fish and Wildlife Service

USGS — U.S. Geological Survey

UMR/IWW — Upper Mississippi River/Illinois Waterway

VEC — Valued Environmental Component

VOC — Volatile Organic Compound

WOPC — Without Project Condition

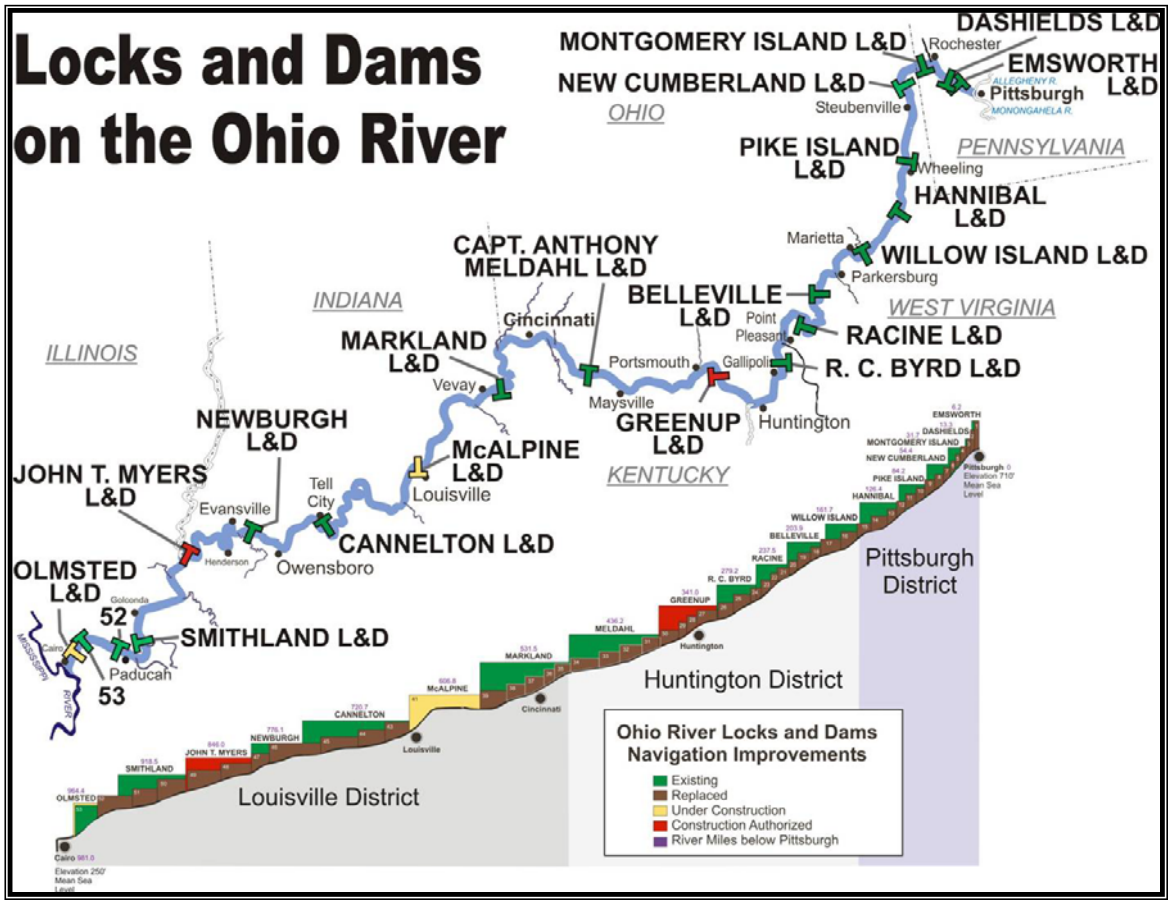
WPC — With Project Condition

EXECUTIVE SUMMARY

1. Valuing Navigation on the Ohio River System.

The Ohio River Mainstem is the principal artery of the Ohio River System (ORS), which also includes the navigable tributaries Allegheny, Monongahela, Kanawha, Big Sandy, Kentucky, Green, Tennessee and Cumberland rivers. Users of the Ohio River System ship by barge 270 million tons of commodities worth over $30 billion, saving over $2 billion in transportation costs annually. These savings result in additional national output estimated at over $11 billion, which makes possible approximately 100,000 jobs and $3 billion in income.[1]

Figure 1
Ohio River Mainstem Plan and Profile



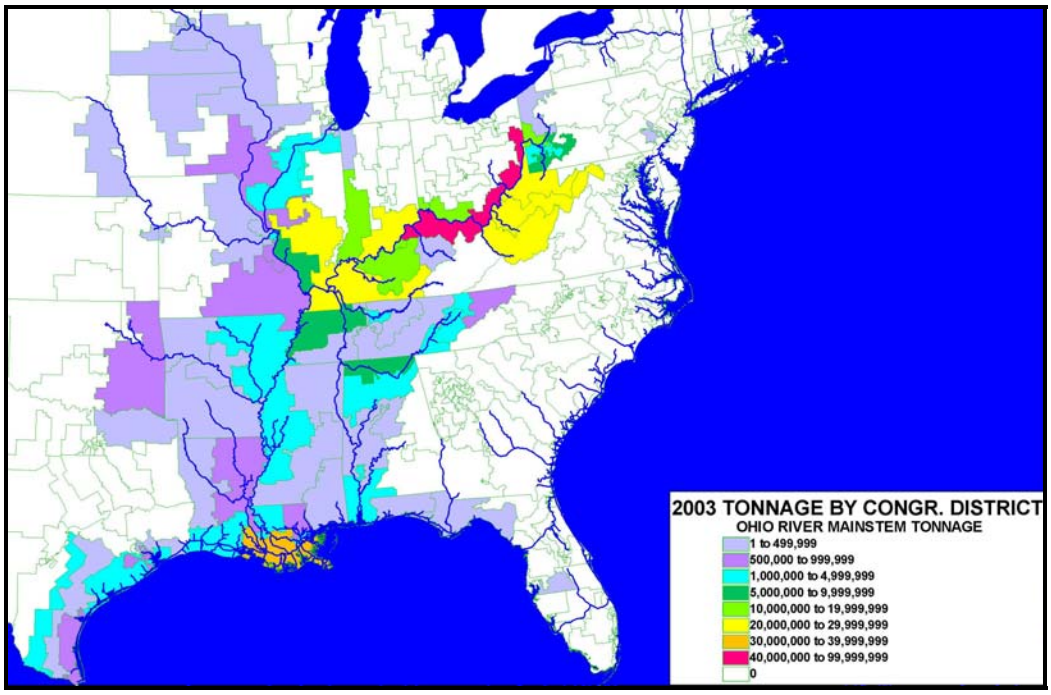
The Ohio River Basin (ORB) is rich in natural resources and is home to over 31.5 million people. There are 57 coal-fired power plants in the ORS that provide 20 percent of

[1] *Regional Economic Development Impacts on the Ohio River Basin due to Commodity Savings Along the Ohio River System*, September 1999, Marianne Matheny, USACE-NAB and Dennis Robinson, USACE-IWR

the nation's coal-fired electric generation capacity. One of the primary reasons the electricity rates in the region are among the lowest in the nation is the relatively inexpensive transportation costs to deliver coal to the power plants via the waterway. Per weight of commodity, coal accounts for 50-60% of the ORS waterway shipments.

The Ohio River is a major transportation artery that serves as an alternative to increasingly congested highways and rail lines for the movement of domestic cargo. Figure 2 shows the extent to which Ohio River mainstem traffic is distributed throughout the eastern United States.

Figure 2
Distribution of Ohio River Traffic*



* Any tonnage that travels at least a portion of the Ohio River.

A significant portion of Ohio River mainstem tonnage passes through Gulf ports in route to/from foreign markets. The value of the Ohio River to communities and industry is transparent during normal operation. However, when lock closures occur, traffic can be slowed or even stopped, affecting the delivery of goods and ultimately increasing costs to consumers. Recent unscheduled closures at Greenup, McAlpine, Hannibal and Montgomery locks have cost millions of dollars in additional transportation costs alone. Table 1 shows data related to these closures. The economic impacts reported in this table reflect only the delay costs imposed on tows waiting to use the lock. Several investigations following these main chamber lock closures found there are other logistical costs associated with closures that can be quite high. For example, a survey of Greenup Lock users uncovered $29 million in costs above and beyond the $13.2 million in delay costs shown in Table 1. In the present business environment of just-in-time delivery of goods and commodities, any closure interrupts production, forces movements onto other transportation modes, and increases costs which are then passed along to the consumer.

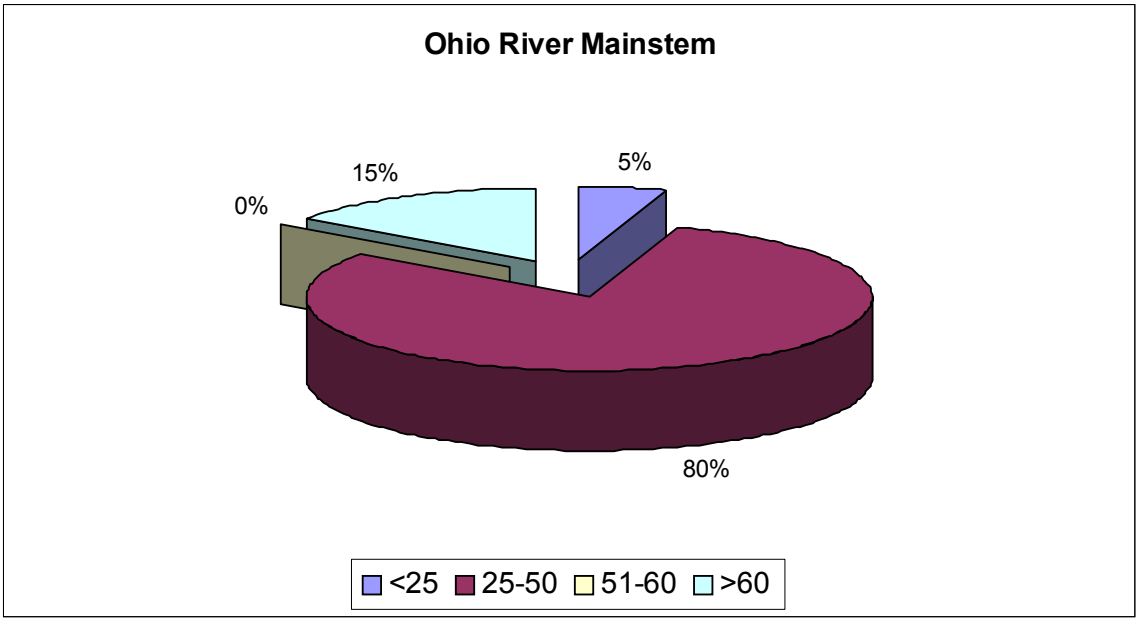
Table 1
Ohio River Mainstem Lock Closures 2002-2005

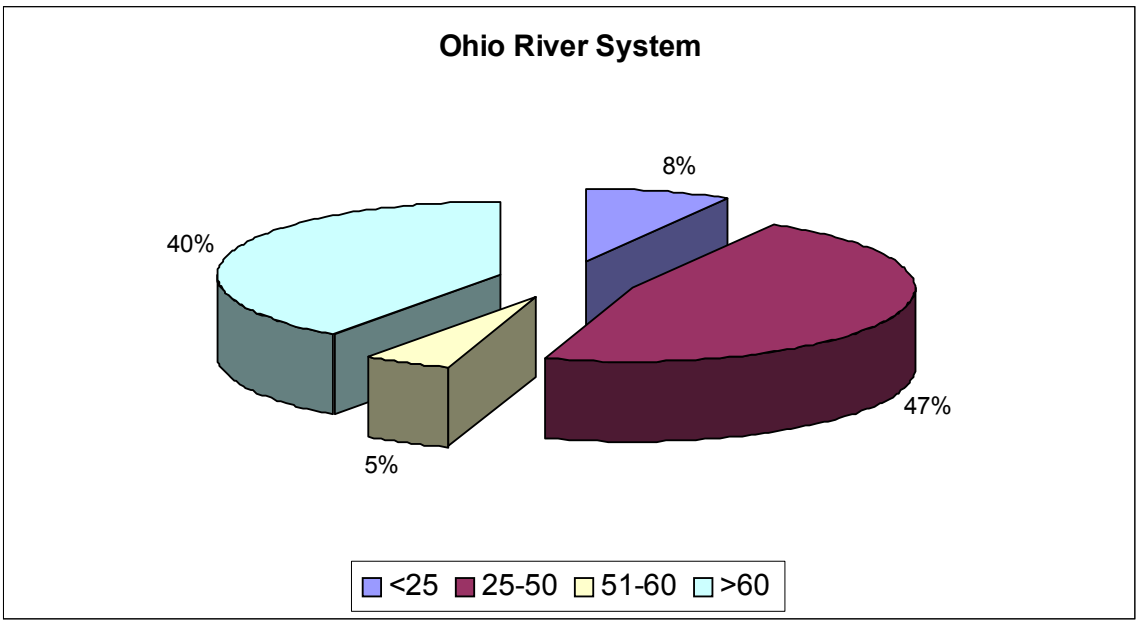
Lock	Closure Dates	Closure Duration	Delay (hrs)		Number of Tows Delayed	Delay Costs $
			Max	Avg		
Hannibal	Nov 1 - 15, 2005	15 days	140	58	125	$ 3,000,000
McAlpine	Aug 8 - 19, 2004	10 days 23.4 hrs	257	77	19	$ 695,000
Greenup	Sep 8 - Oct 31, 2003	52 days, 8 hrs	93	38	718	$ 13,200,000
Montgomery	Jun 18 - 28, 2002	10 days, 17 hrs	110	34	130	$ 1,200,000
Montgomery	Jul 15 - 31, 2002	16 days, 16 hrs	132	33	179	$ 1,700,000

Source: Lock Performance Monitoring System (LPMS) and Institute for Water Resources (IWR) cost data.

The lock closures cited above are symptomatic of an aging infrastructure and projects with small auxiliary lock chambers. As locks reach the limits of their design life, closures of main chambers for repair become more likely. When these closures occur, smaller auxiliary lock chambers must carry the entire traffic burden. Because these chambers are smaller, tows must be uncoupled and moved through in multiple lockage operations (usually two lockage cuts) rather than a typical single cut lockage operation used at a main chamber. The multiple cut lockages take nearly three times as long, and at many lock projects this additional time leads to the lengthy delays shown in Table 1. The age distribution of the mainstem locks is shown in Figure 3. Figure 3 also shows that the vast majority of Ohio River locks are between 25 and 50 years of age, with 15% of locks being greater than 50 years of age. For the system as a whole, nearly half of the locks are between 25 and 50 years of age, and another 45% are over 50 years old, indicating that the problem of aging infrastructure is even more acute on the Ohio River's navigable tributaries. By 2015 locks over 50 years of age represent 40% of Ohio River locks and 68% of Ohio River System locks.

Figure 3
Age Distribution
Ohio River Mainstem and Ohio River System Main Lock Chambers





2. Study Purpose.

The primary purpose of the Ohio River Mainstem Systems Study (ORMSS) is to develop the best System Investment Plan (SIP) for maintaining safe, environmentally sustainable, and reliable navigation on the Ohio River over a 60-year period from 2010 to 2070. The study evaluated the operation and maintenance, rehabilitation, and construction reinvestment needs at the 19 navigation lock and dam sites on the Ohio River Mainstem as shown in Figure 1.[3] The study presents five individual plans for meeting the system needs based on five different traffic forecast scenarios. Reliable operation of these structures is critical to future commercial navigation throughout the Ohio River basin. In response to stakeholder input, the study purpose was modified to include the identification of measures to improve ecological sustainability to provide a balance between economic and environmental improvements.

3. Study Processes.

The ORMSS report is an integrated System Investment Plan (SIP) and Programmatic Environmental Impact Statement (PEIS). The PEIS is centered on a system-wide Cumulative Effects Assessment (CEA) and other studies that focused on specific issues identified through the study scoping process. The study team sought to determine effects on the sustainability of Ohio River resources from all past, present and reasonably foreseeable future activities on the river, not just those associated with navigation improvements. An Interagency Working Group (IWG) consisting of federal and state natural resource agencies and non-governmental environmental interests was involved in the development of the CEA and the PEIS.

Early in the Ohio River Mainstem Systems Study two site specific lock facilities were identified where initiation of construction was warranted prior to the completion of the System Investment Plan (SIP). These two high traffic projects, J.T. Myers and Greenup Locks and Dams, demonstrated immediate, economically justified investment opportunities during early prioritization work. Utilizing the same rigorous engineering risk and reliability-based approach used in this study, feasibility-level documentation and full NEPA analysis were produced for these 'near-term' sites: J.T. Myers and Greenup Locks and Dams. These projects were authorized by the Water Resource Development Act (WRDA) 2000 Sections 101(a) (14) and (15), respectively. In addition, the IWG worked together to develop the Ohio River Ecosystem Restoration Program which was also authorized in WRDA 2000. However, the Ohio River Ecosystem Restoration Program has yet to receive Congressional appropriations for implementation. As such, the program is now on the candidate list for de-authorization. Therefore, it is still mentioned in the final SIP/PEIS, although it is not included as a reasonably foreseeable future action in either the Without- or With-Project Conditions. Though not necessarily a part of the Ecosystem Restoration Program, an assessment of high priority needs to enhance ecological sustainability is included in the current report.

[3] Olmsted L/D will replace L/Ds 52 and 53 when completed.

The study has benefited by the lessons learned in the Upper Mississippi River-Illinois Waterway Navigation Feasibility Study. A number of issues identified by the National Academy of Science review of that study influenced the direction of ORMSS:

- Benefits were estimated on a system basis, rather than one lock at a time.
- Nonstructural alternatives, like traffic scheduling, were evaluated.
- The Ohio River Navigation Investment Model, was developed to fully integrate economic and engineering data..
- Modifications were made to the ORNIM model to produce input data for the Navigation Predictive Analysis Technique (NAVPAT) model, thus integrating environmental and other analyses.
- The cumulative effects analysis incorporated all actions producing impacts to Ohio River resources.
- A range of scenarios based on plausible futures was developed to account for the uncertainty inherent in forecasting traffic.
- The Waterway Analysis Model (WAM), a component of ORNIM, used simulation modeling techniques to estimate throughput capacity.
- A risk and reliability assessment model was developed for analyzing lock structures.

A variety of stakeholders participated in the development of the study through forums as varied as public meetings and workshops with industry groups, environmental groups, and academia. The ORMSS study team has solicited input and shared work with all interested stakeholders through various communication channels.

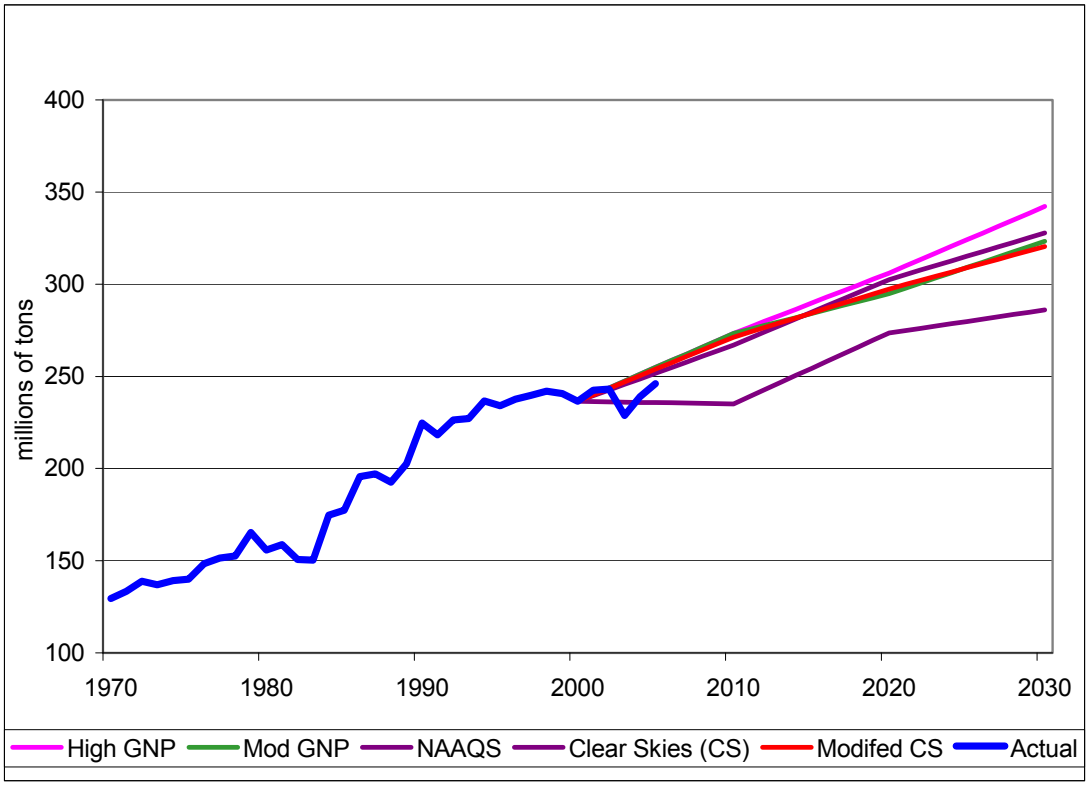
Independent technical review of all of the analyses has been conducted by subject matter experts. The independent technical review of the economics was completed entirely by experts external to the Corps and included two members of the National Academies of Science who specifically looked at traffic forecasts and the Ohio River Navigation Investment Model. Whether these experts were from academia, other agencies, or within the Corps, their reviews have provided authenticity and veracity to the conclusions and recommendations contained herein. An In-Progress Review was also conducted in February 2004 with Corps Headquarters, providing an opportunity to make mid-course adjustments of the study.

4. Risk and Reliability.

The major variables in developing a system investment plan for the mainstem locks are lock condition and traffic demand. Forecasts of both variables are uncertain giving rise to the need for a risk based analysis to insure that the study conclusions and recommendations cover the plausible range of future scenarios. Engineering reliability models were used to analyze lock component reliability and capture the uncertainty of lock performance while accommodating forecasted traffic demand. Multiple traffic forecasts were used to model river traffic. Five forecasts were developed for the study, each recognizing that the primary driver of river traffic is utility coal at 50-60% of system tonnage transported (see Figure 4). Traffic forecasts used in this study indicate that demand for Ohio River navigation is projected to grow between 0.51-1.06 percent annually, depending on the forecast scenario. Forecasted growth is confirmed by recent

announcements made regarding clean-coal technology plants, expansions to coal-fired power plants, and coal gasification plants in the basin.

Figure 4
Ohio River Historic and Forecast Traffic, 1970 - 2030



High GNP -- traffic scenario incorporates high GNP growth forecasts .
Mod GNP -- traffic scenario incorporates moderate GNP growth forecasts.
NAAQS -- traffic scenario incorporates US EPA National Ambient Air Quality Standards.
Clear Skies -- traffic scenario incorporates Bush Administration proposals for emission reductions from electric power plants.
Mod CS -- traffic scenario incorporates all aspects of Bush Administration proposals for emission reductions, excepting proposals regarding Mercury.

The ORMSS process included development of a state-of-the-art analytical model that incorporated the uncertainty of traffic forecasts and the reliability of lock components into a procedure to optimize reinvestment strategies. The Ohio River Navigation Investment Model (ORNIM) used in this analysis determined system-wide benefits and costs of different reinvestment alternatives through the integration of engineering and economic inputs. ORNIM output in the form of traffic forecasts were used as input to the NAVPAT model. ORNIM is able to evaluate tradeoffs among alternatives over time to optimize maintenance, rehabilitation and construction needs.

5. Formulation and Evaluation.

a. Without Project Condition (WOPC). The without-project condition is the most likely condition expected to exist in the future in the absence of implementation of water resource project investment alternative(s). The future without-project condition constitutes the benchmark against which action alternative plans are evaluated. For this study, the WOPC was formulated as the least Federal cost plan providing viable navigation on the Ohio River Mainstem. The WOPC as developed is a reactive maintenance strategy for major lock components. This assumes that as a component fails, it is repaired in a timely fashion; however, no proactive maintenance is performed, i.e., components are not repaired or replaced in anticipation of failure.

Performance of the system's aging infrastructure will continue to deteriorate in the future without aggressive maintenance or lock modernization. The three upper-most projects on the Ohio River (Emsworth, Dashields, and Montgomery (EDM)) range in age from 70 to 85 years, well beyond original design life. There are two major concerns with the physical condition of the lock walls at EDM: 1) concrete deterioration below concrete overlays placed during rehabilitations in the 1980s, and 2) questionable remaining effectiveness of metal anchors installed during those rehabilitations to make these walls stable. These problems contributed to predictions of very high future maintenance costs at EDM in the WOPC.

Physical conditions lead to lock closures. When these closures affect the main lock chamber, traffic through the project must use the smaller auxiliary lock chamber. In the case of projects with 1200' main chambers and 600' auxiliary chambers this means it will take tows two lockage operations to transit the project, and in the case of EDM with their 600' main chamber and 360' auxiliary chambers it will take tows five cuts with tow sizes limited to five rather than the typical 15 barges. All of this means additional time and operating costs to process through the lock. Where traffic exceeds the ability of the auxiliary to process traffic, tows will experience significant delays and incur additional operating costs above and beyond the additional time it takes to process a tow through the auxiliary. So both projections of the future physical reliability of the project and projections of future traffic demands will affect future lock performance. Consistent with Corps guidance, the WOPC also includes the timely completion of authorized improvement projects on the entire Ohio River Navigation System (Olmsted, Greenup, Myers, Marmet, Kentucky, Lower Monongahela, and Chickamauga Locks).

1). Economic Analysis of the WOPC. The Ohio River mainstem offers many economic benefits to the region, including: recreation, tourism, water supply for municipal and industrial purposes, hydropower generation, and transportation. The economic analysis completed for the Ohio River Mainstem System Investment Plan focused solely on transportation benefits. These benefits, or transportation savings, are initially measured by comparing the existing waterway transportation costs versus the least cost alternative overland transportation cost, savings that reflect an historically reliable system. A major problem identified in this study is that without investment in the system, aging infrastructure can be expected to be out of service more frequently and for longer durations of time, eroding the per ton transportation benefits realized today. Garnering these benefits comes at a cost, primarily in terms of operations and maintenance costs in the WOPC.

Table 2 summarizes average annual benefits and costs for the WOPC. Net benefits range from $2.15 to $2.36 billion.

Table 2
WOPC Average Annual System Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Total System Benefits	$2,252.8	$2,373.7	$2,351.8	$2,428.7	$2,460.1
Total System Costs	$99.0	$100.1	$100.0	$99.8	$100.1
Net System Benefit	$2,153.8	$2,273.6	$2,251.8	$2,328.9	$2,360.1

2). Environmental Sustainability in the WOPC. The WOPC is also the No-Action alternative under NEPA for navigation improvements. Looking into the future, all Valued Environmental Components (VECs) are fully sustainable except for mussels and riparian/floodplain resources. In the future the mussels and riparian/floodplain resources will remain marginally sustainable. Significant effects to these two categories have occurred from a number of activities which occur not only along the river but also along the basin's tributaries. These activities include, but are not limited to, water pollution from municipalities and industries; acid mine drainage; instream extraction of sand and gravel; construction and operation of high-lift locks and dams; disruptions to mussel beds due to barge fleeting areas, queuing, disposal of dredged materials, and conversion of habitat for agriculture, residential, commercial, and industrial uses. Habitat conversions are expected to continue in the future as development in or adjacent to the river continues to occur.

Initially, the WOPC for ecosystem sustainability assumes full implementation of the as yet unfunded Ohio River Ecosystem Restoration Program and 14 specific types of measures[3] that were determined to contribute to improving long-term sustainability of aquatic and riparian ecological resources. These are collectively referred to as the "Minimal" alternative. Several of these 14 measures deal with specific types of habitat (e.g., islands, mussel habitat, etc.) and can be described as protecting and improving habitats, increasing diversity and connectivity of habitats, restoring populations of native species, and reducing invasive exotic species. These measures could be implemented through a variety of existing Corps authorities, such as the Ohio River Ecosystem Restoration Program, the Ohio River Basin Comprehensive Study, and Sections 206 and 1135, especially in collaboration with other agencies and interests. While some opportunities among the 14 are relatively low-cost and straightforward, others would require additional planning and/or construction. However, the Ohio River Ecosystem Restoration Program has yet to receive Congressional appropriations for implementation. As such, the program is now on the candidate list for de-authorization. Therefore, it is still

[3] See Table 8-10 for a list of environmental sustainability measures in the WOPC ES Plan.

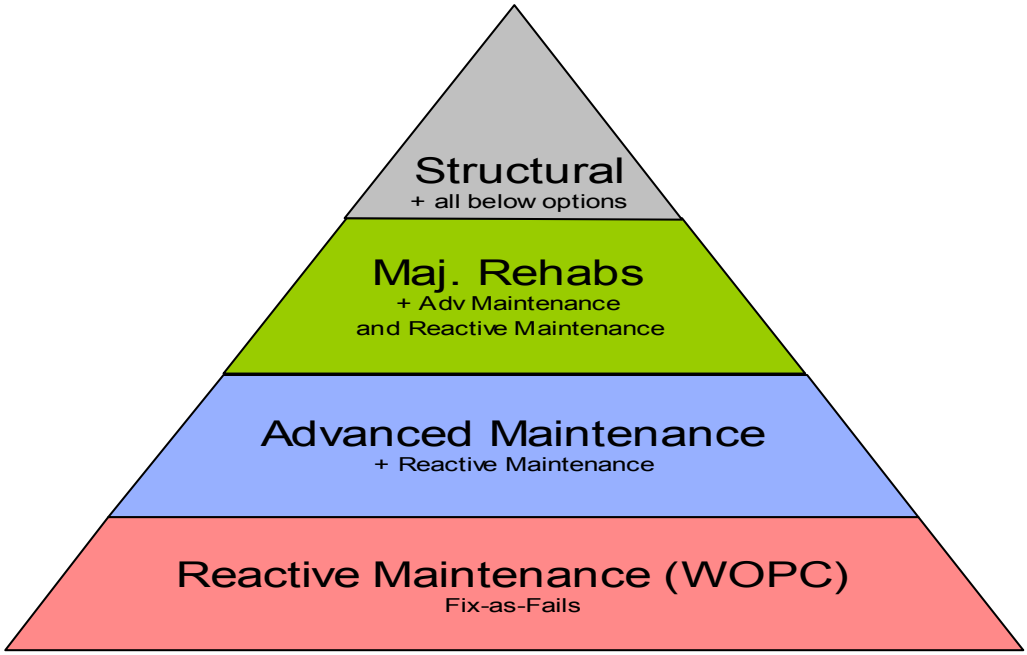
mentioned in the final SIP/PEIS, although it is not included as a reasonably foreseeable future action in either the Without or With Project Conditions.

The Corps operation and maintenance of the navigation system are currently being examined through consultation with the US Fish and Wildlife Service under Section 7 of the Endangered Species Act. In consultation with the US Fish and Wildlife Service, the Corps will develop and implement Reasonable and Prudent Measures being identified through this Endangered Species Act Section 7 consultation. These operational measures along with the various restoration authorities (other than the Ohio River Ecosystem Restoration Program) available to the Corps will help to improve sustainability.

b. With-Project Condition (WPC). The with-project condition is the plan that best addresses the stated planning objectives and addresses the problems and opportunities. The planning objectives were: Ensuring Future Navigability, Improving Navigation Efficiency, and Enhancing Environmental Sustainability. To achieve these objectives, the study team developed a process of formulating and evaluating increasingly intensive alternative actions from proactive maintenance and small scale improvements to large-scale construction reinvestments for navigation improvements. The increasing scale of activities is illustrated in **Figure 5**. Similarly, ecosystem sustainability alternatives in the WPC are described as Moderate and Maximum Plans based on progressive levels of implementation complexity.

Figure 5

Progression of Alternatives in Formulation Process



Proactive maintenance occurs when lock components are replaced or a lock is rehabilitated in advance of component(s) failure. Small-scale improvements considered include floating buoys, permanent mooring cells near lock approach points, and other

infrastructure or procedural opportunities.[4] Large-scale reinvestments evaluated include chamber rehabilitations, construction of new larger lock chambers, and 600' extensions of some auxiliary lock chambers. The key to determining whether an activity should be added to the WPC is if its expected annual benefits exceed its expected annual costs. After all incrementally justified activities are added, the WPC is complete.

Three alternatives involving proactive maintenance and new lock construction were formulated for the WPC analysis and evaluated relative to the reactive maintenance WOPC. Two involved adding more proactive maintenance options. The first, called the Advanced Maintenance Alternative (AMA), allows for scheduled replacement of any critical lock component when economically justified. The second, termed the Major Rehabilitation Alternative (MRA), allows both component replacement and the bundling of component replacements into major rehabilitation packages that meet Corps criteria for that program, again when economically justified. A third alternative, termed the Lock Modernization Alternative (LMA), allows proactive maintenance as well as lock modernization options. Specific lock modernization options considered included 600' extensions of 600'x110' auxiliary chambers and new 600'x110' or 1200'x110' chambers to replace the undersized 360'x56' auxiliaries at Emsworth, Dashields, and Montgomery (EDM). The major elements of the WPC plans that maximize system net incremental benefits for each traffic scenario are shown in Table 3.

Two ecosystem sustainability alternatives were formulated for the WPC analysis to address long-term sustainability of aquatic and riparian ecological resources. The Moderate and Maximum Ecosystem Sustainability Related plans were developed based on approximate costs, need for modified or additional authority, complexity, and several scientific, policy, funding and timing uncertainties of various measures. A total of 26 ecosystem sustainability measures were evaluated; 12 specific types of measures in addition to the 14 from the WOPC. The Moderate plan included 19 of the measures and the Maximum Plan consists of all 26 measures[5]. Existing restoration authorities and operational measures such as the Reasonable and Prudent Measures (being developed through the Endangered Species Act Section 7 consultation) are also carried through into the WPC.

The results of the economic evaluation are quite robust with regard to traffic scenarios; for the most part, the type of investment, whether replacement of a major component of the lock (component replacement - CR), major rehabilitation (MR), or new construction, is unchanged across scenarios and the timing of the investment shows only modest adjustment.

[4] *Small Capital Improvements Study Mooring Facilities*, May 1998, USACE.
[5] The Moderate and Maximum Ecosystem Sustainability Related Plans are described in Table 8-10 of this report.

Table 3.
WPC System Investment Plans for Each Traffic Scenario

Project	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Belleville	CR	MR - 2017	MR - 2017	MR - 2017	MR - 2028
Cannelton	MR - 2017	MR - 2017	MR - 2016	MR - 2017	MR - 2017
Dashields	New 600' - 2011	New 600' - 2010	New 600' - 2010	New 600' - 2010	New 600' - 2010
Emsworth	New 600' - 2010	New 600' - 2010	New 600' - 2010	New 600' - 2010	New 600' - 2010
Hannibal	MR - 2012	MR - 2011	MR - 2011	MR - 2012	MR - 2011
Markland	CR	MR - 2010	MR - 2010	MR - 2010	MR - 2010
Meldahl	MR - 2013	MR - 2010	MR - 2010	MR - 2010	MR - 2010
Montgomery	New 600' - 2010	New 600' - 2010	New 1200' - 2010	New 600' - 2010	New 600' - 2010
Newburgh	MR - 2025	MR - 2016	MR - 2016	MR - 2016	MR - 2016
Pike Island	MR - 2016	MR - 2015	MR - 2015	MR - 2016	MR - 2015
Racine	MR - 2020	MR - 2019	MR - 2020	MR - 2019	MR - 2019
RC Byrd	CR	MR - 2044	MR - 2020	MR - 2030	MR - 2033
Willow Island	MR - 2027	MR - 2027	MR - 2027	MR - 2027	MR - 2028

All lock projects at a minimum have component replacements, some have rehabs and others have new chambers added.

CR = Component Replacements
MR = Main Chamber Rehabilitation
New 600' or 1200' = New Single chamber built in place of the existing auxiliary. The old main is only used when the new chamber is down for maintenance.

1). Economic Analysis of the WPC.

Table 4 displays the incremental benefits and costs of the WPC relative to the WOPC. The ORMSS draft SIP estimates average annual incremental net benefits for meeting mainstem long term reinvestment needs range from $128 to $238 million.

Table 4.
WPC Average Annual Incremental Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Incremental Benefits over WOPC	$147.8	$237.0	$259.9	$207.0	$233.3
Incremental Costs over WOPC	$19.0	$18.6	$21.5	$18.9	$18.4
Incremental Net Benefit	$128.8	$218.4	$238.4	$188.1	$214.9
Benefit / Cost Ratio	7.8	12.7	12.1	11.0	12.7
Total Costs for Optimized WPC	118.0	118.7	121.5	118.7	118.5

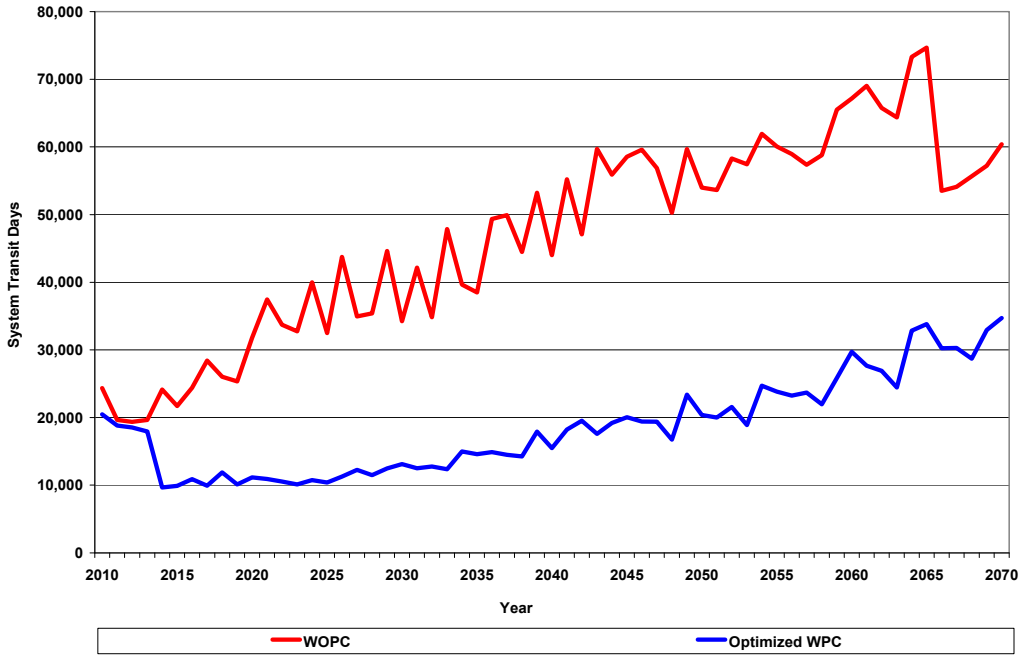
Economic analyses clearly demonstrate the value to the nation of more proactive maintenance. Relative to reactive maintenance, proactive maintenance reduces future maintenance needs and unscheduled emergency repairs, while saving hundreds of millions of dollars annually due in transportation costs. In addition, replacing the small auxiliary locks at EDM with larger locks reduces future maintenance repair costs of the 1930s vintage main chambers, avoids costly interruptions of traffic and results in transportation savings in the tens of millions annually over and above proactive maintenance alone.

The operational effect of the reactive maintenance protocol of the WOPC is illustrated (by the upper red line) in Figure 6. As the system ages, component reliability degrades and in the WOPC, components are not repaired or replaced in advance of failure. The jagged nature of the graphic reflects the interruptions due to ever increasing scheduled maintenance and the greater likelihood of unscheduled reliability lock closures. More frequent closures result in increased total transit days necessary to move projected tonnage in the ORS. In the WPC, components are repaired or replaced in advance of expected failure. The actual protocol is to estimate the expected costs of component failure through the planning period and contrast those with the expected benefits of component replacement. The decision to schedule a component replacement is based on economic efficiency, i.e., when expected benefits exceed expected costs, the component is scheduled for repair or replacement. When it is more efficient to bundle the replacement of several components, a major rehabilitation is scheduled. In every instance of proactive maintenance, expected economic benefits exceed expected economic costs. As a consequence of proactive maintenance, the number of scheduled and unscheduled closure events in the WPC is less than in the WOPC. This results in a reduced number of total transit days as illustrated (by the lower blue line) in Figure 6.

2). Environmental Sustainability in the WPC. The best WPC plan for ecosystem sustainability was the Moderate Plan, which added five specific types of measures to the WOPC; 1) increase seasonal flooding in specific habitats, 2) protect and restore habitats and diminished resources, 3) reintroduce and expand native fauna in historic ranges, 4) re-connect tributary streams and floodplains with the Mainstem Ohio River, and 5) restore wetlands in embayments. The Moderate Plan has less scientific, policy, funding, and timing uncertainties associated with it, which makes it preferable over the Maximum Plan. The added components of the Moderate Plan would require funding in addition to that provided (in the WOPC) for the Ohio River Basin Comprehensive Study and existing authorities such as Sections 206 and 1135. In those cases where new or modified authority is determined to be necessary, efforts should be directed towards obtaining such authority through the Comprehensive Ohio River Basin-wide Study. Implementation of the Moderate WPC plan would improve the long-term sustainability of freshwater mussels and riparian/floodplain resources over that of the WOPC. However, it is not expected that this plan would provide sufficient benefits to bring these resources to a state of full sustainability.

Figure 6.

Transit Days to Accommodate Equilibrium Traffic (WOPC vs. WPC)



The Lock Modernization Alternative is the best plan for long term cumulative impacts by providing a positive contribution to the environmental sustainability of water quality, fish, mussels, riparian resources, recreation, and health and safety. For example, reduction of the queuing near lock and dam projects reduces re-suspension of sediments and substrate scouring in tailwater areas which are sensitive areas for many of the remaining freshwater mussel species (some of which are federally listed) and provide important spawning habitats for several species of fish. By not diverting waterway traffic to highway and rail corridors and associated facilities, impacts of increased fuel consumption, traffic delays, air emissions, accelerated deterioration of roads, traffic-related injury, and delivery prices of diverted materials are also lessened. Implementing the projects in the Lock Modernization Alternative would result in direct and indirect impacts in the form of construction impacts and construction induced queuing. Mitigation for site-specific impacts would be incorporated into project plans developed during feasibility studies, major rehabilitation studies, or other approval processes.

It is important to note that this SIP/PEIS is a programmatic EIS under the National Environmental Policy Act (NEPA). Follow-on study reports for specific projects identified within the study planning horizon will require that site-specific impacts be evaluated during preparation of project EIS(s) or Environmental Assessment(s). Following the Council on Environmental Quality regulations, these site-specific NEPA documents will be tiered from the programmatic assessment provided through this SIP/PEIS. CEQ regulations require certain topics to be considered in any EIS. As related to ORMSS, these topics are addressed as follows:

- Adverse effects that cannot be avoided should the ORMSS recommendations be implemented in association with site-specific improvements (e.g., major rehabilitations and lock modernizations).

- Implementation of the ORMSS recommendations that would not result in irreversible or irretrievable commitment of resources without further evaluations necessary prior to approval or authorization of specific measures.

- Consideration of the relationship between short-term use of the environment and long-term productivity (or sustainability) was essential throughout the conduct of the study, with emphasis placed on both preventing degradation of and enhancing long-term sustainability. This study provides the plans for and the means to optimize returns on investments in the navigation system in combination with identification of high priority ecosystem sustainability improvements.

- All alternatives contribute to energy conservation by providing lower cost delivery of coal to utilities as compared to other delivery modes. Each successive level of navigation investment reduces tow operations fuel consumption through reduction of transit times for commodity movements.

- Coal used in power plants is a depletable natural resource and is a primary commodity transported on the Ohio River mainstem. Investment in the navigation system maintains expected levels of efficiency and service and does not alter the cost competitiveness of waterway shipment relative to other modes of delivery. For these reasons, the proposed investments are not expected to induce increased coal consumption.

- Implementation of the ORMSS recommendations would not be expected to significantly alter urban quality, historic/cultural resources, design of built environment or reuse and conservation of resources.

- No conflicts between the ORMSS recommendations and other government's land use policies, or controls were identified.

- Mitigation plans for site-specific impacts would be developed and justified during studies seeking approval or authorization for such improvements.

- Because the SIP/PEIS is a programmatic NEPA document, no additional federal permits or licenses are needed for implementation.

- Long-term sustainability of mussels and riparian/floodplain resources is an issue that remains to be resolved; however, meeting the needs of these resources will require efforts of many interests in addition to the Corps of Engineers and its cost-sharing partners under various ecosystem restoration authorities.

- Concerted efforts were made during the study process to adequately factor in uncertainties regarding reliability of lock chamber components, traffic projections under multiple scenarios, and reasonably foreseeable actions by the Corps of Engineers and others. Considering the types of concerns raised recently on other

navigation improvement studies and the publicity surrounding those studies, it is anticipated that these uncertainties could become areas of controversy for the ORMSS.

c. Future System Investment Evaluations. In 2004, total *ORS* traffic reached 270 million tons and total ORS savings exceeded $2.0 Billion. The commodity value moving on the system annually exceeds $30 Billion. The uncertainties in any system investment plan that spans sixty years coupled with the potential of under investing in the right solutions and over investing in the wrong solutions, drive the need for a program of continual reevaluation of the system investment plans. In addition, because this study focused on the mainstem locks, a follow on investment evaluation capability must be designed to encompass dams, channels and any other feature which contributes to navigation efficiency. In addition, all of the navigable tributaries should be subject to the same rigor that the current study employed. A follow on capability should be established to build on the methodologies of ORMSS and expand the evaluations to include the entire navigation infrastructure (including locks, dams and channels) on the Mainstem and the navigable tributaries. This initiative would develop and maintain the databases and models capable of providing the scientific basis for decision makers as they address the level of funding essential to provide an efficient and sustainable navigation system. The model results can be used to evaluate future investment decisions with a more holistic approach to optimize system benefits, to manage system risks, and to use performance based criteria.

6. Study Conclusions.

- The Ohio River mainstem is an important natural resource for the nation and together with its six primary navigable tributary rivers provides efficient water transportation for a vast portion of the Nation.

- Each of the traffic scenarios studied are reasonable assumptions of future waterway traffic demands. All of the scenarios studied show increases in navigation traffic in the study period. These scenarios present significant variations in traffic demand at specific locks, though all scenarios indicate traffic growth at a system level.

- No additional authorities are necessary at this time to address the needs related to the reliability of the locks. Follow-on studies are needed for recommended major rehabilitations and lock improvements. Further, follow-on studies are necessary to develop and refine measures to improve ecosystem sustainability.

- The need for early construction of new main lock chambers at the three upper Ohio River locks, namely Emsworth, Dashields, and Montgomery, is apparent across all traffic forecast scenarios.

- Minor repairs and small jobs associated with routine maintenance would cause only localized and limited effects on the ten VECs evaluated in the cumulative effects analysis. Routine maintenance, scheduled maintenance, and an N-Up/N-Down lockage policy would be expected to reduce tow queuing prior to passage through the locks, and to facilitate tow movement through the locks in a timelier manner and thus provide beneficial impacts (effects) on several VECs. Such beneficial effects would result from reductions in localized water turbidity levels; decreases in

habitat disturbances for fish, mussels, and riparian resources; lowered accident potentials; and improved recreation opportunities.

- High priority ecosystem sustainability measures are needed for the Ohio River, its tributaries and its associated natural resources on a large scale. These include habitat protection and restoration, control of exotic species, reintroduction of native species, improved connectivity of habitats, and reduction of sources of degradation. These measures are needed to help improve sustainability of many resources including mussels and riparian/floodplain habitats and the species they support.

- The conduct of this study was assessed in accordance with the seven Corps of Engineers Environmental Operating Principles and was found to be consistent with all of them.

- The Lock Modernization Alternative would result in reduced cumulative effects compared to the WOPC and other WPC plans. Reduction of cumulative effects would be a positive contribution to sustainability of water quality, fish, mussels, riparian resources, recreation, and health and safety.

- The Cumulative Effects Assessment indicated that future navigation investments would not adversely impact long-term resource sustainability. However, mussels and riparian/floodplain resources are not expected to become fully sustainable in the future due to continued degradation from previous actions combined with the future actions identified.

7. Study Recommendations.

ORMSS draft SIP recommendations follow. The annual costs for the SIPs over the period 2010 to 2030 are shown in Table 5.

- Increase Operation and Maintenance (O&M) investments to maximize economic efficiency. Complete all authorized navigation improvements; Olmsted, JT Myers, Greenup, Lower Monongahela, Kentucky Lock and Chickamauga.

- Provide optimal funding for the Upper Ohio River Study currently underway in order for this project to be included in a WRDA in the FY 2010 time frame.

- Initiate main chamber rehabilitation studies for Meldahl, Hannibal, and Myers and complete by 2009. Initiation of design of these efforts should begin in 2010.

- Initiate main chamber rehabilitation study for Pike Island to complete in 2014.

- Pursue planning and implementation of measures to improve environmental sustainability in collaboration with other interests.

- Incorporate all Reasonable and Prudent Measures into the Operation and Maintenance of the river.

- Complete work on the Markland gates as soon as possible. Funds provided in FY 2006 will initiate design and continued funding in FY 2007 and beyond will be used to construct the gates and place them in service.

- All detailed evaluation of site-specific impacts for follow on studies and other actions would be tiered from the SIP/PEIS.

- Initiate the Ohio River Basin Comprehensive Study in order to assess water resource opportunities throughout the basin in collaboration with other interests. Planning efforts should include identification and evaluation of opportunities to improve environmental sustainability throughout the basin including the tributaries.

- Establish a stand alone program (Ohio River Navigation System Investment Program) to update the data and models used in preparing the System Investment Plan. Expand the program capability to include the Ohio River dams and include tributary (Allegheny, Monongahela, Kanawha, Green, Tennessee and Cumberland Rivers) locks and dam structures to support navigation investment decisions and manage future system risk. Use these tools in annual budget formulation.

- Use the Ohio River Navigation System Investment Program to reexamine the medium and long term needs identified in the SIP to optimize investments on these projects.

- All detailed evaluation of site-specific impacts for follow on studies and other actions would be tiered from the SIP/PEIS.

- The Federal budget was not considered as a constraint in the development of the System Investment Plan. Follow on actions need to be conducted to analyze investment strategies with a constrained federal budget and expanded to include all navigation locks, dams and channels on the Ohio River and its navigable tributaries.

Table 5
Annual Costs of Optimal SIP Actions,
By Scenario Over Time Period 2010 to 2030
($ Millions)

Year	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
2010	237.87	237.67	238.25	237.45	237.43
2011	124.76	134.59	135.39	127.90	134.41
2012	107.97	111.76	112.67	108.67	111.78
2013	92.95	95.83	95.75	100.90	95.94
2014	231.80	280.39	216.65	285.21	281.20
2015	292.74	295.82	320.75	289.95	294.27
2016	292.61	295.95	323.06	295.10	299.68
2017	152.21	100.12	205.62	101.66	95.86
2018	91.01	101.02	96.56	106.10	91.00
2019	72.95	84.09	73.13	85.60	78.40
2020	72.27	79.11	74.84	80.00	76.83
2021	78.02	73.38	79.94	73.32	73.40
2022	73.59	64.86	69.22	64.80	67.12
2023	67.55	66.20	66.85	66.13	68.46
2024	56.24	55.09	55.35	55.01	56.73
2025	69.22	66.38	62.18	64.39	62.23
2026	69.70	57.68	59.92	57.59	57.69
2027	78.33	68.10	68.76	68.26	61.86
2028	63.57	64.78	63.70	62.40	71.40
2029	71.51	66.54	64.39	66.27	79.29
2030	74.44	66.18	73.36	71.70	74.93

SECTION 1
STUDY AUTHORITY

1. The basic authority for the Ohio River Mainstem Study (ORMSS), is contained in the resolution adopted by the Committee on Public Works of the United States Senate dated 16 May 1955:

> Resolved by the Committee on Public Works of the United States Senate, that the Board of Engineers for Rivers and Harbors created under Section 3 of the River and Harbor Act, approved June 13, 1902, be, and is hereby requested to review the reports on the Ohio River published in House Document No. 306, Seventy-fourth Congress, First Session, House Committee on Flood Control Document No. 1, Seventy-fifth Congress, First Session, and related reports, with a view to determining whether any modifications in the present comprehensive plan for flood control and other purposes in the Ohio River basin is advisable at this time.

2. Further authority was provided through a resolution adopted by the U.S. House of Representatives Committee on Public Works and Transportation adopted 11 March 1982. This resolution reads as follows:

> Resolved by the Committee on Public Works and Transportation of the House of Representatives, United States, that the Board of Engineers for Rivers and Harbors established by the Section 3 of the River and Harbor Act approved June 13, 1902, is hereby requested to review the reports on the Ohio River published as House Document No. 492, 60th Congress, First Session, and House Document No. 306, Seventy-fourth Congress, First Session, and other pertinent reports with a view to determine whether any modification in the authorized plan for modern barge navigation and other purposes on the Ohio River is advisable at this time with particular emphasis on need for improvement or replacement of Emsworth Locks and Dam, Ohio River Mile 6.1; Dashields Locks and Dam, Ohio River Mile 13.3; Montgomery Island Locks and Dam, Ohio River Mile 31.7; and other locations where obsolete or inadequate facilities impede the orderly flow of commerce.

SECTION 2
PURPOSE AND SCOPE

1. This section provides the purpose and scope for the primary output of this study; a System Investment Plan (SIP) that identifies potential navigation improvement projects on the Ohio River and fully considers the environmental sustainability needs for the Ohio River and associated floodplains. Purpose and scope discussions are extended for two related environmental documents. The direct, indirect, and cumulative effects of the plan itself are described in a Programmatic Environmental Impact Statement (PEIS). The Cumulative Effects Assessment (CEA) addresses the accumulation of meaningful impacts to the Ohio River study area due to all past, present, and reasonably foreseeable future actions both by the Corps of Engineers and others. Section 2.1 describes the purposes for each of these products and the need for their development at this point in time. The scope of studies to develop each product is contained in Section 2.2. Section 2.3 contains the overall report organization. The plan formulation process is described in Section 2.4, and study participants and roles are listed in Section 2.5.

2. A large-scale, long-term study such as ORMSS inevitably evolves from its inception to its completion because additional knowledge and insights are gained and institutional approaches change. Three important project components evolved during ORMSS and form the cornerstones of the study framework:

- The **Federal decision-making process** for ORMSS developed in a distinctive way that generated many possible study outcomes and recommendations related to navigation investment options. More typical feasibility studies tend to identify a narrower set of alternatives.

- The Corps' **Environmental Operating Principles**, introduced and formalized during this study, have outlined important environmental imperatives for the Corps' operations in the 21st century. These principles incorporate synergy, sustainability, interdependence, and collaboration along with other concepts exemplified by ORMSS.

- **Innovation in project design and development** form the third important cornerstone, resulting in an integrated study characterized by its cutting-edge approach and comprehensiveness.

These three components permeate the ORMSS study and will be discussed in greater detail in other sections of this PEIS and accompanying documents.

2.1 STUDY PURPOSE & NEED FOR ACTION

1. The goal of the Ohio River Mainstem Systems Study (ORMSS) is to identify the best long-term comprehensive program for maintaining a viable navigation system on the main stem of the Ohio River while striving to achieve environmental sustainability[1]. The primary purpose of the Ohio River Mainstem Systems Study (ORMSS) is to develop the best System Investment Plan (SIP) for maintaining safe, environmentally sustainable, and reliable navigation on the Ohio River over a 60-year period from 2010 to 2070. Specifically, the study evaluates the need for maintenance of major lock components, including replacement and major rehabilitation, opportunities for operational efficiency and low cost structural measures, and new lock construction needs and for all 19 navigation lock and dam sites on the Ohio River Mainstem from 2010 – 2070 with an aim to identify the optimum plan for meeting these needs during that time period[2]. The study also identifies high priority needs for improving sustainability of aquatic and riparian/floodplain resources. The current system is shown in **Figure 2-1** and each lock and dam is described in **Table 2-1** (which does not include Locks and Dams 52 and 53 as they will shortly be replaced with the new Olmsted project). These lock and dam structures are crucial to the efficient passage of commodities throughout the Ohio River Basin. Typical Ohio River tows must lock through several of these facilities during their trips. Any lockage delays translate to increased transportation costs and additional costs to consumers.

2. As traffic grows within the Ohio River Valley and the current infrastructure becomes less reliable, commercial traffic will experience greater delays in locking through these facilities for two main reasons. Increased traffic will result in greater number of tows desiring to lock through many projects and result in greater amounts of time that tows must spend waiting in line to lock through even when the locks are operating efficiently. Less reliable locks will translate into greater down times to repair failed components and will be particularly onerous during closures of the larger (or main) chambers. During these times, traffic will be forced through smaller lock chambers at many projects. As documented later in this report (Section 6), closures of the main chambers along the Ohio River result in extremely large delays to barge traffic (and high additional costs passed on to consumers). Therefore a large focus of this study is reducing or eliminating these particularly onerous closures in an economically efficient manner.

3. In the course of the study, the Corps will also assess current management practices, infrastructure and operations/maintenance practices to seek ways to balance the needs of both navigation and natural systems.

4. In response to stakeholder input, the study was modified to include identification of measures to improve ecological sustainability to provide a balance between economic and environmental improvements.

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[1] Environmental sustainability is defined in Corps Engineer Circular 1105-2-404 (PLANNING CIVIL WORK PROJECTS UNDER THE ENVIRONMENTAL OPERATING PRINCIPLES, 1 May 2003) as "a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations."

[2] Currently, there are 20 lock and dam sites on the Ohio River, but after completion of Olmsted L&D, tentatively scheduled for 2009, L/Ds 52 and 53 will be subsequently decommissioned and removed.

5. The purpose of the System Investm ent Plan, Programmatic Environm ental Impact Statement, and Cumulative Effects Assessment, is briefly discussed in Section 2.2.

2.1.1 System Investment Plan

1. The primary purpose of the Ohio River Mainstem Systems Study (ORMSS) is to develop the best System Investment Plan (SIP) for maintaining safe, environmentally sustainable, and reliable navigation on the Ohio River over a 60-year period from 2010 to 2070. Another purpose is to identify high priority needs to improve ecosystem sustainability for the Ohio River. To do this, the SIP will identify where, and approximately when, various investments should be made along the Ohio River during the time period 2010-2070. **The SIP does not recommend any specific projects for Congressional authorization**; such authorizations would result from future Feasibility studies that focus on site-specific improvements. From information developed in the SIP, the schedule of these future feasibility studies will be developed. Development of this schedule and budget for future studies will help ensure the completion of these efforts such that improvements are in place when needed.

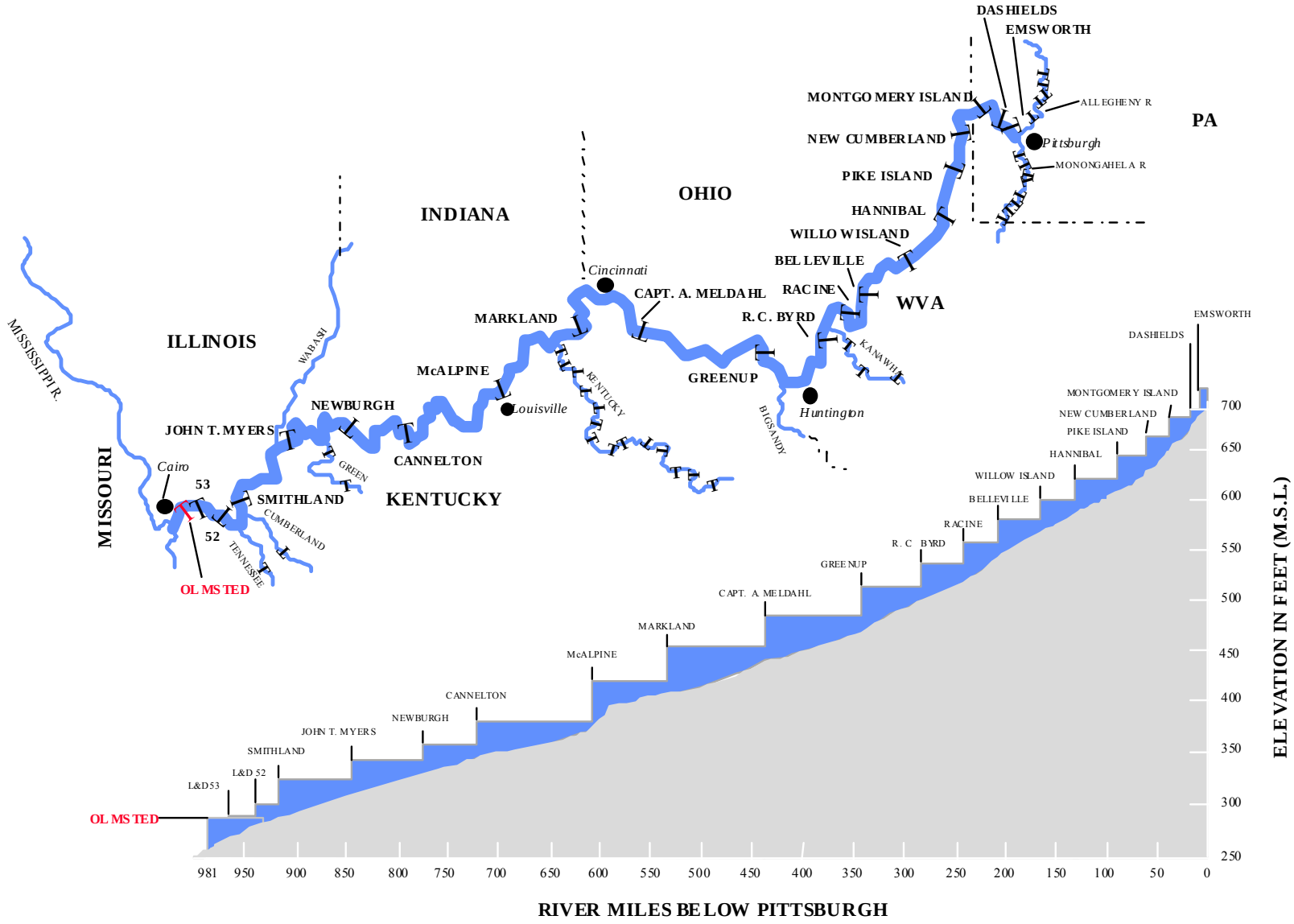


Figure 2-1. Plan and Profile of the Ohio River Lock and Dam System

TABLE 2-1
Description of Ohio River Locks and Dams

Emsworth Locks and Dams, Ohio River Mile 6.2

LOCKS: Two parallel locks, main lock 110' by 600', auxiliary lock 56' by 360'.
DAMS: Non-navigable, gated dams on main + back channels. Main Channel comprised of 8 vertical-lift gates, each 100' in length, with one fixed weir with 34' open crest. Top length of dam is 967'. Back Channel composed of 6 vertical-lift gates, each 100' in length. Top length of dam is 750'. Lift is 18.0'. Operation Commenced: 1921. # Vessel Lockage Cycles[3] in 2003: Main-6569; Auxiliary-4368. Federal Energy Regulatory Commission (FERC) hydropower preliminary permits are active (i.e. a non-Federal entity is studying the feasibility of constructing a hydroelectric plant) at the both dams.

Dashields Locks and Dam, Ohio River Mile 13.3

LOCKS: Two parallel locks, main lock 110' by 600' (actual length is 599,25', the 600' length will be used in this report for ease and convenience.), auxiliary lock 56' by 360'. DAM: Fixed Crest Weir, top length of dam 585'. Lift is 10.0'. Operation Commenced: 1929. # Vessel Lockage Cycles in 2003: Main 6612; Auxiliary-3550. FERC Preliminary Permit is active.

[3] A vessel lockage cycle is required for both the emptying or filling of the lock required by a vessel lockage and a "turnback" which occurs when the lock is turned back empty in order to service a vessel going in the same direction as the previous vessel.

Montgomery Locks and Dam, Ohio River Mile 31.7

LOCKS: Two parallel locks, main lock 110' by 600' (actual length is 597.0', the 600' length will be used in this report for ease and convenience), auxiliary lock 56' by 360'. DAM: Non-navigable dam comprised of 10 vertical-lift gates, each 100' in length, with two fixed weirs, each with a 101.5' open crest length. Top length of dam is 1,379'. Lift is 17.5'. Operation Commenced: 1936 # Vessel Lockage Cycles in 2003: Main-6772; Auxiliary-3164. FERC Preliminary Permit is active.

New Cumberland Locks and Dam, Ohio River Mile 54.4

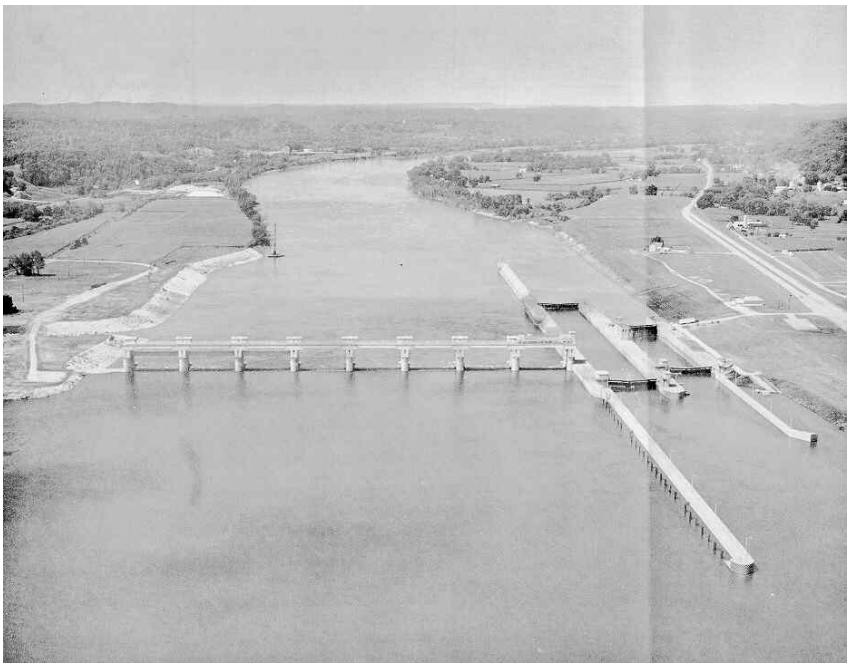
LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110' by 600'
DAM: Non-navigable dam composed of 11 tainter gates, each 110' in length. Top length of dam is 1,315'. Lift is 20.5'. Operation Commenced: 1956 # Vessel Lockage Cycles in 2003: Main-5012; Auxiliary-2766. Surrender of hydropower license was accepted by FERC in October 2009.

Pike Island Locks and Dam, Ohio River Mile 84.2

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110' by 600'
DAM: Non-navigable dam composed of 9 tainter gates, each 110' in length, and one 196' fixed weir section. Top length of dam is 1,306'. Lift is 21.0'. Operation Commenced: 1963
Vessel Lockage Cycles in 2003: Main-5875; Auxiliary-2499. FERC hydropower license (i.e. authorization from FERC to construct plant) is active.

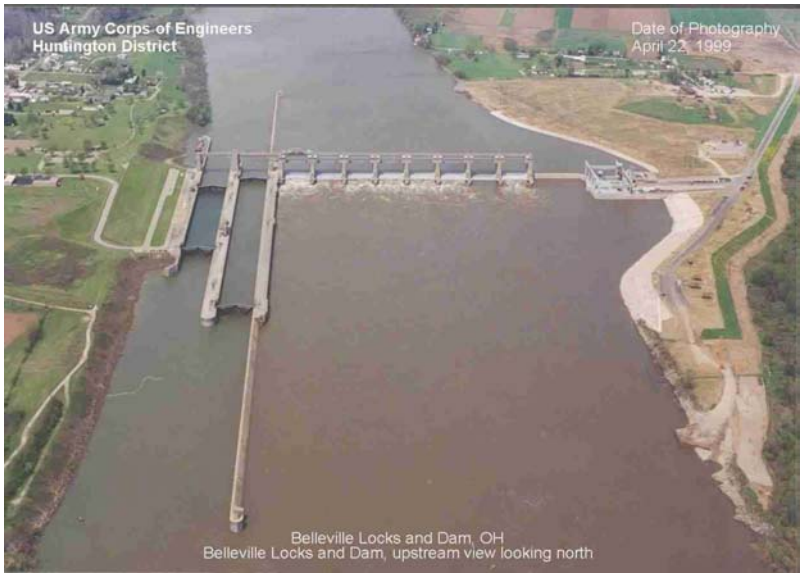
Hannibal Locks and Dam, Ohio River Mile 126.4.

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110' by 600'
DAM: Non-navigable dam composed of 8 tainter gates, each 110' in length, and one 79' fixed weir section. Top length of dam is 1,306'. Lift is 21.0'. Operation Commenced: 1972 # Vessel Lockage Cycles in 2003: Main-5933; Auxiliary-1308. Non-Federal hydroelectric plant is located on abutment side.



Willow Island Locks and Dam, Ohio River Mile 162.4.

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110' by 600'
DAM: Non-navigable dam composed of 8 tainter gates, each 110' in length, and one 84' fixed weir section. Top length of dam is 1,128'. Lift is 20.0'. Operation Commenced: 1972
Vessel Lockage Cycles in 2003: Main-5459; Auxiliary-1777. FERC hydropower license is active.



Belleville Locks and Dam, Ohio River Mile 203.9.

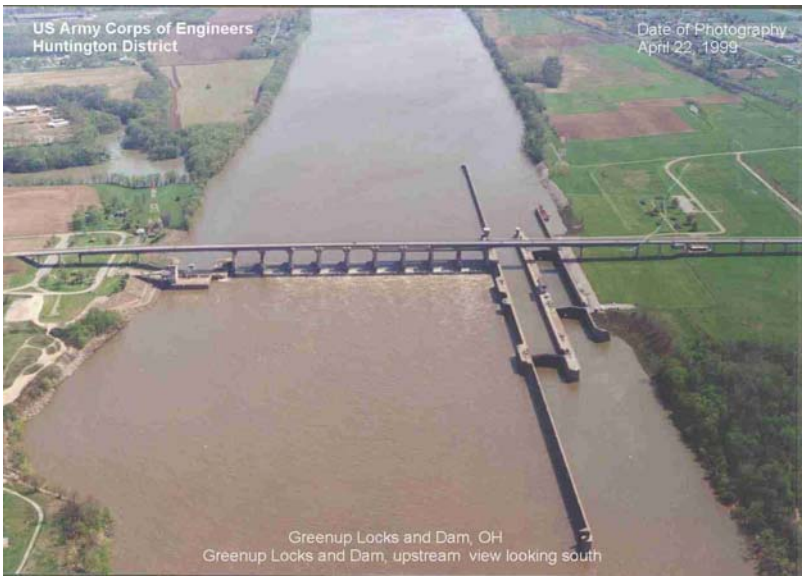
LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110' by 600'
DAM: Non-navigable dam composed of 8 tainter gates, each 110' in length, and one fixed weir section with 130' open crest. Top length of dam is 1,206'. Lift is 20.0'. Operation Commenced: 1968.
Vessel Lockage Cycles in 2003: Main-5789; Auxiliary-1084. Non-Federal hydroelectric plant is located on abutment side.

Racine Locks and Dam, Ohio River Mile 237.5.

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110' by 600'
DAM: Non-navigable dam composed of 8 tainter gates, each 110' in length, and one fixed weir section with 130' open crest. Top length of dam is 1,160'. Lift is 22.0'. Operation Commenced: 1967.
Vessel Lockage Cycles in 2003: Main-5996; Auxiliary-1160. Non-Federal hydroelectric plant is located on abutment side.

R.C. Byrd Locks and Dam, Ohio River Mile 279.2

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110' by 600'
DAM: Non-navigable dam composed of 8 roller gates, each 125.5' in length. Top length of dam is 1,206'. Lift is 23.0'. Note: The operating locks are the rightmost (landward) pair, each with two sets of lock gates visible. Operation Commenced: 1993. # Vessel Lockage Cycles in 2003: Main-6320; Auxiliary-1494. FERC hydropower license is active.

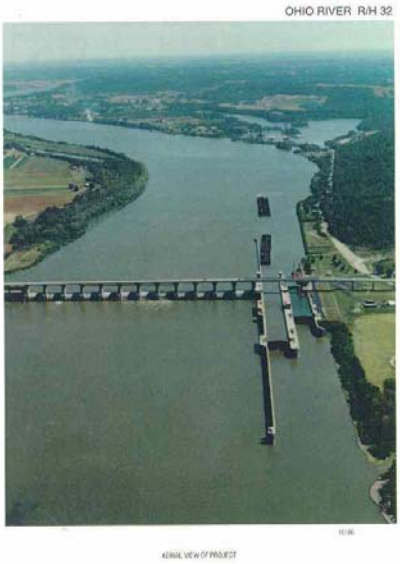


Greenup Locks and Dam, Ohio River Mile 341.0

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110' by 600'.
DAM: Non-navigable dam composed of 9 tainter gates, each with 100' clear span, and one fixed weir section with 223' open crest. Top length of dam is 1,206'. Lift is 30.0'. Operation Commenced: 1959. # Vessel Lockage Cycles in 2003: Main-7292; Auxiliary-3379. Non-Federal hydroelectric plant located on abutment side.

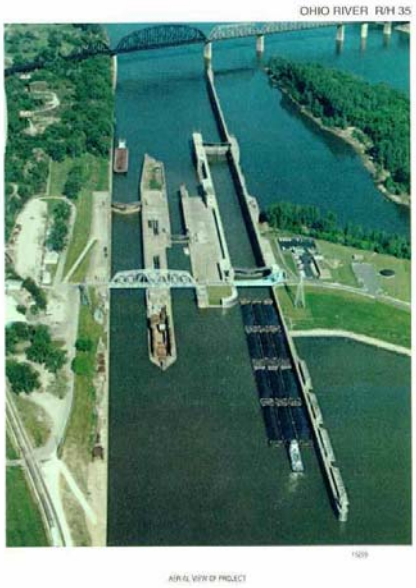
Meldahl Locks and Dam, Ohio River Mile 436.2

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110' by 600'.
DAM: Non-navigable dam composed of 12 tainter gates, each with 100' clear span, and one fixed weir section with 310' open crest. Top length of dam is 1,756'. Lift is 30.0'. Operation Commenced: 1962.
*# Vessel Lockage Cycles in 2003: Main-7028; Auxiliary-1843. FERC hydropower license is active.



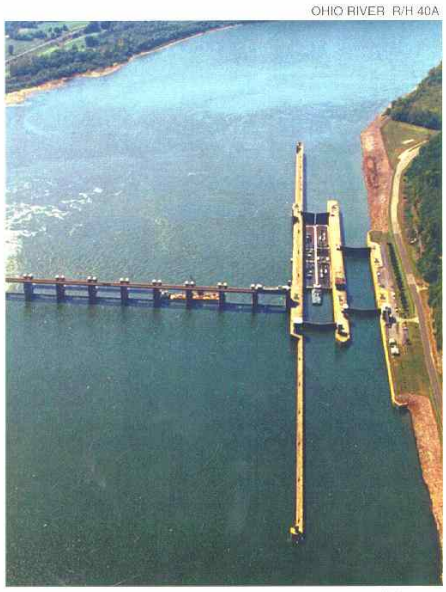
Markland Locks and Dam, Ohio River Mile 531.5

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110’ by 600'.
DAM: Non-navigable dam composed of 12 tainter gates, each with 100’ clear span. Top length of dam is 1,395’. Lift is 35.0’. Operation Commenced: 1959. # Vessel Lockage Cycles in 2003: Main-5983; Auxiliary-2012. Non-Federal hydroelectric plant located on abutment side.



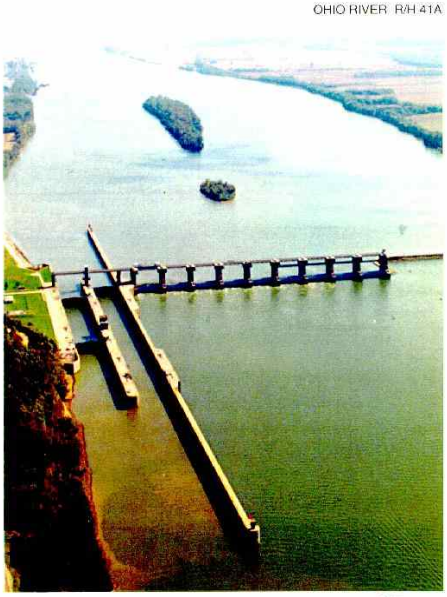
McAlpine Locks and Dam, Ohio River Mile 606.8

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110’ by 1200'. Second 110’ by 1200’ lock opened in 2009.
DAM: Consists of fixed weir and tainter gate sections. . Lift is 37.0’. Operation Commenced: 1961. # Vessel Lockage Cycles in 2003: Main-8073; Auxiliary-0 (Being Reconstructed). Non-Federal hydroelectric plant located on abutment side.



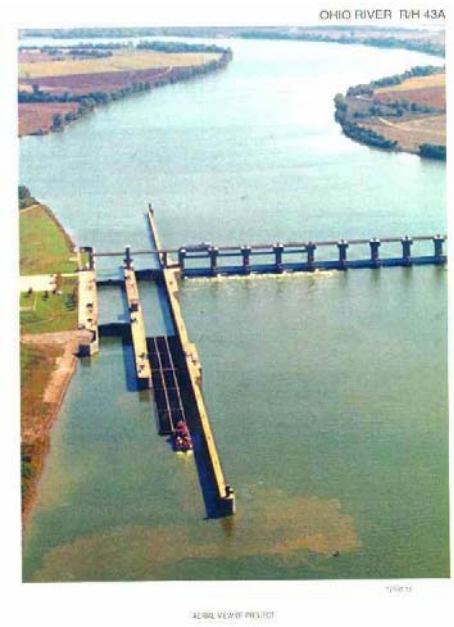
Cannelton Locks and Dam, Ohio River Mile 720.7

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110’ by 600'.
DAM: Non-navigable dam composed of 12 tainter gates, each with 100’ clear span, and one fixed weir section with 195’ crest. Top length of dam is 1,395’. Lift is 25.0’. Operation Commenced: 1971.
Vessel Lockage Cycles in 2003: Main-6935; Auxiliary-1319. FERC hydropower license is active.



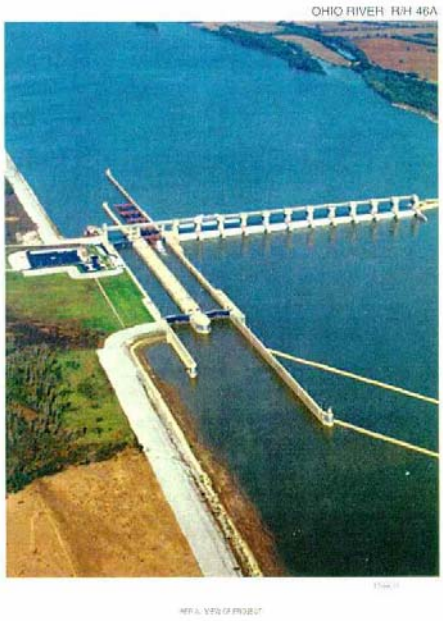
Newburgh Locks and Dam, Ohio River Mile 776.1

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110’ by 600'.
DAM: Non-navigable dam composed of 9 tainter gates, each with 110’ clear span, and one fixed weir section 1300’ long. Top length of gated dam is 1,140’. Lift is 25.0’. Operation Commenced: 1975.
Vessel Lockage Cycles in 2003: Main-8354; Auxiliary-1454. FERC hydropower preliminary permit is active.



J.T. Myers Locks and Dam, Ohio River Mile 846.0

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110’ by 600'.
DAM: Non-navigable dam composed of 10 tainter gates, each with 110’ clear span, and one fixed weir section 2,239’ long. Top length of gated dam is 1,265’. Lift is 22.0’. Operation Commenced: 1975.
Vessel Lockage Cycles in 2003: Main-7929; Auxiliary-2626. FERC hydropower preliminary permit is active



Smithland Locks and Dam, Ohio River Mile 918.5

LOCKS: Two parallel locks, main lock 110' by 1,200', auxiliary lock 110’ by 1,200'.
DAM: Non-navigable dam composed of 11 tainter gates, each with 110’ clear span, and one fixed weir section 1,572’ long. Top length of gated dam is 1,390’. Lift is 22.0’. Operation Commenced: 1979.
Vessel Lockage Cycles in 2003: Main-6503; Auxiliary-6963. FERC hydropower license is active.

2.1.2 Programmatic Environmental Impact Statement

1. The purpose of the Programmatic Environmental Impact Statement (PEIS) under the National Environmental Policy Act (NEPA) is to document consideration of various alternative Federal actions formulated to meet overall program goals and disclose environmental impacts associated with those alternatives prior to making any decisions. For this study, the No-Action alternative (also called the Without-Project Condition) is assessed as required by NEPA. The focus of this PEIS differs from EIS's developed in the past for impacts of specific project(s). This PEIS presents sufficient economic, engineering, and environmental information to evaluate broad system investment alternatives. The PEIS also provides information regarding overall impacts of the program, including system-wide cumulative effects, so that the decision-makers can make a reasoned judgment of the merits of the actions at the present stage of planning or development through consideration of effects of navigation improvements on environmental sustainability. This SIP/PEIS also provides information on sustainability needs for ecological resources throughout the study area.

2. According to regulations of the Council on Environmental Quality for implementing NEPA, the PEIS is required to contain specific subject material. Since the format of this report differs significantly from a standard PEIS, **Table 2-2** is provided to assist the reader in locating the required sections.

Table 2-2
Location of Subject Material Required by the National Environmental Policy Act of 1969

SUBJECT	LOCATION
Cover Sheet	Cover Sheet
Summary Executive	Summary
Table of Contents	Table of Contents
List of Preparers	Section 13
List of Agencies, Organizations and persons to whom copies of the statement are sent	Section 11
Index	Table 2-3 and Index
Purpose of and need for action	Section 2.1
Alternatives	Section 8, 9
Affected Environment	Section 5
Environmental Consequences	Sections 8, 9, 10
Appendices	

3. The PEIS index should have a level of detail sufficient to focus on areas of the PEIS of reasonable interest to any reader. Sections within this report that deal with environmental issues are shown in **Table 2-3**. This table provides the reader interested in tracking the environmental discussion with the pertinent topics to review.

TABLE 2-3
Environmental Content in System Investment Plan For Ohio River Mainstem Study

2. PURPOSE AND SCOPE Introduction 2.1 STUDY PURPOSE & NEED FOR ACTION 2.1.2 Programmatic Environmental Impact Statement 2.1.3 Cumulative Effects Assessment 2.2 SCOPE OF STUDIES 2.2.1 System Investment Plan 2.2.2 Programmatic Environmental Impact Statement 2.2.3 Cumulative Effects Assessment 2.4 STUDY PLAN FORMULATION PROCESS
SECTION 5 – AFFECTED ENVIRONMENT Complete section
6. OHIO RIVER PROBLEMS, NEEDS AND OPPORTUNITIES 6.1 BACKGROUND - ECOSYSTEM BENEFITS 6.1.4 Ecosystem Considerations – Environmental Operating Principles 6.2 Planning Objectives - Enhancing Environmental Sustainability 6.4 PROBLEMS AND OPPORTUNITIES RELATED TO ENVIRONMENTAL SUSTAINABILITY 6.4.1 Identification of Environmental Sustainability Concerns and Opportunities 6.4.1.1 Environmental Sustainability of Priority Valued Environmental Components (VECs) 6.4.1.1.1 Water and Sediment Quality VEC 6.4.1.1.2 Fish VEC

TABLE 2-3
Environmental Content in System Investment Plan
For Ohio River Mainstem Study

6.4.1.1.3 Mussels 6.4.1.1.4 Riparian/Floodplain Resources 6.4.1.1.5 Health and Safety 6.4.1.1.6 Recreation 6.4.1.2 VEC Interdependencies 6.4.2 Environmental Sustainability Concerns and Opportunities For Ohio River Aquatic and Riparian Resources 6.5.1 Navigation Stewardship Program 6.5.5 Additional Environmental Sustainability Improvement Options
8. OHIO RIVER MAINSTEM WoPC FORMULATION AND ASSESSMENT 8.5 ECOSYSTEM MEASURES - EXISTING ECOSYSTEM AUTHORITIES 8.5.1 Existing Corps Authorities and Regulatory Responsibilities 8.5.2 Sustainability Focus for Mitigation and Design 8.5.3 Other Agencies' Authorities and Regulatory Responsibilities 8.7 EVALUATION OF THE REACTIVE MAINTENANCE ALTERNATIVE (WITHOUT PROJECT CONDITION) 8.7.2 Impacts to Valuable Environmental Components 8.7.3 Cumulative Effects 8.8 EVALUATION OF ECOSYSTEM SUSTAINABILITY MEASURES 8.8.1 Methodology 8.8.2 Sustainability in the Without-Project Condition 8.9 REMAINING PROBLEMS AND OPPORTUNITIES 8.9.3 Environmental Considerations
9. FORMULATION OF ALTERNATIVE SYSTEM INVESTMENT PLANS 9.3.8 Refinements To Accommodate Environmental Concerns 9.4 SUSTAINABILITY MEASURES (NOT RELATED TO LOCK CONSTRUCTION) CONSIDERED 9.4.1 Existing Authorities 9.4.2 Seeking Additional Authorities 9.7 FORMULATION OF ECOSYSTEM RESTORATION WITH-PROJECT ALTERNATIVE 9.7.1 Impacts to Valuable Environmental Components 9.7.2 Cumulative Effects 9.8 EVALUATION OF ECOSYSTEM SUSTAINABILITY MEASURES 9.8.1 Methodology 9.8.2 Sustainability in the With Project Condition 9.9 REMAINING PROBLEMS AND OPPORTUNITIES
10 EVALUATION OF ALTERNATIVE SYSTEM INVESTMENT PLANS 10.2 ENVIRONMENTAL CONSEQUENCES OF NAVIGATION MEASURES 10.2.1 Impacts of WOPC and WPC Alternatives on Major VECS 10.2.2 Cumulative Effects 10.2.2.1 Approach To Analyzing Cumulative Effects 10.2.2.2 Environmental Sustainability Conclusions By Valued Environmental Component 10.2.2.3. Interactions With Other Valued Environmental Components 10.2.2.4. ES Overview Of All VECs 10.2.3 DISCUSSION OF DIRECT AND SECONDARY INFLUENCES 10.2.3.1 Eroded Savings 10.2.3.2 Transit Time 10.2.4.3 Diverted Traffic 10.2.4.4 Construction Impacts of WPC Alternatives 10.2.4.5 Expansion of Terminals and Fleeting Areas

TABLE 2-3
Environmental Content in System Investment Plan
For Ohio River Mainstem Study

10.2.4.5.1 Impacts of Intermodal Facilities
10.2.4.5.2 Fleeting Areas on the Ohio River
10.2.4.6 SUMMARY OF NAVIGATION PREDICTIVE ANALYSIS TECHNIQUE (NAVPAT)
10.2.3.6.1 Input Considerations
10.2.3.6.2 Output Features
10.2.3.6.3 Discussion of Results
10.2.3.6.4 Anticipated Improvements to the NAVPAT Model
10.3 COMPARISON OF ALTERNATIVE SYSTEM INVESTMENT PLANS (SIPS)
10.3.1 Requirements from the Corps' Planning Process
10.3.2 Requirements from the NEPA Process
10.3.3 Screening Process for Navigation-Related Plans
10.3.4 Description of Components within the Navigation-Related Alternative Plans
10.3.5 Prioritization Process for Environmental Sustainability-Related Plans
10.3.6 Overall Comparisons of the Alternative Plans
10.3.7 Detailed Comparison of the Alternative Plans
10.3.8 The Combined NED/NES Plan

2.1.3 Cumulative Effects Assessment

1. Consideration of cumulative effects is a requirement of the National Environmental Policy Act as described in regulations issued by the President's Council on Environmental Quality (CEQ) and in the guidance document "Considering Cumulative Effects Under the National Environmental Policy Act," 1997, Executive Office of the President, Washington, D.C. As such, a cumulative effects assessment is a central focus in Programmatic Environmental Impact Statements. In a system-wide study such as the ORMSS, it is important to consider the cumulative effects of possible actions within the context of the CEQ definition. CEQ defines cumulative effects as follows (40 CFR 1508.7 and 1508.8):

> "Cumulative impact" is the impact on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

2. Consideration of cumulative effects requires a broader perspective than examining just the direct and indirect effects of a proposed action. It requires that future impacts be assessed in the context of past and present effects to each important resource. Often it requires consideration of a larger geographic area than just the immediate "project" area. One of the most important aspects of cumulative effects assessment is that it requires consideration of how actions by others (including those actions completely unrelated to the proposed action) have and will affect the same resources. In assessing cumulative effects, the key determinant of importance or significance is whether the incremental effect of the proposed action will alter the sustainability of the resource in light

of other effects that resource has experienced up until the present and/or will experience in the future.

3. The Cumulative Effects Assessment (CEA) for the ORMSS analyzes the impacts on the environment that result from implementation of the Ohio River mainstem navigation system modernization features and ecosystem sustainability measures of the SIP when added to other past, present and reasonably foreseeable future actions regardless of what agency or person undertakes such other actions. Guidance provided by CEQ in 1997 was followed in conducting the CEA for the ORMSS. CEQ's guidance document describes an 11-step process, with the steps grouped into three larger assessment phases (scoping, describing the affected environment, and determining the environmental consequences). The process of analyzing cumulative effects enhances traditional approaches used in environmental impact assessment in that it focuses the analysis on the resources potentially affected rather than just on the action being proposed.

4. The CEA report is in the Environmental Appendix to this SIP/PEIS. The CEA was prepared considering a reasonable upper limit of possible navigation improvement needs identified through the ORMSS in order to examine the total effects to each resource. For this reason comparisons among alternatives are made in the SIP/PEIS rather than in the CEA report.

2.2 SCOPE OF STUDIES

2.2.1 System Investment Plan

1. This System Investment Plan (SIP) considers economic, social, and environmental aspects of lock modernization as well as maintenance and operational efficiency and low-cost structural measures at all 19 Ohio River navigation facilities as well as measures undertaken to improve ecosystem sustainability. The planning horizon for all economic, engineering and environmental analyses addressed by this report is 2010-2070.

2. Maintenance activities include routine or day-to-day maintenance, cyclical maintenance, replacement or repair of major lock components, and major rehabilitation of those components. The focus of major rehabilitation is to restore the functioning of existing locks, not on construction of larger locks.

3. Operational efficiency and low-cost structural improvements include measures where the Corps has authority to construct and generally costing less than $10 million in capital costs. Measures to improve operational efficiency are also considered. Examples of small-scale improvements include:

- Installation of per manent m ooring buoys or cells near lock approach points (which could enhance tow m ooring in queuing situations and possibly speed up double-cut processing);
- Extension of guide or guard walls to improve lock approach times;,

- Implementation of traffic management policies whereby the Corps would schedule arrivals of commercial tows at some or all Ohio River locks in an attempt to reduce delays during main chamber closures.

4. Full consideration of maintenance and operational efficiency and low-cost structural measures is made both without and with large-scale lock modernization improvements in an attempt to maximize project performance prior to recommending any large-scale investments.

5. Examples of lock modernization improvements include:

- the lengthening of existing 600' x110' auxiliary chambers at projects with an existing 1200'x110' main chamber,
- provision of replacement locks at the three oldest facilities on the Ohio River, namely Emsworth, Dashields, and Montgomery Locks & Dams.

6. The study also takes into consideration the environmental costs and benefits in its recommendations. Environmental inputs into the planning process are not quantified in economic terms. Therefore, when possible, these inputs address habitat impacts or effects on the ability of the environment to sustain a given resource.

7. Currently, improvements are already underway (or authorized) at the following sites on the Ohio River:

- Olmsted Locks and Dam – now under construction near Olmsted, Illinois – replaces two very old structures, L&D 52 and L&D 53. This work is assumed to be operational before 2010.
- McAlpine Locks and Dam – construction to replace one of the oldest components of the system -- the existing 70-year old landside 600-foot chamber -- with a new 1200-foot lock chamber has been completed. This new lock became operational in 2009.
- Greenup and Myers Locks and Dams – preliminary engineering and design has begun to extend the existing 110'x600' auxiliary chamber at each site to 1200' through construction of approach walls, an intake structure, culverts and valves. These improvements were recommended in the Greenup/Myers Feasibility Study, an interim feasibility study conducted as part of ORMSS (see Section 3.1). Also at each site, the main chamber lock gates will be modified to accommodate a Miter Gate Quick Changeout System. The new Greenup lock extension is assumed to be operational before 2010, the lock extension at Myers is assumed to become operational by 2012. Since the authorization for these two structures was achieved under the ORMSS program, the Corps has agreed to include these two projects in the CEA as part of total navigation improvements resulting from the ORMSS.
- The Ohio River Ecosystem Restoration Program was authorized in WRDA 2000. However, the Ohio River Ecosystem Restoration Program has yet to receive Congressional appropriations for

implementation. As such, the program is now on the candidate list for de-authorization. Therefore, it is still mentioned in the final SIP/PEIS, although it is not includ ed as a reasonably foreseeable future action in either the Without or With Project Conditions.

In accordance with Corps guidance, the improvements listed above will be considered complete in all system-wide alternatives considered in this report.

8. To address concerns about uncertain traffic demands on the Ohio River, alternative traffic demand scenarios have been developed. There is actually a series of System Investment Plans developed to correspond to each traffic scenario (See Section 2.4).

2.2.2 Programmatic Environmental Impact Statement

1. The Programmatic Environmental Impact Statement (PEIS) documents the consideration of impacts resulting from implementation of all actions determined to be appropriate through the planning horizon (2010-2070), including maintenance, operational efficiency and low cost structural measures, and high-cost lock modernization activities. The PEIS also assesses the effects of environmental sustainability alternatives developed as part of the ORMSS. Drawing from information in the Environmental Appendix, the PEIS includes comparisons among alternatives being considered. In order to fulfill commitments made during the Greenup and Myers Interim Feasibility study, the PEIS examines the incremental impacts of including those two projects only in future WPC system investment plans.

2. The final report should not be viewed as a one-time plan for the next 60 years. Once the final report is completed, an on-going Monitoring and Adaptive Management phase may be recommended to assess changes in needs and to respond by adjusting the plan accordingly to reflect the most up to date set of conditions and forecasts. The tools being developed through the current study will provide the means to monitor and adapt at a reasonable cost such that the plan continues to optimize the Federal investment.

3. Tiering is a process in NEPA that encourages examination of b Revised May 09 concerns at a programmatic level, followed by examination of narrower, site-specific issues at an individual action or project level. This is the process that has been pursued for the ORMSS. The current SIP/PEIS is a system-wide study wherein relatively larger scale matters (e.g., system-wide effects, cumulative effects, etc.) are assessed. Following development of the SIP/PEIS, site-specific studies and proposals would be prepared. Effects of each of these actions would be assessed in subsequent tiers of NEPA documents (Site-specific Environmental Impact Statements or Environmental Assessments) at the time the action is being studied. Because the larger scale issues have already been examined, the site-specific studies would primarily focus on the impacts of that particular proposal.

2.2.3 Cumulative Effects Assessment

1. Because the system investment plan was undetermined at the outset of the CEA process, the CEA initially assumed implementation of a reasonable upper limit of navigation improvements to bracket the analysis (i.e., insure that all data necessary to evaluate the potential impacts of actual implementation are available). The reasonable maximum lock size on the Ohio River is governed by channel dimensions, which permit the safe navigation of 15-barge configurations that fit snuggly into a 1200'x110' chamber. Based on this maximum lock size and traffic projections (described in Sections 6 and 9), the reasonable upper limit of lock sizes along the Ohio River was determined to consist of:

– Twin 1200'x110' lock chambers at each dam from Olmsted through Robert C. Byrd L&Ds

– A 1200'x110' main lock chamber and a 600'x110' auxiliary lock chamber from Racine through Emsworth

2. Based on the public input, where public is defined as other federal and state agencies, tribes, non-government organizations (NGOs), and individuals and on technical evaluations, ten "Valued Environmental Components" (VECs) were identified as pertinent to this study for the CEA. Those VECs are:

- Water and Sediment Quality
- Fish
- Mussels
- Riparian/Floodplain Ecological (islands, terrestrial, wetlands, soils/geology, floodplains/hydrology, protected species)
- Air Quality
- Health and Safety
- Recreation
- Transportation
- Socioeconomics
- Cultural Resources

3. The CEA process closely follows the 11-step process provided in CEQ's 1997 Guidance Document "Considering Cumulative Effects Under the National Environmental Policy Act." The process outlined by CEQ groups the 11 steps into three assessment phases as follows:

- Scoping
  - Identify the significant cumulative effects issues associated with the proposed actions and define the assessment goals
  - Establish the geographic scope for the analysis
  - Establish the time frame for the analysis
  - Identify other actions affecting the resources, ecosystems, and human communities of concern

- Describing the affected environment
  - Characterize the resources, ecosystems, and human communities identified in scoping in terms of their response to changes and capacity to withstand stress
  - Characterize the stresses affecting these resources, ecosystems, and human communities and their relation to regulatory thresholds
  - Develop a baseline condition for the resources, ecosystems, and human communities

- Determining the environmental consequences
  - Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities
  - Determine the magnitude and significance of cumulative effects
  - Modify or add alternatives to avoid, minimize, or mitigate significant cumulative effects
  - Monitor the cumulative effects of the selected alternative and adapt management

4. The effects on VECS due to the following types of actions are considered in this assessment:

- Construction of new Corps facilities
- Tow traffic patterns and changed tow operating practices
- Operation and Maintenance practices
- Moving cargo by alternative means
- Reasonably Foreseeable Future Actions by others:
  - actions by others that occur only because there is an efficient navigation system ("but for" actions)
  - actions by others that could occur regardless of the Ohio River navigation system
  - natural disasters
  - regulatory environment.

2.3 REPORT ORGANIZATION

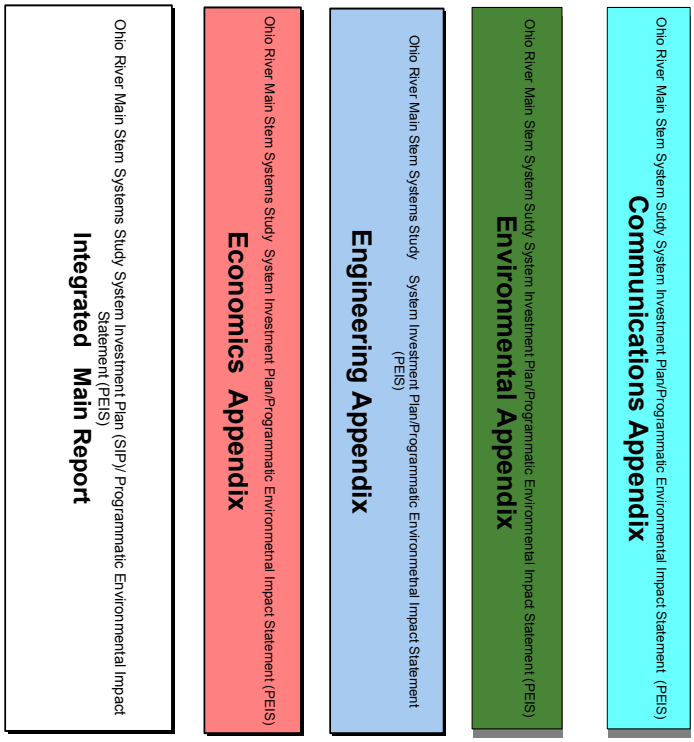
1. This document integrates material usually found in the Main Report and documentation required by the National Environmental Policy Act of 1969 (NEPA), or in

other words, is an integrated report. This structure differs from many of the navigation reports completed before this one, including the Interim Feasibility Report: J.T. Myers and Greenup Locks Improvements. In the past the Corps has opted to segregate the Main Report from the environmental documentation, usually an Environmental Impact Statement, and different color paper was used to distinguish the two report components. NEPA material in this report is not distinguished by a different colored paper; however, sections required specifically by NEPA regulations are marked with a star (*) in the Table of Contents and are provided in Table 2.2. Although there is no format specified by regulation for an integrated report, integration of NEPA documents with other agency reports is encouraged (40 CFR 1500.4(o), 1506.4, 1502.10 – 1502.18). This report structure is viewed as beneficial in comparison to the traditional style as it reduces work efforts and paperwork and should tend to keep report preparation costs down. This format is encouraged by Corps regulations

2. This report systematically presents the study findings relating to development of the System Investment (Sustainability) Plan and all associated environmental analyses. The study process and team participants (agencies and organizations) are described below in this Section. Section 3 lists pertinent reports applicable to all phases of this current study, including the prior Interim Reports on Greenup and Myers Locks and Dams and Ecosystem Restoration, as well as pertinent earlier navigation and environmental reports for the Ohio River projects. Section 4 describes the historical development and current status of the Ohio River navigation system. Section 5 concentrates on the affected environment considered for this study, including adjacent land areas. Section 6 describes the problems and needs for both navigation and environmental sustainability of the Ohio River. Section 7 describes the Public Involvement activities for all phases of this study and how this process impacted the study analyses. Section 8 describes the formulation and determination of "Without-Project Conditions" for several future scenarios of navigation traffic on the Ohio River along with ecosystem sustainability under the WOPC. Sections 9 and 10 address the formulation and determination of WPC plans for the same traffic scenarios as well as formulation of ecosystem sustainability alternatives. Section 11 contains public comments and resolution of those comments as reflected in this report. Section 12 completes the report with findings and recommendations for additional studies.

3. Because of the detail required in a study of this type, and the need to address issues to various audiences, the Draft Report includes four appendices (Economics, Environment, Engineering and Communications) to supplement the SIP Main Report and PEIS. **Figure 2-2** shows these volumes in a pictorial illustration.

FIGURE 2-2
System Investment Plan Report Organization



2.4 STUDY PLAN FORMULATION PROCESS

1. The formulation process used to develop the SIP/PEIS was in accordance with the Corps six-step planning process specified in Engineering Regulation (ER) 1105-2-100 (USACE 2000a: http://www.usace.army.mil/inet/usace-docs/eng-regs/er1105-2-100/toc.htm). As mentioned earlier, this study does not result in the recommendation of any project for authorization; therefore, detailed site-specific plan formulation at any site will be deferred until follow-on site-specific feasibility or other studies. However, the same basic plan formulation process will be followed. This process provides for systematic response to problems and needs that relate to planning (Federal) objectives and pertinent state and local concerns. Essential to this process is consideration of the uncertainty in predicting parameters critical to the formulation and evaluation process. An example of such a critical parameter for a navigation study is future demand for water transportation. An example for environmental sustainability is impacts of future introductions of invasive non-native species. The six steps comprising the plan formulation process for this study are briefly described in sections 2.4.1 through 2.4.6.

2.4.1 Identify Problems and Opportunities.

1. Problems are existing or future undesirable conditions, whereas opportunities refer to attainable and desirable conditions to strive for. Based on these needs or desired conditions, measures are identified to address problems and attain opportunities. Planning objectives are defined and the necessary constraints that may limit the range of viable solutions are identified. The past performance of the ORS has been used as a guide to project potential future problems. The history of the ORS is described in Section 4 and the Environmental Setting of the study area is described in Section 5. Problems and Opportunities are outlined in Section 6. The major planning objectives derived from the problems and opportunities include: ensuring future navigability, improving navigation efficiency and enhancing environmental sustainability.

2.4.2 Inventory and Forecast Critical Resources.

1. Starting with existing conditions, the future status of critical navigation resources is forecast under five scenarios for the most likely future over the 60-year period of analysis. Uncertainty in system demand for water transportation was addressed by developing several future waterway traffic "scenarios" that incorporate different predictions for shipments of coal, the primary commodity moved on the Ohio River. The rationale behind these scenarios and the resulting predictions of waterborne commerce on the Ohio River are contained in Section 8. Uncertainty in the reliability of system components was addressed by engineering reliability analysis. Reliability issues do not define separate scenarios, but are treated probabilistically within each traffic demand scenario. Reliability is also discussed in Section 8.

2. Ten categories of environmental resources (referred to as Valued Environmental Components or VECs) were considered for cumulative effects. Historic and current conditions for each VEC are presented in Section 5 of this report. Forecasts of reasonably foreseeable future conditions and discussions of sustainability are summarized in Sections 6 (Ohio River Problems, Needs and Opportunities) 8 (Ohio River Mainstem Without-Project Condition Assessments), and 9 (Identification of Mainstem Ohio River With-Project System Investment Plans). Detailed assessment of cumulative effects for each of the ten VECs are in the Environmental Appendix, Cumulative Effects Assessment Report.

2.4.3 Formulate Alternative SIPs For Each Traffic Forecast Scenario.

1. Alternative System Investment Plans for navigation investments were formulated by first identifying "measures" to address problems and realize opportunities. As previously described, measures include maintenance, operational efficiency and low cost structural activities, and new lock construction. Structural measures involve construction activities; non-structural involves either low cost construction or operational policies that focus on processing traffic more efficiently. After measures are identified, they are assessed and either dropped from consideration or carried forward for inclusion in one or more alternatives. The same alternatives are formulated for each traffic scenario. The initial step is development of the "without-project" condition, defined as the most likely future conditions at Ohio River mainstem locks and dams without federal investments in high cost maintenance or new lock construction. To improve upon the without-project

SIPs, the high cost maintenance and new lock construction requiring Congressional authorization are considered in "with-project condition" SIPs. The formulation of without-project SIPs is described in Section 8; with-project SIPs are formulated in Section 9.

2. Ecosystem sustainability alternatives were developed by the project team, independent of navigation alternatives, using two sources: the previously authorized Ecosystem Restoration Program (ERP) authorized in 2000 and group discussions with regional aquatic and terrestrial resource experts. See Section 3.2 for more information on the ERP. Sessions were convened to identify actions needed to improve long-term sustainability of ecological resources. The only constraint was to accept that the system is highly modified and will remain so (i.e. it isn't reasonable to return the river and floodplain to predevelopment conditions; however, the system is amenable to further modifications that may affect the resource either positively or negatively). The effort was to be forward looking only, i.e., to consider what can be done in the future. Instructions to the groups were to think only about the resource and to not consider other constraints such as who would take the actions, how or when actions would be implemented, or who would pay for the actions. Ecosystem sustainability needs are the same under all traffic scenarios as sustainability needs were not expected to vary among those scenarios.

2.4.4 Evaluate Alternative SIPs For Each Traffic Scenario.

1. Alternative plans are evaluated to assess future levels of economic, engineering, environmental, and social impacts and outputs. The primary criteria for evaluation of navigation investments are net economic benefits for the nation, referred to as "National Economic Development" (NED) benefits. This process is followed for both the without- and with-project SIPs. Important differences in the levels of these parameters are described and appraised. Evaluations are performed using the Ohio River Navigation Investment Model (ORNIM), developed by Oak Ridge National Laboratory, Oak Ridge, Tennessee, for the Corps of Engineers specifically for the evaluation of alternative Ohio River navigation system investments. This model consists of a suite of four modules that integrate economic, engineering and environmental considerations to the greatest extent possible.[4] Details of the ORNIM model are provided in the Economics Appendix. Plans are carried forward and compared to one another. The best plans for the SIPs for the without- and with- project conditions are carried forth for evaluation. Evaluations are described in Sections 8 and 10 for the without- and with-project navigation SIPs, respectively.

2. Without-project ecosystem sustainability alternatives include those needed actions that could be implemented without additional congressional authority. With-project ecosystem sustainability alternatives add those measures that may require additional authorization by congress, are appropriate for implementation by other agencies, or are likely to incur high costs for planning and implementation. The primary criteria for evaluation of ecosystem alternatives are relative contributions toward restoring ecological functions and attaining long-term resource sustainability. Without-project ecosystem

[4] Engineering considerations are linked through the Lock Risk Module (LRM), economic considerations through the Waterway Supply and Demand Module (WSDM), and environmental through the Navigation Predictive Analysis Technique module (NAVPAT). Finally, the Optimizer module in ORNIM assists in finding the best plan across our 19 lock and dam sites and across time.

sustainability and with-project sustainability alternatives are described in Sections 8 and 9, respectively.

2.4.5 Determine the SIP For Each Traffic Scenario.

1. For each traffic scenario, the set of maintenance, operational efficiency and low cost structural and new lock construction measures that maximize NED benefits is identified. Ecosystem sustainability evaluations do not vary among traffic scenarios so that the same set of measures are preferred. Sections 8 and 10 describe and compare the evaluations for the Without- and With-Project SIPs, respectively, for economic and ecosystem components.

2.4.6 Identify Final SIP and Near Term Activities To Be Implemented

1. The plan with the greatest net economic benefit consistent with protecting the nation's environment is termed the NED plan. The SIP or set of measures that maximize NED benefits in consideration of all five traffic scenarios are considered and that set of measures that best address the whole range of traffic scenarios is identified as the Final SIP. Activities that must be started in the near term to accommodate those measures identified for early in the analysis period are identified for budgeting purposes. Ecosystem measures are considered and included in the Final Combined SIP as appropriate. Further efforts toward implementation of ecosystem sustainability measures may be in the form of "sustainability-focused" mitigation for site-specific impacts or may require non-federal cost sharing partners for feasibility studies and implementation.

2. High cost modernization investments identified as economically justified in this study are not meant to be final recommendations for congressional implementation. Rather, the key point is the identification of a priority list (or blue-print) of modernization needs and the timing when such or similar investments are likely justified, not the specific nature of the investment. Details of the modernization projects will be worked out in follow-on site specific feasibility studies. Feasibility studies are required to confirm or adjust basic assumptions made in this study as to the range of modernization alternatives to consider at each site, allow for more intensive engineering studies that refine the concept-level costs, and to update if necessary economic and environmental data, all of which could have a material bearing on the recommended plan. Finally, the findings in this study are adequate and essential in determining what projects to budget for feasibility study and when those studies should be started.

3. Examples of activities that may be implemented as a result of this study include studies required for structural measures, construction of low-cost structural features, or implementation of operational procedures. The Final SIP and near term actions are described in Section 12. Because ecosystem sustainability alternatives did not vary among traffic scenarios, there was no need to conduct analyses similar to those for navigation SIPs.

2.5 STUDY PARTICIPANTS

1. ORMSS participants are grouped into four major categories, with sub-categories as shown below. The technical study team includes Corps Districts, consulting architect/engineering firms, and universities. Independent Technical Review teams were developed corresponding to the primary study disciplines, namely plan formulation, economics, engineering, and environmental. Within several of these teams, sub-groups of reviewers with very specialized areas of expertise were developed to review specific products. Resource agency and navigation interests were consulted throughout the study for input and comments on work progress. Study oversight was provided by a committee of management staff from the Great Lakes and Ohio River Division (LRD) and the four river districts (Huntington, Louisville, Pittsburgh, and Nashville). The head of this Oversight Committee was the Chief of Planning, LRD.

2.5.1 Technical Study Team

1. This SIP/PEIS is the product of a multi-discipline team of Corps and non-Corps study team members. The three Districts with Ohio River projects within their jurisdictions served as the lead with ample help from navigation and environmental consultants, resource agencies and non-governmental organizations, and navigation industry partners. Study execution involved numerous meetings and communication as described in Section 7 of this report. The major team members are noted below for each category.

Production Team - Ohio River Districts:
U.S. Army Engineer District, Louisville
U.S. Army Engineer District, Huntington
U.S. Army Engineer District, Pittsburgh

Study Team Navigation Design Consultants:
INCA Engineers (Bellevue, WA)
Black & Veatch Engineers (Overland Park, KS)

Study Team Economics and Transportation Consultants:
Center for Transportation Analysis, Oak Ridge National Laboratory
Tennesse Valley Authority
Marshall University
Carnegie Mellon University

Study Team Environmental Consultants:
The Mangi Environmental Group, Inc.
Gulf Engineers and Consultants
Parsons Engineering Science, Inc.
Woolpert, LLP
Environmental Impact Training

Study Team Cultural Resources Consultants:
Gray and Pape (Cincinnati, OH)
Hardlines: Design & Delineation (Columbus, OH)

2.5.2 Resource Agency Interests and Environmental Non-Government Organizations

1. Resource agencies and Environmental Non-Governmental Organizations (NGOs) were involved throughout this study by representation on the Interagency Working Group (IWG). The IWG consisted of approximately 40 members representing federal and state agencies with responsibilities for environmental management, as well as several NGOs. The Corps environmental team (including team members from the environmental consulting firm, Woolpert, Inc. and their sub-contractors), met three to four times annually with the IWG. These one to two day joint meetings generally included information dissemination and updates related to the status of the CEA study, status reports on specific research projects, and working sessions on specific topics. Additional details on this working arrangement can be found in the Environmental Appendix. The agencies represented on the IWG are listed below.

U.S. Fish and Wildlife Agency Field Offices in:

Cookeville, Tennessee
Bloomington, Indiana
Elkins, West Virginia
Marion, Illinios
Ohio River Islands National Wildlife Refuge
Reynoldsburg, Ohio
State College, Pennsylvania
Frankfort, Kentucky
Fisheries Group in Marion, Illinois

Other Federal Agencies:

US Environmental Protection Agency
US Geological Society

State Natural Resources' agencies:

Kentucky Dept. of Fish & Wildlife Resources
Illinois Dept. of Natural Resources
Indiana Dept. of Natural Resources
Ohio Dept. of Natural Resources
Pennsylvania Fish and Boat Commission
West Virginia Dept. of Natural Resources

State Historical Preservation Officers:

Kentucky
Illinois
Indiana
Ohio
Pennsylvania
West Virginia

Other Resource Organizations:

Ohio River Sanitation Commission (ORSANCO)
Non-Governmental Organizations (NGOs)
The Nature Conservancy
Sierra Club
American Rivers
Ohio River Foundation

Navigation Interests

Inland Waterways Users Board (established by Water Resources Development Act of 1986)
The Association for Development of Inland Navigation in America's Ohio Valley (DINAMO), whose Board of Directors include:
Secretary, West Virginia Department of Transportation
Special Assistant to the Governor, Commonwealth of Kentucky
American Waterways Operators (AWO)
Huntington Navigation Advisory Committee
Waterways Association of Pittsburgh
Port of Pittsburgh Commission

2.5.3 Independent Technical Review and Quality Control

1. Independent Technical Review (ITR) is a procedure followed by the Corps to ensure overall quality of a variety of products ranging from planning studies to construction projects. The ITR process is a key part of the Quality Control (QC) of study products. All ITRs involve review by qualified independent personnel not affiliated with the development of the product being reviewed for the purpose of confirming the Corps studies are done in accordance with clearly established professional principles, practices, codes and criteria. For this study, the overall ITR team consisted of sub-groups tasked to review study products produced by a specific team due to the complexity and range of issues. The ITR process supplemented the frequent interactions among study participants referred to as the Product Delivery Team (PDT) and the PDT's review of various products and all report materials. For example, the team leaders of the Economics, Environmental, and Engineering teams reviewed this volume to ensure consistency with the corresponding technical report appendices.

2. The overall ITR process was overseen and coordinated by the U.S. Army Engineer Nashville District (LRN). Oversight of and guidance for the entire study, including production and ITR, was led by the U.S. Army Engineer Great Lakes and Ohio River Division (LRD) located in Cincinnati, Ohio through an Oversight Board (OSB). The Oversight Board was comprised of senior leaders from the Huntington, Louisville, Nashville, and Pittsburgh Districts in addition to senior leaders in the Division office. Teleconferences between the OSB and the PDT were held monthly. At key decision points in the study the OSB and PDT held face-to-face meetings.

3. Independent Review Teams were selected for each of the five disciplines involved in this study, specifically Engineering, Economics, Environmental, Plan Formulation, and Real Estate. The ITR team members included Corps team members having the appropriate expertise to conduct an adequate ITR from throughout the Corps of Engineers. Nashville District and other Corps districts not involved in production of the study conducted much of the ITR. Several topics of the economic analysis required review by special expertise

available only outside of the Corps and the ITR team was expanded to include non-Corps members. Two Corps guidance documents addressing the ITR process that were issued during the latter stages of this study are Engineering Circular (EC) 1105-2-2005, Planning-PEER REVIEW OF DECISION DOCUMENTS, 31 May 2005, and EC 1110-1-105, Engineering-INDEPENDENT TECHNICAL REVIEW, 31 December 2004. The former presents a framework for establishing the appropriate level and independence of review and when and how review by peers outside of the Corps should be assigned. This study follows the spirit of these guidance documents as demonstrated by the external review of economic products, integration of the IWG for environmental issues, and involvement of multiple Corps Districts in all other aspects of the report.

4. A list of the organizations and individuals involved in ITR is shown below and in **Table 2-4**. External experts from outside the Corps were used to review several of economic analyses and reports. The affiliation of these experts are also noted below.

U.S. Army Engineer District, Nashville (Overall Lead, Environmental, and Engineering Design and Cost)
U.S. Army Engineer District, Mobile (Plan Formulation)
U.S. Army Engineer District, Tulsa (Plan Formulation)
U.S. Army Engineer District, New England (Enginering Reliability)
U.S. Army Engineer District, Louisville and Pittsburgh (Office of Counsel)
John Burns of John Burns Assoc. (Economics-Overall)
Mike Bronzini of George Mason University and Karl Pavlovic of DOXA, Inc. (Ohio River Navigation Investment Model-ORNIM)
Janet Skees of Skees Inc. (Economics-Capacity Analysis and Traffic Management)
Steve Fuller of Texas A&M University (Economics – Traffic Demand Forecasts)
Jim Corbett of the University of Delaware (Economics-Transprotation Rates and Willingness to Pay [Elasticities])

5. In addition to this formal ITR, non-navigation stakeholders were involved throughout the study. At the outset of the study, the environmental team established an Interagency Working Group (IWG) made up of State and Federal natural resource agencies and regulatory personnel. Later in the process non-governmental organizations were also represented in the IWG. The IWG met periodically throughout the study to identify issues to be addressed, provide input to the study process, help determine effects, and review results. Although not a part of the formal ITR team, the reviews provided by the IWG were especially valuable to the PDT.

TABLE 2-4
Independent Technical Review Team Functions

Team	Review Responsibilities	Applicable Report Volumes
Engineering	Engineering Data, Reliability Functions, Maintenance Schedules and Costs, New Lock Costs	Engineering Appendix
Economics	Lock Capacities for Existing and New Locks, Traffic Forecasts, Ohio River Navigation Investment Model (ORNIM), Economic Analyses of Maintenance and New Lock Plans, Traffic Management Evaluations	Economic Appendix and Attachments
Environmental	Cumulative Effects Assessment, System Investment Plan/Programmatic Environmental Impact Statement	SIP/PEIS, Environmental Appendix and Attachments
Plan Formulation	Overall Main Report Organization and Content, Plan Formulation Process, Policy Compliance	SIP/PEIS
Real Estate	Real Estate Issues	SIP/PEIS & Engineering Appendices

2.6. INNOVATIVE APPROACHES AND METHODS

1. Traditional navigation planning measures used by the Corps have focused on delineating economic benefits and costs for infrastructure maintenance and navigation improvements. Criticism of these measures have centered on the minimal attention given to risk and uncertainty in the planning analysis (Hammond and Weekly 2005). Risk and uncertainty issues are associated with navigation traffic forecasting, development of proactive schedules for routine maintenance and periodic major rehabilitation of locks and dams, delineation of the environmental effects of single projects in a multi-project system, and enhancement planning for the sustainability of key resources and ecosystems.

2. In a departure from traditional planning measures, the Corps has incorporated several innovative approaches in the ORMSS effort to address and reduce risk and uncertainty over the planning period. Examples of innovative approaches include the generation of environmentally-based traffic demand forecast scenarios, the procurement and analysis of engineering component reliability data for the lock and dam infrastructure, the incorporation of non-structural measures in plan formulation and evaluation, and the development of a state-of-the-art navigation investment model that integrates economic and engineering data along with selected environmental data (Hammond and Weekly 2005). Further information on these approaches follows:

- Five traffic demand forecast scenarios were developed over the planning period to 2070. These scenarios were based on traditional forecasts for basic commodity

groups moved on the river, along with environmentally-driven forecasts for utility coal and sorbent materials (lime and limestone) for flue gas desulphurization. Three alternative regulatory futures relative to air quality management were incorporated in the scenarios along with two economic forecasts based on a survey of the utility industry. These five scenarios, which are assumed to bracket the risk and uncertainty of the forecasts, provide a range of navigation traffic demand for each year in the planning horizon. This range provides the opportunity for more robust and time-sensitive planning for the navigation infrastructure.

- Engineering reliability data surveys were conducted on the key components and overall structural conditions of the existing locks and dams. Based on these data, probability-based component degradation functions and event trees were developed and used to forecast the structural performance of major components of the infrastructure. The forecasts were then used to determine time-sensitive needs for maintenance, major rehabilitations, and lock improvements (Rife, et al. 2005).

- Non-structural measures include those navigation traffic-management schemes that could be utilized to increase the operational efficiency of the navigation system. Such measures can be considerably less expensive than the costs associated with size increases for selected main and auxiliary locks. Further, these measures can be blended with proactive maintenance measures and scheduled major rehabilitation efforts. Traditional navigation planning studies have not routinely included non-structural measures in the analyses. However, at this time for the Ohio River navigation system, these measures will provide operational, economic, and environmental benefits.

- The Ohio River Navigation Investment Model (ORNIM) was developed as a tool to facilitate the integration of information involving probability-based forecasts of lock performance, multiple scenarios of traffic demand, and a host of investment options over the planning horizon. The output from ORNIM identifies the optimal set of investment options (e.g., proactive maintenance, major rehabilitation, etc.) for each existing lock over the planning horizon to 2070 (Hammond and Weekly 2005). ORNIM itself is based on sound economic theory and state-of-the-art computer programming techniques. Systematic usage of ORNIM enables the examination of both individual locks and their combinations in the overall navigation system.

3. Another innovative approach routinely used during the ORMSS involved special efforts to be aware of comparable navigation planning studies; recently-released Corps policies, regulations, and guidelines; new scientific studies on specific topical issues; and emerging themes associated with the NEPA process. The approach involved gathering information on the subject, discussions of the information by the study team, and, as appropriate, incorporation of the requirements or information into the ORMSS. Illustrations of the above-listed categories include:

- Consideration of the National Research Council's review of the Upper Mississippi/Illinois Waterway (UMR/IWW) draft navigation study (National

Research Council 2001). This review provided a basis for incorporating non-structural measures into the ORMSS.

- Review of 2001 guidance from Corps Headquarters to the UMR/IWW study team to include environmental sustainability improvements in every alternative (Rife, et al. 2005). This review provided the impetus for adding improvements to ecosystem sustainability as an objective for the ORMSS. Further, the achievement of ecosystem sustainability was stressed in the Chief of Engineers' seven Environmental Operating Principles (U.S. Army Corps of Engineers 2002 and subsequent guidance and regulation). In fact, all seven principles were incorporated in this study.

- Review of the National Research Council's book on functions and strategies for management of riparian areas (National Research Council 2002). The scientific and policy information provided the foundation used to identify, predict, and assess cumulative effects on the riparian resources of the Ohio River mainstem.

- In 2003, the Council on Environmental Quality (CEQ) issued a report on modernizing the implementation of NEPA requirements (Council on Environmental Quality, 2003). The use of monitoring and adaptive management (AM) as a follow-on to a NEPA document (e.g., a Programmatic EIS) was encouraged as a new "NEPA model". The review of this report, along with numerous other references related to the use of AM for natural resources and infrastructure projects formed the basis for a recommendation for the establishment of an AM program for the Ohio River mainstem (National Research Council, 2004).

4. The environmental features of the ORMSS included several innovative approaches. First and foremost, a programmatic impact study was conducted for all the actions and resources associated with the mainstem. Cumulative effects assessment (CEA) was the integrating tool for this impact study. The goal of the CEA study was to assess the full direct, indirect, and contributed impacts of maintenance, major rehabilitation, and further modernization of the navigation system on resources, ecosystems, and human communities along the mainstem. The analyses addressed the accumulation of meaningful impacts to valued environmental components (VECs) from the actions related to the navigation system in concert with actions and impacts from other past, present, and reasonably foreseeable future actions (RFFAs) by the Corps and others.

5. During the early stages of the detailed planning for the CEA study, it was determined that there were no precedent-setting studies or comprehensive examples for large rivers involving waterway navigation. Accordingly, several new and innovative approaches were developed. Summary information on these approaches follows:

- To provide a planning framework for the CEA study, the CEQ's 11-step CEA process was applied at both a general planning level and a detailed level for identified VECs. Steps 1 to 4 relate to scoping, Steps 5 to 7 to describing the affected environment, and, Steps 8 to 11 to determining the environmental consequences (Council on Environmental Quality, 1997).

- To achieve coordination across the large study area with numerous institutional boundaries and overlapping responsibilities of various federal and state agencies, a 40-person Interagency Working Group (IWG) was formed to provide input and reviews during the conduct of the CEA study. The IWG met three to four times per year at various locations throughout the study area.

- To maintain flexibility due to numerous pragmatic uncertainties associated with performing the study, a multi-component continuous scoping process was developed. The components were comprised of a Project Delivery Team (PDT), oversight board (OB), IWG, scoping meetings (agencies and general public), use of questionnaires, and use of an informational website.

- To consider multiple past, present, and RFFAs in relation to their individual and cumulative effects on the selected VECs, RFFA matrices were developed to delineate cause-and-effect relationships between the actions and 22 selected VECs and their subcomponents. A total of 87 RFFAs were identified and divided into six categories: navigation investment actions, other Corps actions, "but for" actions (actions that would not occur "but for" the existence of the navigation system), actions by others, natural disasters, and regulatory environment. Each listed RFFA was characterized in terms of its anticipated effects, its anticipated time of occurrence, probability of occurrence, and location on the river. Finally, the importance (high, medium, or low) of each RFFA relative to cumulative effects on each VEC or subcomponent was described. As a result, it was determined that RFFA matrices are valuable tools for facilitating a systematic process for considering and evaluating RFFAs in a CEA study. RFFA matrices force the users to consider multiple future actions that may impact a given VEC or subcomponents. Also, completed RFFA matrices provide a documented basis for "scoping" RFFAs and determining which should be addressed in a more detailed manner. Further, information extracted from completed RFFAs can be utilized to summarize a number of key points related to a CEA study. Examples include time periods when given RFFAs are expected to occur; their occurrence probabilities; the settings on or along the river where the given RFFAs are expected to occur; the RFFAs with anticipated negative effects, positive effects, and combinations thereof; and the importance categories for the RFFAs.

- To assess the cumulative effects of multiple actions on environmental sustainability (ES) of the selected VECs, an analysis of environmental sustainability (AES) was developed. This method combines the effects of actions on hierarchical indicators of ES so that sustainability classes can be designated. The AES approach was comprised of four parts: (1) identification of "common effects" on the VEC or subcomponent thereof from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix; (2) selection of indicators of ES for the VEC or subcomponent thereof, and their tiered grouping, as appropriate; (3) description of the "connections" between the common effects (and related High and Medium importance RFFAs) and the indicator groups; and (4) assignment of a "bottom line" sustainability category for the VEC or subcomponent, based on considering the past, present and future conditions. The ES categories included "not sustainable",

"marginally sustainable", and "sustainable". Specific ES definitions were developed for each VEC or subcomponent. Lessons learned from this approach were: (1) it encourages the user to think about the connections between multiple actions and indicators in both a relative and holistic manner, thus encouraging the synthesis of a large body of information; (2) it could be strengthened with quantitative information on each action, indicator, and tiers of indicators; however, in the absence of time-related information on each part, a qualitative discussion of the connections can still be useful; and (3) the structured framework of the approach can be useful for identifying current and future monitoring, mitigation, and sustainability needs, and for planning AM programs, as appropriate.

- To identify VEC-based actions that could be used to improve sustainability, the PDT utilized groups of experts to delineate sustainability needs for aquatic and riparian/floodplain resources (Swor, et al., 2005). The results of this "expert elicitation" were then considered in the development of several ES measures that could be incorporated in the SIP. In addition, the findings of an authorized ecosystem restoration program for the Ohio River were used in the formulation of these ES measures (U.S. Army Corps of Engineers, 2000).

6. During planning and conduct of the CEA study, several specific research efforts, surveys, or data needs were identified in relation to the selected VECs. Accordingly, another innovative approach involved the following special efforts related to the CEA study:

- Study of various engineering and hydraulic factors related to Ohio River locks and dams, along with fish swimming velocities of 44 target species, to ascertain upstream fish passage opportunities at the mainstem dams.

- Study of winter habitat types used by fishes in the Smithland and Belleville navigation pools, and comparison of the results between the downstream and upstream pools.

- Study of fish movement in the Ohio River based on fish tagging and tag return data; a survey of fish community structures within lock chambers in relation to tailwater fish communities, along with short-term movement patterns of targeted species at the Winfield locks and dam on the Kanawha River; and a description of the results of creel surveys (recreational angling) in the tailwaters of Ohio River locks and dams.

- Compilation of basic literature and historical data on mussel species in the navigation pools of the Ohio River mainstem, (including the preparation of an Ohio River Mussel Database CD); and a survey of glochidial infestation on Ohio River fish species.

- A study of recreational usage of the Ohio River mainstem.

- A focus group study of recreational trends on the Ohio River.

- Collection of data on bottom substrates, bathymetry, and structure for navigation pools in the Ohio River mainstem -- the results were used in the Navigation Predictive Analysis Technique (NAVPAT) modeling.

- Several other databases have been developed from these studies; they include a spatial database for the fish tagging studies, angler use surveys, and NAVPAT field data. These databases provide resource information that can be used for a variety of purposes by various stakeholder groups.

7. The final innovative approach to be noted is that this integrated report has been developed to present the SIP. The report includes interwoven information related to navigation traffic demands, engineering reliability analyses of the existing lock and dam infrastructure, cumulative effects on various resources and ecosystems, analyses of the benefits and costs related to time-sensitive maintenance and rehabilitation of the infrastructure, and identification of high priority ecosystem sustainability needs for aquatic and riparian/floodplain resources. Further, the information is presented so as to include the components of a programmatic EIS as required under NEPA. Finally, the integrated main report is supported by multiple appendices, including those related to traffic demand forecasts, engineering reliability analyses, the comprehensive CEA study, outputs of the ORNIM model, a communications plan, and others.

Selected References

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Rife, V. L., Benedict, J. M., and Swor, C. T., "Overview and Status of the Ohio River Mainstem System Study", presented at the International Association for Impact Assessment (IAIA'05) Theme Forum entitled "The Ohio River Mainstem Systems Study (ORMSS) – A Case Study Illustrating Innovative Approaches", May 30-June 3, 2005, Boston, Massachusetts.

Swor, C. T., Canter, L. W., Rieger, D., Hollins, E., and Harrell, L., "Analysis of Environmental Sustainability Needs for the Ohio River Mainstem System Study", presented at the International Association for Impact Assessment (IAIA'05) Theme Forum entitled "The Ohio River Mainstem Systems Study (ORMSS) – A Case Study Illustrating Innovative Approaches", May 30-June 3, 2005, Boston, Massachusetts.

U.S. Army Corps of Engineers, "Environmental Quality – Policy for Implementation and Integrated Application of the U.S. Army Corps of Engineers (USACE) Environmental Operating Principles (EOP) and Doctrine", ER 200-1-5, October, 2003 Washington, D.C.

U.S. Army Corps of Engineers, "Planning Civil Works Projects under the Environmental Operating Principles", EC 1105-2-404, May, 2003, Washington, D.C.

U.S. Army Corps of Engineers, "USACE Environmental Operating Principles and Implementation Guidance", March 26, 2002, Washington, D.C.

U.S. Army Corps of Engineers, "Integrated Decision Document and Environmental Assessment, Ohio River Ecosystem Restoration Program", 2000, Great Lakes and Ohio River Division, Cincinnati, Ohio.

SECTION 3
PRIOR STUDIES AND REPORTS

The Ohio River Mainstem System Study (ORMSS) that reviewed all lock projects on the Ohio River mainstem as a system began in 1995. Prior to that point, this study concentrated on the Uniontown {now J.T. Myers} project with a 1200' main chamber and a 600' auxiliary chamber that resulted in the Uniontown Reconnaissance Report. Corps review of that report set the stage for subsequent studies, stating:

> The Corps must take a "systems look" to properly address the level of investments needed to continue to provide a viable navigation system ***on the Ohio River Mainstem***. ... the entire Ohio River Mainstem navigation system should be carefully reviewed, but your primary emphasis for this study should concentrate on the lower portion of the river.

Thus, ORMSS is a Master Plan for long-term needs along the entire 981-mile Ohio River for a 60-year planning horizon. The Project Study Plan for ORMSS also allowed for the development of interim authorization (feasibility) documentation for near term system projects, if appropriate, prior to completion of the final report due to time requirements. These reports are summarized in Sections 3.1 and 3.2. Section 3.3 contains a list of other pertinent reports and summaries.

3.1 INTERIM FEASIBILITY REPORT: J.T. MYERS & GREENUP LOCKS IMPROVEMENTS (APRIL 2000)

Based on industry input and supporting investigations and analyses that documented critical needs at J.T. Myers and Greenup Locks and Dams early in preparation of the SIP, an interim feasibility report was initiated in 1998 that focused those facilities. A Notice of Intent to Prepare an Environmental Impact Statement for the Ohio River Main Stem System Study was published in the Federal Register on October 21, 1998. The J.T. Myers and Greenup Locks Improvements Interim Feasibility Report was completed in April 2000 and recommended similar improvements at each site that included:

- Extending the shorter 600' locks (the land-side chambers) to 1200' length. (These are nominal dimensions, i.e. a *1200'-chamber* means that a 1200-foot long tow can be accommodated in the chamber.)
- Installation of a Miter Gate Quick Changeout System (MGQCS). The MGQCS provides for significantly faster repairs to the lock gates in the future at these two sites, whenever gate repairs are required.

These improvements were authorized by the Water Resource Development Act of 2000 (WRDA 2000). Both projects are currently in the design phase and initial construction has begun at J.T. Myers.

3.2 OHIO RIVER ECOSYSTEM RESTORATION PROGRAM (OCTOBER 2000)

During preparation of the J.T. Myers and Greenup Locks Improvements Interim Feasibility Report, the need of and support for an ecosystem restoration program tailored to the unique characteristics of the Ohio River and its associated floodplain became a recurrent theme. Because of the apparent need for such a program, a component of the ORMSS became a study to determine whether an ecosystem restoration program specifically tailored to the Ohio River and associated floodplain corridor should be recommended for authorization. A Notice of Intent to Prepare an Environmental Assessment for Proposed Authorization of an Ecosystem Restoration Program was published in the Federal Register on June 9, 2000. This study was conducted independent of navigation aspects of the ORMSS. A second interim report, the Ohio River Ecosystem Restoration Report, was prepared and the program authorized in WRDA 2000. The integrated Decision Document and Environmental Assessment provide the following conclusions and recommendations for authorization of an Ohio River Ecosystem Restoration Program:

- A comprehensive, managed ecosystem restoration program is needed for the Ohio River corridor consistent with current law and Corps policy.
- A recommendation for authorization of a multi-year program, with maximum Federal funding of $10 million annually, for each of the first five years, and $15 million annually for the remainder of the program.
- The creation of a partnership composed of representatives from government resource agencies, universities, and other environmental concerns, for monitoring, evaluating and managing the Ohio River ecosystem.
- A corridor-wide ecosystem needs assessment and strategy, or Program Implementation Plan, would be developed initially to refine ecosystem goals and prioritize restoration efforts.
- Implementation of site-specific projects to accomplish program goals.

Non-Federal sponsors would fund 35 percent of site-specific project first costs and 100 percent of operation, maintenance, repair, rehabilitation, and replacement. This program has not been funded to date and is now a candidate for de-authorization.

3.3 OTHER PERTINENT REPORTS

Table 3-1 summarizes major decision documents pertinent to the ORMSS SIP/PEIS. The two most recent studies are for Major Rehabilitation projects at Markland Locks and Dam (April 2000) in the Louisville District and for Emsworth Locks and Dams in the Pittsburgh District (July 2001). These rehabilitation projects are on-going. Work at Markland includes replacement of lock gates and hydraulic machinery in the main chamber, whereas work at Emsworth involves replacement of all pre-World War II vintage

vertical lift dam gates with new hydraulic lift structures and the scour protection downstream of both dams. These rehabilitations are designed to extend the useful life of the affected components by at least fifty years.

TABLE 3-1
LIST OF PRIOR MAJOR REPORTS PERTINENT TO THE ORMSS SYSTEMS INVESTMENT PLAN REPORT (sheet 1 of 5)

Document Title	Date	Produced by	Summary
Lower Ohio River Navigation Feasibility Study, IL-KY (Mouth to Cumberland River) Locks and Dams No. 52 and 53 and Final Environmental Impact Statement	Nov-85	Louisville District	Recommended a new project near Olmsted, IL (Ohio River Mile 964.4) to replace Locks and Dams 52 and 53. The new project will be comprised of a gated dam with navigable wicket section and twin 1200'x110' lock chambers. Comstruction scheduled to be complete in 2013.
Ohio River Mainstem Study, Gallipolis Interim Navigation Feasibility Report and Emvironmental Impact Statement	Feb-81	Huntington District	Recommended new 1200'x110' and 600'x110' lock chambers. Construction completed in 1995. Project now R.C. Byrd L/D.
Report on Replacement-Emsworth, Dashields and Montgomery Locks and Dams	Apr-71	Pittsburgh District	Analyzed alternatives for rehabilitation and replacement for the three upper-most projects on the Ohio River. Recommendation never processed.
OTHER REPORTS SUPPORTING ORMSS			
Expert Elicitation for Concrete Monoliths at Emsworth, Dashields and Montgomery L/Ds, Ohio River	Sep-00	Pittsburgh District	Assessed Concrete Condition and Probabilities of Failure at Emsworth, Dashields, and Montgomery
Ohio River, Emsworth, Dashields, and Montgomery Locks and Dams, Condition Report	Jul-00	DLZ for Pittsburgh District	Detailed Condition Summary for Emsworth, Dashields, and Montgomery
ORMSS - 100% Submittal Constructibility and Cost Estimate (Analyses) for Prototype Alts. (DACW27-95-C-0126)	May-98	INCA Engineers (Bellevue, WA) for the Louisville District	Descriptions, drawings, constructn schedules, & cost estimates for 9 configuratns of F/E systems. Constructibility evaluations.
ORMSS - 100% Submittal Conceptual Design of Emsworth, Dashields, and Montgomery Locks and Dams, Ohio River	Sep-97 & Jan-98	INCA For the Pittsburgh District	Cost estimates for alternatives with 1200' & 600' locks and twin 600' locks at these sites.

TABLE 3-1
LIST OF PRIOR MAJOR REPORTS PERTINENT TO THE ORMSS SYSTEMS INVESTMENT PLAN REPORT (sheet 2 of 5)

Document Title	Date	Produced by	Summary
Lower Ohio River Navigation Feasibility Study, IL-KY (Mouth to Cumberland River) Locks and Dams No. 52 and 53 and Final Environmental Impact Statement	Nov-85	Louisville District	Recommended a new project near Olmsted, IL (Ohio River Mile 964.4) to replace Locks and Dams 52 and 53. The new project will be comprised of a gated dam and twin 1200'x110' lock chambers.
Ohio River Mainstem Study, Gallipolis Interim Navigation Feasibility Report and Emvironmental Impact Statement	Feb-81	Huntington District	Recommended new 1200'x110' and 600'x110' lock chambers
Report on Replacement-Emsworth, Dashields and Montgomery Locks and Dams	Apr-71	Pittsburgh District	Analyzed alternatives for rehabilitation and replacement for the three upper-most projects on the Ohio River. Recommendation never processed.
OTHER REPORTS SUPPORTING ORMSS			
Expert Elicitation for Concrete Monoliths at Emsworth, Dashields and Montgomery L/Ds, Ohio River	Sep-00	Pittsburgh District	Assessed Concrete Condition and Probabilities of Failure at Emsworth, Dashields, and Montgomery
Ohio River, Emsworth, Dashields, and Montgomery Locks and Dams, Condition Report	Jul-00	DLZ for Pittsburgh District	Detailed Condition Summary for Emsworth, Dashields, and Montgomery
ORMSS - 100% Submittal Constructibility and Cost Estimate (Analyses) for Prototype Alts. (DACW27-95-C-0126)	May-98	INCA Engineers (Bellevue, WA) for the Louisville District	Descriptions, drawings, constructn schedules, & cost estimates for 9 configuratns of F/E systems. Constructibility evaluations.
ORMSS - 100% Submittal Conceptual Design of Emsworth, Dashields, and Montgomery Locks and Dams, Ohio River	Sep-97 & Jan-98	INCA For the Pittsburgh District	Cost estimates for alternatives with 1200' & 600' locks and twin 600' locks at these sites.

TABLE 3-1
LIST OF PRIOR MAJOR REPORTS PERTINENT TO THE ORMSS
SYSTEMS INVESTMENT PLAN REPORT (sheet 3 of 5)

Document Title	Date	Produced by	Summary
Impacts of Diversion of Traffic Off Of the River System Due to Unreliable Lock Service at The Upper Ohio River Navigation Projects Emsworth, Dashields and Montgomery Locks and Dams	Jul-00	Gannett Fleming, Inc. for the Pittsburgh District	Estimated the potential for lost jobs and wages due to long-lock closures at Emsworth, Dashields and Montgomery locks and dams.
ORMSS Field Inspection Report of all L&D Facilities on the Ohio River (Pittsburgh, Huntington & Louisville Districts)	1996-1997	CELRP; inspections by a core group of engineers from the Huntington, Louisville, and Pittsburgh Districts.	Details visual inspection of facilities at each L&D plus interviews with Lockmasters & projects' O&M Leaders. Provides numerical ratings for various L&D components, and photos of conditions at each L&D.
Impacts on Traffic Volumes due to Modernization of Emsworth, Dashields and Montgomery Locks	Jan-01	Tennessee Valley Authority for the Pittsburgh District	Evaluated potential barge movements that would be induced with construction of new 1200'x110' lock chambers at each of the Emsworth, Dashields, and Montgomery projects.
OTHER OHIO RIVER NAVIGATION REPORTS			
Great Lakes and Ohio River Navigation Systems Commerce Reprot, 2002	2002	Huntington District Navigation Planning Center	Intervening year statistical updates to biennial Ohio River and Great Lakes Navigation Systems
OHIO RIVER NAVIGATION SYSTEM -- 1999 Statistical Supplement (also 1997, 1994 and 1990)	1999	Huntington District Navigation Planning Center	Intervening-year statistical updates to the biennial Ohio R. Nav. System Report (1998)

TABLE 3-1
LIST OF PRIOR MAJOR REPORTS PERTINENT TO THE ORMSS
SYSTEMS INVESTMENT PLAN REPORT (sheet 4 of 5)

Document Title	Date	Produced by	Summary
Ohio River Basin Comprehensive Survey in 14 volumes	Aug-69	Ohio R Basin Survey Coordintg Comm.: Departments of Agriculture; Army; Commerce; Health, Education & Welfare; Interior; Federal Power Commission, Various States	A basin freamework study covering economics, water supply, pollution, F&W resources, navigation, flood control, etc.
OTHER OHIO RIVER ENVIRONMENTAL REPORTS			
Ohio River Section 7 Report	Dec-04	Louisville, Huntington and Pittsburgh Districts	
Ohio River Navigation Project, Final Environmetnal Impact Statement	Jan-80	Huntington District	
Draft Environmental Impact Statement on Commercial Sand and Gravel Dredging Operations in the Allegheny (Mile 0 to Mile 69.5) and Ohio (Mile 0 to 40) Rivers	1/1/2005 (projected)	Pittsburgh District	
Hydroelectric Power Development in the Upper Ohio River Basin	Sep-88	Federal Energy Regulatory Commission	Final Environmental Impact Statement prepared by the FERC to evaluate potential environmental impacts of up to 19 hydropow er projects in the upper Ohio River Basin. The recommendation w as to allow for up to sixteen of these possible projects to be constructed and operated.

TABLE 3-1
LIST OF PRIOR MAJOR REPORTS PERTINENT TO THE ORMSS SYSTEMS INVESTMENT PLAN REPORT (sheet 5 of 5)

Document Title	Date	Produced by	Summary
OHIO RIVER MAINSTEM SYSTEM STUDY ENVIRONMENTAL STUDIES			
Winter Habitat Used by Fishes in Smithland Pool and Belleville Pool, Ohio River	Dec-03	J. Garvey, S. Welsh, K. Hartman, et.al. (Southern Illinois Univ.)	
Fish Passage Study Conducted for ORMSS - Distribution of Mussles and Fish Within the Ohio River	Jan-03	G. Watters, T. Cavender, C. Myers, M. Kibbey, V. Gordon, B. Pittinger, T. Pohlman, (The Ohio State Univ)	
Upstream Fish Passage Opportunities at Ohio River Mainstem Dams	Dec-03	B. Knights, J. Wlosinski, J. Kalas, S. Bailey, (USGS)	
Ohio River Mainstem Context Study	Sep-01	D. McVarish, D. Berg, R. Carlisle, W. Mulligan (ed by Greenhorne & O'Mara)	
Fish Passage Issues Associated with Ohio River High-Lift Dams	Apr-04	C. O'Bara (WV DNR)	
NAVPAT Application to the Ohio River Mainstem System Study and the Evaluation of NAVPAT Habitat Relationships	Jan-06	US Army Corps of Engineers	
Project Report for Woolpert Ohio River Recreation	Jan-04	T. Shaw, J. Minser (Institute for Policy Research, Univ of Cincinnati)	

SECTION 4

OHIO RIVER NAVIGATION SYSTEM

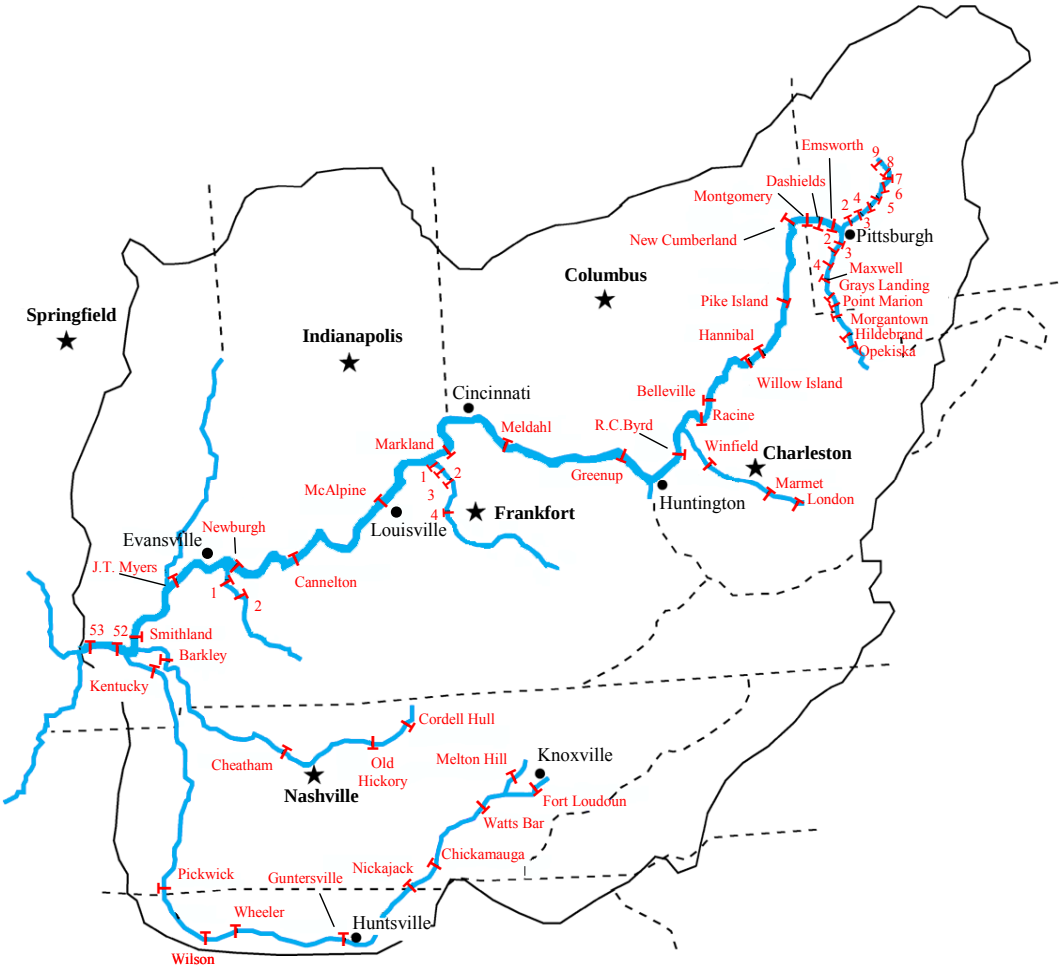
This section provides an overview of the Ohio River Navigation system – its geography, history of Federal development, and commodity movements and statistics focusing on the period 1970-2000. Navigation along the mainstem Ohio River and throughout the Ohio River Basin is described.

4.1 DESCRIPTION OF OHIO RIVER NAVIGATION STUDY AREA

1. The navigation study area includes the entire mainstem Ohio River, which extends 981 miles from the junction of the Allegheny and Monongahela Rivers at Pittsburgh, Pennsylvania, to near Cairo, Illinois where the Ohio flows into the Mississippi River. Year-round navigation is provided on the Ohio River by 20 locks and dams (soon to be 19 with the completion of Olmsted and subsequent removal of L/Ds 52 and 53) and periodic maintenance dredging. This river forms the backbone of the navigation system within the entire Ohio River basin, referred to as the Ohio River Navigation System, or ORS (**see Figure 4-1**). The ORS comprises more than 2,600 miles of commercially navigable waterways. Within this basin, the Corps has also constructed and operates and maintains 82 reservoirs, primarily for flood control, water supply, low flow augmentation and recreation. Releases from these reservoirs during periods of drought can sustain navigation during drought periods. The basin comprises 204,000 square miles and is home to over 31.5 million people (2000 census), and encompasses all or portions of fourteen states, including Alabama, Georgia, Kentucky, Indiana, Illinois, Maryland, Mississippi, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. Pittsburgh, Cincinnati, Columbus, Indianapolis, Louisville, and Nashville are the region's largest cities. Locks and dams also provide year-round navigation on seven tributaries to the main stem Ohio River (Allegheny, Monongahela, Kanawha, Green, Kentucky, Cumberland and Tennessee Rivers). These tributaries are not part of this study.

2. The topography of the basin varies from rugged mountains to flat plains. The Appalachian Mountains dominate the eastern portion. West of these mountains and south of the Ohio River, the landscape contains considerable local relief, which gradually modifies to rolling plains through most of Kentucky and Tennessee. North of the Ohio River, broad valleys with only minor relief extend from southwestern and central Ohio through central Indiana into southern Illinois.

FIGURE 4-1
Locks and Dams of the Ohio River Navigation System



4.2 HISTORY OF FEDERAL DEVELOPMENT OF THE OHIO RIVER

1. Federal involvement in improving the Ohio River for commercial navigation began in 1824, when Congress directed the Corps to find a method of removing sandbars and snags. The desired channel depths to be attained by this clearing and snagging program were 3 feet and 30 inches for the lower and Upper River reaches, respectively. This depth was deemed adequate for vessels at the time, consisting of steamships, keelboats, and flatboats. By 1870, William Milnor Roberts proposed that a six-foot navigation pool along the entire Ohio River would be necessary to accommodate future navigation. It was estimated that sixty-six locks and dams would be required to provide this channel. The River and Harbor Act of 1875 provided funds for the construction of a movable dam 4.7 miles downstream of Pittsburgh at Davis Island, also known as Lock and Dam 1. Federal canalization of the Upper Ohio River for 6-foot navigation was started in 1877 with the start of construction of Davis Island Lock and Dam. Completed in 1885, the project consisted of one lock chamber 600' long and 110' wide (600'x110') and a wicket dam which allowed traffic to navigate the river without proceeding through the lock in high flows. This was the only federally constructed facility in the nineteenth century. One other lock (78' wide) was constructed with funding provided by private sources and the

city of Louisville in the Portland Canal that skirted the "Falls of the Ohio" at Louisville. The six-foot channel was never realized.

2. By 1908, Locks and Dams 2 through 6 were constructed extending down to Ohio River mile 30. However, by 1900, coal barge tows requiring nine-feet of draft were already operating on the Ohio River and a nine-foot channel depth for the entire river gained popularity. Subsequent to a recommendation by the Board for Rivers and Harbors in 1906, the River and Harbor Act of 1910 authorized a 9-foot slack-water navigation project for the Ohio River, with projects consisting of movable (wicket) dams and a single lock chamber 600'x110'. The Act originally provided for the construction of 54 locks with movable dams and for the widening of the Louisville-Portland Canal at Louisville, Kentucky, and the construction of a new lock in the canal. This plan was modified with certain substitutions and eliminations under authorities of the River and Harbor Act of 18 July 1918 and 30 August 1935. The original Ohio River "project", when completed in 1929, consisted of 50 lock and dam structures and the Louisville-Portland Canal and canal lock and provided reliable channel depth of 9 feet. During this period, Ohio River traffic grew substantially, increasing from 10 million to 20 million tons between 1923 and 1925. **Table 4.1** chronicles the construction history of the original Ohio River project (three left columns).

3. During construction of the original Ohio River project, it was recognized that fixed, non-navigable dams had some advantages over the movable (navigable) dams, particularly in maintaining permanent pools for the convenience of navigation and in providing better conditions for industrial development along the river banks. Accordingly, the River and Harbor Act of 18 July 1918 provided "That the Secretary of War is hereby authorized to modify the project for the improvement of the Ohio River in accordance with the report submitted in House Document 1695, 64th Congress, 2nd Session. The House Document recommended replacement of original Ohio River Locks and Dams 1 and 2 by the Emsworth Locks and Dams (where the dam was comprised of two sections separated by Neville Island) and dual locks. The original Emsworth project included fixed weir dam sections. The dams were reconstructed in 1937 with a low sill and vertical lift gates to provide a deeper and more stable pool at Pittsburgh. Dashields Locks and Dam was constructed under the 1918 authority to replace original Lock and Dam No. 3.

TABLE 4.1
History of Ohio River Lock and Dam Construction

Original Lock and Dam #[1]	Miles Below Pittsburgh[1]	Navigation Commenced	High Lift Locks & Dam(s)	Miles Below Pittsburgh	Navigation Commenced
1 (Davis Island)	4.7	1887	Emsworth	6.2	1921
2	9.0	1906			
3	10.9	1908	Dashields	13.3	1929
4	18.6	1908			
5	23.9	1907			
6	29.3	1904	Montgomery	31.7	1936
7	36.5	1914			
8	46.4	1911	New Cumberland	54.4	1956
9	56.1	1914			
10	66.2	1915			
11	76.9	1911	Pike Island	84.2	1963
12	87.0	1917			
13	95.8	1911			
14	114.0	1917	Hannibal	126.4	1972
15	129.1	1916			
16	146.6	1917	Willow Island	162.4	1972
17	167.5	1918			
18	179.9	1910			
19	192.2	1916			
20	202.5	1917	Belleville	203.9	1968
21	214.6	1919			
22	220.9	1919			
23	231.4	1921	Racine	237.5	1967
24	242.4	1919			
25	260.7	1922			
26	278.5	1912	R.C. Byrd	279.2	1993
27	301.0	1923			
28	311.6	1915			
29	319.9	1916			
30	339.4	1923	Greenup	341.0	1959
31	359.3	1920			
32	382.6	1925			
33	405.1	1921			
34	434.1	1925	Meldahl	436.2	1962
35	451.0	1919			
36	461.0	1925			
37	483.2	1911			
38	501.3	1924			
39	529.6	1912	Markland	531.5	1959
41	606.8	1927	McAlpine	606.8	1961
43	630.2	1921			
44	660.3	1926			
45	703.0	1928	Cannelton	720.7	1971

46	752.9	1928			
47	772.5	1927	Newburgh	776.1	1975
48	804.1	1921			
49	845.0	1927	J.T. Myers	846.0	1975
50	876.8	1929	Smithland	918.5	1979
52	938.9	1928			
53	962.6	1929	Olmsted		2013[2]

[1] Lock and Dam Mileposts for Original Navigation Project taken from Ambler, C.H., A History of Transportation in the Ohio Valley, Greenwood Press, 1931, pp. 421-422.
[2]Projected Completion Date.

Montgomery Locks and Dam, comprised of a fixed, gated dam was built under the same 1918 authority to replace Locks and Dams 4, 5, and 6. The sizes of the locks at these chambers were the same; 600’ x 110’ (main chamber) and 360’ x 56’ (auxiliary chamber). Congress also specifically authorized the Gallipolis Locks and Dams in the River and Harbor Act of 39 August 1935. That project replaced the three lower locks and dams on the Kanawha River and Locks and Dams Nos. 24, 25 and 26 on the Ohio River. It consisted of a single high-lift, gated dam and dual chambers, 600’ x 110’ and 360’ x 110’. By 1937, with construction of Emsworth, Dashields, Montgomery and Gallipolis locks and dams, the total number of locks on the Ohio River reduced to 46.

4. Ohio River traffic in the early 1900’s was highly dependent upon coal movements from Pittsburgh to New Orleans. Due to heavy declines in this traffic, which was diverted to steel plants in the Upper Ohio Valley, Ohio River traffic dropped to its lowest level in 1917, 4.6 million tons. Then, transportation demands of World War I severely overburdened existing overland transportation systems and river traffic increased. The original canalization project was completed in 1929. Ohio River tonnage rebounded to over 22 million tons by 1930. This waterway spurred economic growth and assisted the rapid nationwide mobilization during World War II. Sustained post-war expansion of the national economy increased the use of all types of commodities carried on the river. Oil and gasoline products moved upriver while coal moved downriver in great quantities. This rapid growth in traffic exceeded the government's ability to increase lock capacity and by the 1950s serious delay problems had become obvious. The original 600-foot lock chambers built during the days of paddleboats and wooden barges were obsolete and could not handle large modern tows in a single lockage.

4.3 RECENT OHIO RIVER LOCKS AND DAMS IMPROVEMENTS

1. As increased navigation costs began to affect the region's economy, plans were formulated beginning in the 1950s to modernize the original navigation system. The improvement plan developed called for the replacement of earlier low-lift structures with a lesser number of high-lift locks. The modernized structures provide higher-lift dams, with longer pool-reaches between projects, and larger lock dimensions. Modernization of the Ohio River Navigation System began in 1954 with construction of Greenup Locks and Dam, a structure with a 30-foot lift, a 1200 by 110-foot Main lock, and a 600 by 110-foot Auxiliary lock. The modernization program envisioned 19 modern high-lift projects, and this system will finally be realized after construction of Olmsted and the decommissioning

of Locks and Dams 52 and 53, tentatively scheduled for 2009. The construction history of the modern high-lift projects is shown in **Table 4-1** (rightmost three columns). The specifications for these projects are listed in **Table 4-2**. A map of the current system was show in **Figure 2.1**.

2. Improvements on the Ohio River Mainstem continue today at Robert C. Byrd Locks and Dam (formerly Gallipolis) located just upstream of Huntington, West Virginia; Olmsted Locks and Dam on the lower Ohio River, see **Table 4-1**). The last lock modernization project was completed in January 1993 at Robert C. Byrd Locks, where two new locks measuring 1200 by 110 feet and 600 by 110 feet replaced the outdated 600'x110' main chamber and 360'x110' locks. The Olmsted project at river mile 964.4, which will provide a modern structure to replace Locks and Dams 52 and 53, will consist of twin 1200 by 110-foot locks and a new dam with submersible gates to allow tow passage over the dam during higher flow conditions. With completion of Olmsted, the number of Ohio River mainstem projects will be reduced from 20 to 19. The McAlpine project at river mile 606.8 replaced the old 600' Auxiliary Lock with a new 1200' chamber -- providing this site with twin 1200 by 110-foot chambers.

3. The Ohio River is a vital transportation artery for the Ohio River basin states, as well as a large number of other states due to its interconnections with the Mississippi River, the Great Lakes, and U. S. coastal ports.

TABLE 4-2.
Ohio River Lock Specifications

Lock & Dam Project Name	RiverMile (downstream of Pittsburgh)	Year Operational			Year Rehabilitated			Chamber Sizes	
		Main	Aux.	Dam	Main	Aux.	Dam	Main	Aux.
Emsworth	6.2	1921	1921	1922	1984	1984	1984	600x110	360x56
Dashields	13.3	1929	1929	1929	1990	1990	1990	600x110	360x56
Montgomery	31.7	1936	1936	1936	1989	1989	1989	600x110	360x56
N. Cumberland	54.4	1956	1959	1961				1200x110	600x110
Pike Island	84.2	1963	1963	1965				1200x110	600x110
Hannibal	126.4	1972	1972	1975				1200x110	600x110
Willow Island	162.4	1972	1972	1973				1200x110	600x110
Belleville	203.9	1968	1968	1969				1200x110	600x110
Racine	237.5	1967	1967	1970				1200x110	600x110
R.C. Byrd	279.2	1993	1993	1937			2000	1200x110	600x110
Greenup	341.0	1959	1959	1962				1200x110	600x110 b
Meldahl	436.2	1962	1962	1964				1200x110	600x110
Markland	531.5	1959	1959	1964				1200x110	600x110
McAlpine	606.8	1961	1921	1964		1965		1200x110	1200x110 a
Cannelton	720.7	1971	1971	1971				1200x110	600x110
Newburgh	776.1	1975	1975	1975				1200x110	600x110
J.T. Myers	846.0	1975	1975	1975				1200x110	600x110 b
Smithland	918.5	1979	1979	1979				1200x110	1200x110
L&D No. 52	938.9	1969	1928	1929		1983	1984	1200x110	600x110 c
L&D No. 53	962.6	1980	1929	1929		1982	1984	1200x110	600x110 c

a The new 1200'x110' chamber at McAlpine opened in 2009.

b Auxiliary locks at J.T. Myers and Greenup L/Ds will be extended to 1200'.

c Olmsted L&D, now under construction at river mile 964.6, will replace both L&D 52 and 53. This new facility will have 2 identical chambers, both of size 1200'x110' with completion by 2013.

4.4 CURRENT STATE OF THE OHIO RIVER

1. Existing conditions on the Ohio River mainstem may be described as follows:

A large canalized river open year-round, consisting of 20 pools formed by 20 locks and dam structures. (After the completion of Olmsted L&D in 2008, which replaces L&Ds 52 and 53, there will be 19 pools and 19 locks and dam structures.) By *canalized* we mean that the original free-flowing river was controlled, starting over 100 years ago, into a series of relatively flat pools ("canals") for purposes of maintaining year-round navigation. The locks are open 24 hours a day, except during periods when a chamber is closed due to weather or for inspection and maintenance/repair work. A minimum navigation channel of 9-foot depth and 300-foot width is provided with use of dredging and snagging (tree and log removal).

The current geometry of the river, as modified by the higher pool levels of the modernized dam system, generally provides for safe navigation of commercial tows as long as 1200' long x 108' wide. A typical large jumbo-hopper-barge tow consists of fifteen 195'x35' barges, plus a towboat of varying dimensions, resulting in a tow of about 1170'x105'. Occasionally, tows on the lowermost reaches of the Ohio, below Smithland L&D, operate in a double-wide configuration of 30 barges (5 long x 6 wide), typical of the larger tows on the lower Mississippi River. During winter months, these 6-barge-wide tows can navigate over the navigable wickets of Dams 52 and 53 (and after 2009 the wickets at the new Olmsted L/D). Such tows cannot navigate through these wickets during the drier months, when they must use the locks at L&D 52 and 53. Locks at Olmsted will also be used during low flow periods

In terms of age and size, the locks and dam facilities may be classified into 3 broad groups:

The 60+ year old upper three structures (Emsworth, Dashields, and Montgomery L&Ds) just downstream of Pittsburgh PA. These 3 locks each have one 600'x110' Main chamber and a 360'x56' Auxiliary chamber. Fifteen-barge tows must be processed in double-cuts through the Main chamber, while tow sizes are limited to five-cuts in the small Auxiliary chamber.[1] The condition of these old structures, together with the inefficiently-small lock sizes, are major concerns. In the year 2010, 14 of the 40 lock chambers will be over 50 years old, and 24 will be between 30 and 50 years old.

The 13 modernized lock and dam structures constructed between 1954 and 1979, plus Byrd L&D which has new locks completed in 1993. This includes all the locks from New Cumberland downstream to J.T.Myers, a distance of 791.6 miles. Each of these newer locks has a 1200'x110' Main lock chamber and a 600'x110' Auxiliary chamber. The 1200' long Main chamber allows 15-barge tows to lock through in a single operation, while smaller tows or other vessels usually use the Auxiliary chambers. These newer locks and dams are spaced about 60 miles apart, on average, and replaced a series of about 50 old lower-lift structures built around the turn of the century.

[1] Tows too large for a lock chamber are broken into smaller pieces, or cuts. Each cut is processed through the chamber individually. A tow that must be broken into two pieces is referred to as a double-cut, and its processing through the lock as a double-cut lockage.

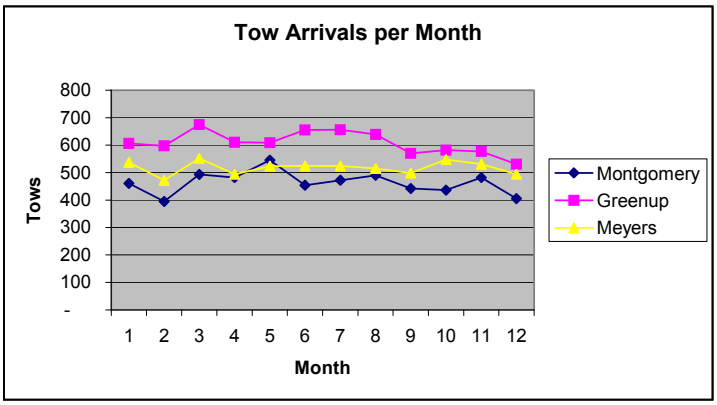
Locks which have two side-by-side 1200'x110' locks. These include Smithland L&D (placed in operation in 1980), McAlpine (placed in operation in 2009) and Olmsted L&D (now under construction).

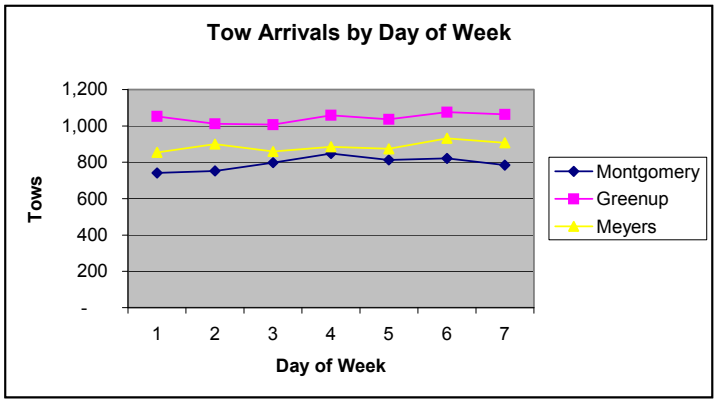
Tow arrival patterns at all locks are uniformly distributed throughout the year. As shown in **Figure 4-2** for Montgomery (upper river), Greenup (middle river), and Myers (lower river) L/Ds, traffic is relatively constant by month, day of week and even hour of day.

- During normal operations, the main chamber at mainstem projects is used predominantly by large tows and the auxiliary chamber is used by single cut tows of less than 600' in length, recreational traffic, and other smaller vessels like lightboats (tow boats with no barges). (Based on data from 2000-2004, just 13.5% of all recreational vessels and 30.5% of all lightboats used the main chambers at Ohio River locks.) The maximum number of cuts allowed is a single cut through the main chamber and a double cut through the auxiliary chamber except for the upper three projects where, due to smaller size, double cut lockages are allowed at the main chamber and five-cut lockages at the auxiliary. Multiple cut lockages are allowed in the auxiliary chamber during periods of closure of the main chamber.

- The general steps of the lockage procedure for any tow are shown in **Figure 4.3**.

FIGURE 4-2
Ohio River Traffic Patterns





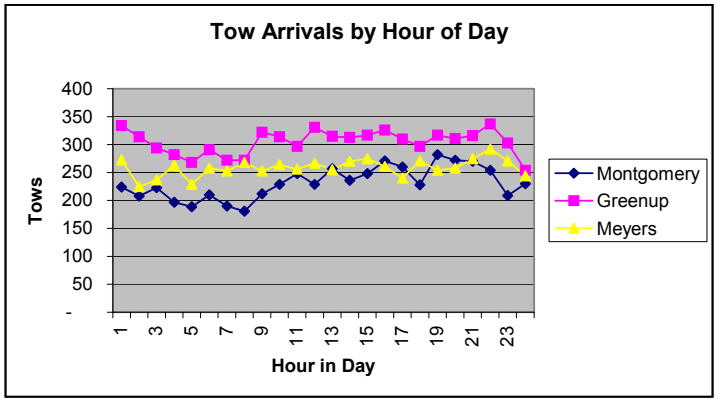
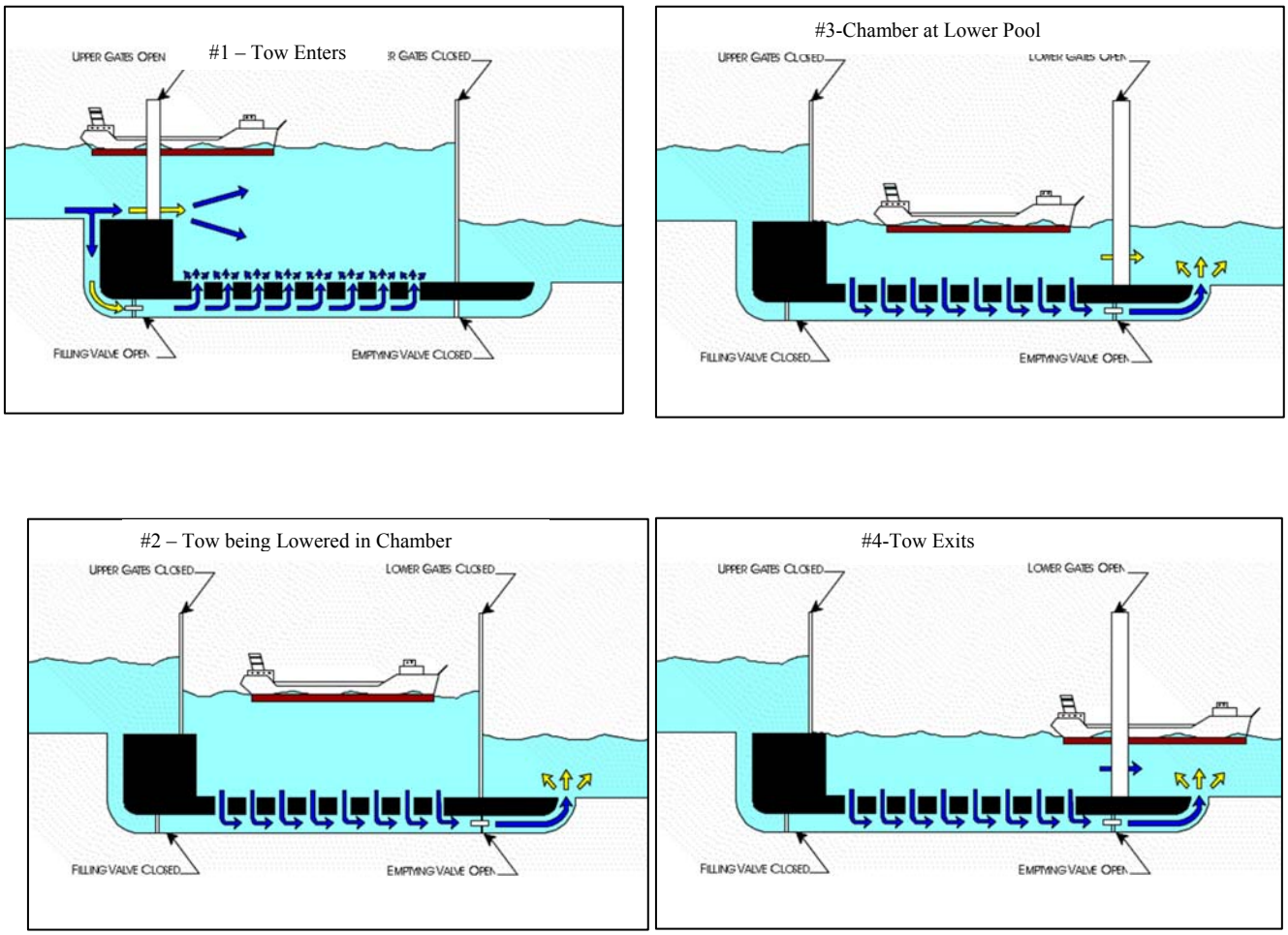


FIGURE 4-3

Lockage Process



2. The typical tow through all locks with a 1200'x110' main chamber consists of fifteen "jumbo" barges (each of dimension 195'x35"). **Tables 4-3, 4-4 and 4-5** describe the types of barge and tanker equipment used on the Ohio River, commodities moved, and average tow sizes and loadings through each project during 1990-2000. For additional details on Ohio River traffic, see Section 5 of the Economics Appendix.

TABLE 4-3
Description of Barge Types on Ohio River

Barge Type	Dimension	Capacity (Ktons)	Typical Commodities
Hopper			
Irregular	135'x27'	867	Aggregates
Standard	175'x26'	1,069	Coal, Aggregates
Stumbo	195'x26'	1,121	Coal
Jumbo	**195'x35'**	**1,669**	**Coal, Aggregates, Ores & Iron**
Covered Jumbo	195'x35'	1,764	Grains, Chemicals
Super Jumbo	245'x35'	2,106	Coal, Aggregates
Giant Jumbo	260'x52'	3,329	Coal, Grains, Aggregates and Coke
Tanker			
Jumbo	195'x35'	1,454	Petroleum Products & Chemicals
147'	147'x52'	1,711	Petroleum Products & Chemicals
175'	175'x54'	2,317	Petroleum Products & Chemicals
264'	264'x52'	2,820	Petroleum Products & Chemicals
290'	290'x54'	3,295	Petroleum Products & Chemicals

Source: COE LPMS Data.

TABLE 4-4
Annual Ohio River Trips and Tonnage by Barge Type
Averaged Over 1990 – 2000

Barge Type	Dimension	Avg. Annual		Percent of Total	
		Trips	Tons*	Trips	Tons
Hopper					
Irregular	135'x27'	3,215	2,004,284	2%	1%
Standard	175'x26'	5,571	4,943,714	4%	2%
Stumbo	195'x26'	8,535	9,428,949	6%	5%
Jumbo	**195'x35'**	**97,691**	**151,960,762**	**72%**	**73%**
Covered Jumbo	195'x35'	7,752	12,002,606	6%	6%
Super Jumbo	245'x35'	390	807,399	0%	0%
Giant Jumbo	260'x52'	869	2,497,370	1%	1%
Sub-Total		124,023	183,645,084	91%	88%
Tanker					
Jumbo	195'x35'	5,005	7,153,370	4%	3%
147'	147'x52'	1,734	2,695,467	1%	1%
175'	175'x54'	643	1,244,841	0%	1%
264'	264'x52'	1,188	2,886,932	1%	1%
290'	290'x54'	3,749	11,405,339	3%	5%
Sub-Total		12,319	25,385,949	9%	12%
Total		136,341	209,031,033	100%	100%

Source: WCSC data
* excludes intra-pool traffic

TABLE 4-5
Average Ohio River Tow Sizes

Project	Total Barges Per Tow	Loaded Barges Per Tow	Tons Per Tow	Tons Per Loaded Barge
Emsworth	6	4	4,845	1,352
Dashields	6	4	5,298	1,327
Montgomery	7	4	5,861	1,375
New Cumberland	9	5	7,901	1,472
Pike Island	9	6	8,667	1,482
Hannibal	11	7	11,099	1,494
Willow Island	11	8	11,527	1,502
Belleville	11	8	11,971	1,508
Racine	11	8	11,482	1,511
R.C. Byrd	11	7	11,481	1,556
Greenup	11	7	10,409	1,585
Meldahl	11	7	11,505	1,603
Markland	10	7	10,702	1,593
McAlpine	10	7	10,678	1,594
Cannelton	11	8	11,916	1,569
Newburgh	11	7	11,058	1,565
J.T. Myers	11	8	12,187	1,606
Smithland	11	7	11,250	1,613
L/D 52	10	6	9,999	1,616

Source: COE LPMS Data.

4.5 WATERWAY DEPENDENT INDUSTRIES IN THE OHIO RIVER BASIN

1. Waterway dependent industries are those industries that realize some advantage for locating alongside a navigable waterway system. The two major advantages are the availability of a large and reliable supply of water for use in the industrial process, and the availability of an efficient and reliable waterway transportation system for the movement of goods into or out-of the facility. The transportation advantage is the advantage of interest to this study, since locks and dam projects are sized and constructed to facilitate waterway transportation. Other location factors, including taxes, labor force, terrain, and rail and road access are also important, but are beyond the scope of this study.

2. The major users of the Ohio River System are the coal industry and the electric generating industry (see **Table 4-6**). While it is likely that both industries would have developed even without a navigable transportation system, it is unlikely that they would have grown to the extent that they have. The reason is that waterway transportation provides a cost-advantage over other modes, which allows coal produced in the area to be competitively priced in a geographically wider market than it would be otherwise. As far back as a hundred years ago, coal produced in the Monongahela River Basin was shipped down-river as far as Oklahoma. In contrast, no coal was delivered overland to these markets. The same is true of the electric generating industry; because of the low transportation cost of waterway shipments, and the multiple sources of coal available via waterway transportation, electric generating costs in the basin are among the lowest in the nation.[1] Electricity produced in the basin can be economically exported to high-cost production areas. Again, the size of the market and the amount of electricity generated would be less without the transportation cost savings provided by the waterway system.

[1] According to the U.S. Department of Energy, Energy Information Administration, average revenue per kilowatt-hour is 5.9 cents for the eight Ohio River Basin states and 6.8 cents for the entire United States. Only six states have lower average revenues than the mean average revenue for the basin states.

TABLE 4-6
ORS Waterway Commodity Traffic, 2001

Commodity		Tons (Millions)
Coal	**Total**	**157.1**
	Steam Coal	130.7
	Metalurgical Coal	10.1
	all else	16.3
Crude Petroleum	**Total**	**0.3**
Petroleum Products	**Total**	**20.2**
Chemicals	**Total**	**10.6**
	Fertilizers	2.8
	all else	7.8
Aggregates	**Total**	**46.7**
	Sand & Gravel	18.4
	Limestone	24.6
	all else	3.7
Grains	**Total**	**18.2**
Ores & Minerals	**Total**	**6.9**
Iron & Steel	**Total**	**11.0**
	Steel Scrap	1.6
	all else	9.4
Others	**Total 8.**	**9**
	Wood Products	0.6
	all else	8.3
Grand Total		**279.9**

3. The markets for coal are electric generating plants, coke plants, other industrial plants such as cement, and export. The electric generating industry dwarfs the other sectors, consuming 911 million tons a year or 87 percent of the one billion tons of coal produced in the U.S. every year. The Ohio River Basin is an important production region and proximity to waterways infers an advantage. Over ten percent of national production came from these large ORB mines in 2001.

4. The electric power industry involves the generation, transmission, and distribution of electricity. Fossil fuels are the most widely used fuel for electricity generation. Coal is the most widely used fossil fuel in the United States, and particularly in the ORB. In fact, the ORB is the U.S. region most dependent upon coal for electric power generation. Fossil fuels are transported to generating plants by rail, river barge, truck, conveyor, and pipeline. Electricity is transmitted from generating plants to consumers by wire. The electric power industry is the largest user of the ORS. In 2001, over 130 million tons of coal and 2.3 million tons of lime were barged to electricity generating plants. These movements represent almost fifty percent of total tonnage transported on the ORS.

5. The electricity industry is an important consumer, as well as a key producer (i.e. owner and operator of coal mines) of coal in the economy. The industry consumes about 87 percent of the over 1 billion tons of coal produced in the country. Of this amount, about 14 percent or nearly 120 million tons moves on the Ohio River system to waterside power plants. The tonnage accounts for about 1 of every 2 tons shipped on the system.

6. Low-cost electricity also attracted energy-intensive industry to the region. Foremost among these are the aluminum and the steel industries, particularly the new electric furnace plants that recycle scrap into steel. The principal input of both industries is electricity, and therefore, the availability of low-cost electricity is a major consideration in location decisions. Other industries dependent upon the ORS as reflected in the commodity movements in Table 4-6 are steel, sand and gravel, petroleum, and chemical plants.

7. There are a number of other waterway dependent industries along the waterway as well that depend on the waterway more for water supply and as an optional transportation mode, and for an occasional barge shipment, rather than for continuous/high volume shipments. These types of plants include mineral processing plants such as zinc, nickel and aluminum plants. Other facilities are highly dependent on the waterway transportation system, but may ship modest quantities on the system. These facilities would include the intermodal ports that provide a wide variety of shipping options to a wide variety of industries and cargoes in order to survive.

8. Additional details on many of these industries are contained in the Economics Appendix.

4.6 OHIO RIVER SYSTEM AND MAINSTEM COMMODITY MOVEMENTS

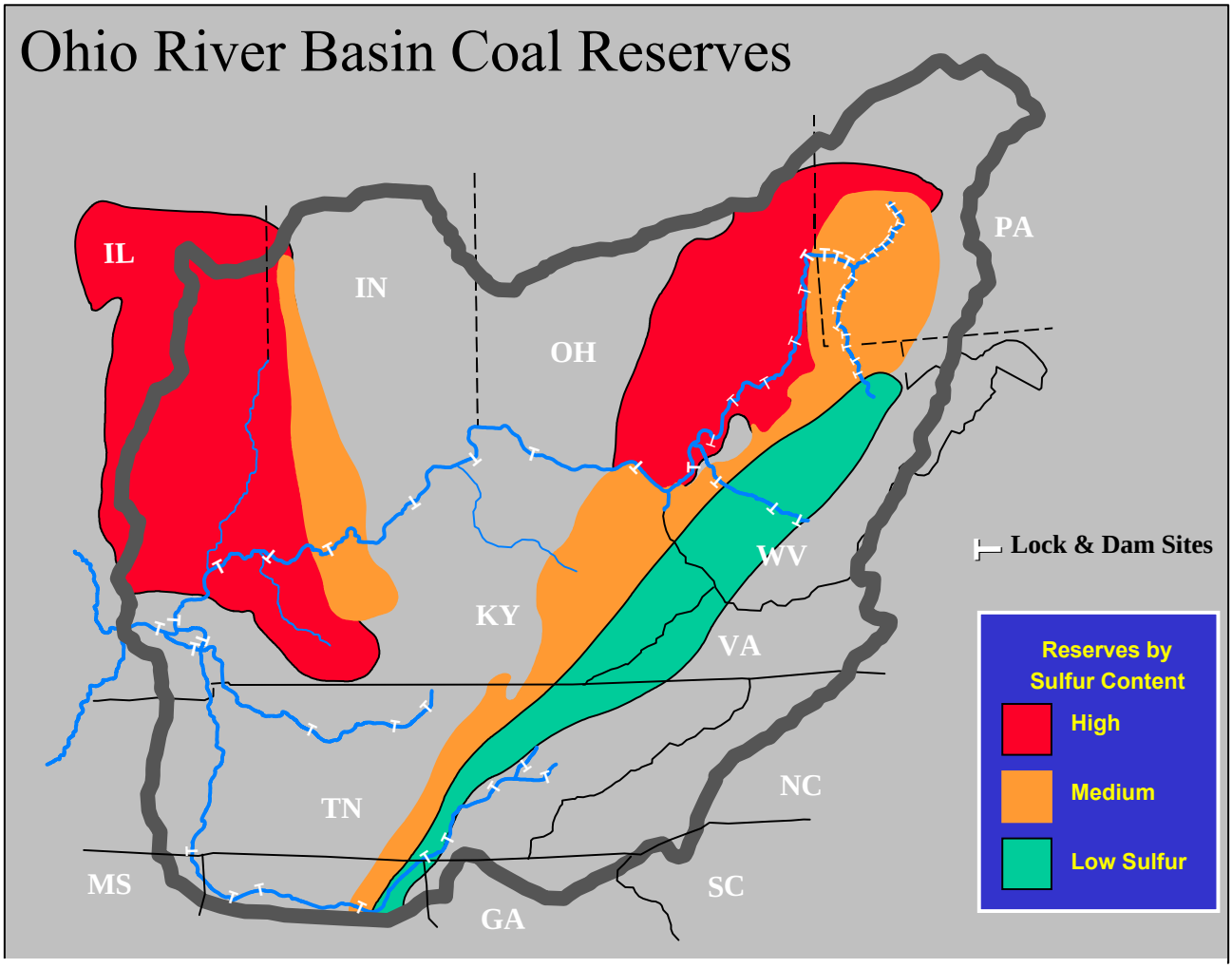
1. Waterborne commerce throughout the Ohio River Basin is made possible year-round in the basin by a series of 60 lock and dam projects spread throughout the Ohio River and its 12 navigable tributaries, a navigation network known as the Ohio River System (ORS) (see **Figure 4.1**). In recent years barges along the ORS have carried approximately 270 million tons of commodities on all navigable rivers within the basin. These commodities are the product of coal mines, petroleum refineries, stone quarries, cement plants, and farms and the raw material for construction companies, steel mills, electric utilities, paper plants, aluminum manufacturers, and chemical companies; the foundation of the region's economy.

2. Ohio River System transportation consists largely of coal and other bulk or raw commodities -- goods with a long "shelf-life" and which are moved efficiently in large volumes. The ORS extends this efficient transportation mode deep into the interior of the North American continent. The availability of this form of transportation, along with the availability of rich deposits of coal (approximately 70 billion tons of demonstrated reserves), have made Pittsburgh, Pennsylvania and Huntington, West Virginia, the second and fourth largest coal ports, respectively, in the United States. **Figure 4.4** is a map of the region's coal reserves consisting of the Appalachian Coal Province (low-medium sulfur content) to the east and the Eastern Interior Coal Province (high sulfur content) to the west.

3. Most of the basin's coal moves to domestic markets -- primarily to the electric utility industry. Over the last 30 years, much of the region's electricity generating capacity has moved away from small streams and large cities to more rural areas along the Ohio River and its system of navigable rivers. Dependable supplies of cooling water and access

to low-cost transportation are the primary attractions. In fact, electric utility companies account for nearly half of system traffic.

FIGURE 4-4
Ohio River Basin Coal Fields



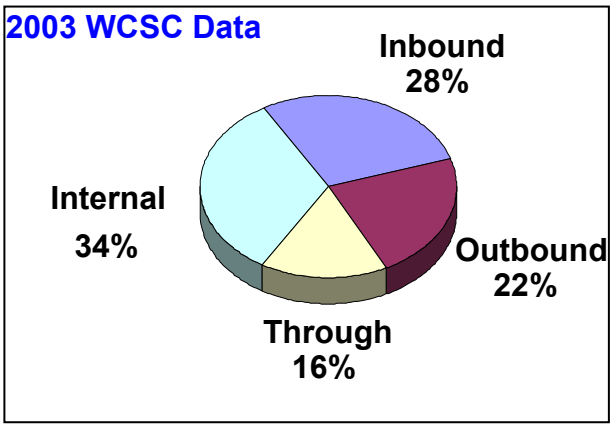
4. The main artery of the Ohio River System is the mainstem Ohio. Approximately eighty nine percent of system traffic moves on the Ohio River (see **Table 4-7**). Between 1950 and 1965, traffic on the mainstem doubled, and then doubled again between 1965 and 1990. Most of this traffic growth was driven by massive investments in waterside coal-fired electric generating facilities that were expanding to accommodate the needs of an expanding economic base. Electric utilities were locating plants along the Ohio River and expanding their existing waterside facilities to take advantage of the river as a source of water supply and for low-cost water transportation of coal. Since 1990, with no growth in coal traffic, the small percent growth in Ohio River traffic has been driven by increases in aggregates, ores and minerals, and iron and steel traffic. Mainstem traffic reached a peak of just under 243 million tons in 2002, total tonnage fell slightly to about 229 million tons in 2003. As can be seen in **Figure 4-5** below, most of this traffic (34 percent) is internal to (i.e. both origin and destination on) the mainstem.

TABLE 4-7
Historic Ohio River System and Mainstem Ohio Traffic
(Million Tons)

Year	ORS	Ohio River	% ORS
1940	51.2	29.5	58%
1950	66.1	48.6	74%
1960	105.3	79.5	75%
1970	163.9	129.6	79%
1980	200.5	160.7	80%
1990	257.8	225.7	88%
2000	271.7	236.5	87%
2004	269.9	239.0	89%
Annual Growth:			
- 1940-04	2.7%	3.4%	
- 1990-04	0.1%	0.1%	

Source: USACE Waterborne Commerce Statistics

FIGURE 4-5
Inbound, Outbound, Through and Internal Traffic on the Ohio River Mainstem Traffic



Note: Inbound, Outbound and Internal Traffic as defined previously, through traffic has neither origin or destination on mainstem but travels on mainstem for part of trip.

5. The mainstem Ohio River handled about 229 million tons of traffic in 2003, representing about 88 percent of the traffic on the Ohio River System (ORS). The Ohio River handled all of the petroleum fuels moving on the ORS in 2003, and nearly all of the grains, chemicals, ores and minerals, and iron and steel traffic. The mainstem handled a considerably smaller share of the system's coal and coke and aggregates traffic. The commodity traffic distribution in 2003 both for the Ohio River and the ORS are shown in **Table 4-8.**

TABLE 4-8
Commodity Traffic on Ohio River Mainstem and the ORS, 2003
(Million Tons)

Commodity	ORS	Ohio River	Ohio River % of ORS
Coal & Coke	140.9	118.5	84.1%
Petroleum	16.8	16.3	97.0%
Aggregates	47.4	41.7	88.0%
Grains	14.1	13.8	97.9%
Chemicals	11.4	10.3	90.4%
Ores & Minerals	7.4	7.4	100.0%
Iron & Steel	14.3	13.9	97.2%
Other	7.4	6.8	91.9%
TOTAL	259.7	228.7	88.1%

Source: WCSC data

6. Ohio River traffic by commodity group for selected years between 1970 and 2000 is shown in **Table 4-9**. On the mainstem, each of the major commodity groups increased in tonnage between 1970 and 2000, with the exceptions of petroleum fuels and crude petroleum. The completion of major pipeline projects into the ORB diminished the need for waterborne transport of petroleum fuels and crude petroleum. The highest annual growth rates over the 30-year period occurred for shipments in the all others category (principally cement, lime, asphalt and animal feeds); iron and steel; grains; and ores and minerals, followed by aggregates and coal and coke. Chemicals traffic was flat over the 30-year period and petroleum products and crude petroleum diminished, as previously mentioned. Between 1990 and 2000, traffic growth was dominated by iron and steel, ores and minerals, and aggregates, followed by chemicals and all others. Grains and petroleum fuels grew much more slowly over this 10-year span, while crude petroleum and coal and coke traffic diminished.

TABLE 4-9

Historic Ohio River Commodity Traffic, 1970 - 2000

(Million Tons)

						Annual % Growth	
Commodity	1970	1980	1990	1995	2000	1970-00	1990-00
Coal & Coke	59.0	86.1	136.7	130.3	121.8	2.4	-1.1
Petroleum Fuels	15.5	17.7	13.4	13.4	14.1	-0.3	0.5
Crude Petroleum	7.1	0.6	0.5	0.2	0.4	-9.4	-2.9
Aggregates	17.2	21.2	28.7	33.4	38.9	2.8	3.1
Grains	3.6	6.7	10.3	12.0	10.8	3.7	0.5
Chemicals	10.6	11.5	9.3	10.7	10.8	0.0	1.5
Ores & Minerals	3.9	3.2	5.5	6.7	9.1	2.9	5.2
Iron & Steel	4.4	4.1	6.5	10.1	14.3	4.0	8.2
All Others	5.5	9.6	17.0	19.0	18.9	4.2	1.0
TOTAL	126.8	160.7	225.7	235.8	236.5	2.1	0.6

SOURCE: USACE Waterborne Commerce Statistics

7. **Table 4-10** shows total commodity traffic at Ohio River mainstem projects for the period 1970-2000 from the Corps Waterborne Commerce Statistics (WCS). Annual percentage growth rates during this period ranged from 0.3 percent at Dashields to 3.2 percent at Greenup. During the last decade of the century, growth rates remained robust within the middle portion of the river and turned negative at the lower end. Commodity traffic growth was hampered in the 1990s by a substantial drop-off in export coal and grain traffic, the loss of some domestic utility steam coal markets outside of the ORS, and a reduction in the usage and waterborne movement of Illinois Basin and Northern Appalachian coals by electric utilities. The projects most severely affected during the 1990s were the lower river projects. Traffic at the uppermost Ohio River projects remained about the same or slightly lower at Dashields during 1990-2000. The traffic for the more recent 1994-2004 time period from the Corps Lock Performance Monitoring Statistics (LPMS) period is shown as **Table 4-11**. (WCS data vary slightly from LPMS data.) Growth rates are a little more negative on the upper river than the lower, while traffic has remained about the same for the middle third.

TABLE 4-10
Historic Traffic at Ohio River Projects, 1970-2000
(Million Tons)

Project	1970	1980	1990	1995	2000	Annual % Growth 1970-00	Annual % Growth 1990-00
Emsworth	19.6	20.0	21.8	21.6	21.9	0.4	0.1
Dashields	20.2	21.0	23.2	22.8	22.4	0.3	-0.4
Montgomery	17.4	20.4	25.0	25.2	25.2	1.2	0.1
New Cumberland	19.2	23.2	30.4	36.5	34.2	1.9	1.2
Pike Island	19.8	26.4	36.0	43.9	42.3	2.6	1.6
Hannibal	22.4	30.4	36.3	47.9	49.8	2.7	3.2
Willow Island	25.6	31.6	34.5	45.6	47.0	2.0	3.1
Belleville	26.1	32.6	37.0	48.4	50.9	2.3	3.2
Racine	27.0	34.0	38.2	49.0	51.5	2.2	3.0
Byrd	28.9	37.4	42.3	60.3	59.1	2.4	3.4
Greenup	28.7	34.8	56.2	71.0	74.0	3.2	2.8
Meldahl	28.5	34.6	55.2	65.0	64.6	2.8	1.6
Markland	29.4	37.8	53.6	58.8	56.0	2.2	0.4
McAlpine	33.0	41.5	58.4	60.0	55.2	1.7	-0.6
Cannelton	38.1	43.2	62.4	60.5	54.1	1.2	-1.4
Newburgh	32.8	43.9	74.3	73.5	63.0	2.2	-1.6
Myers	34.8	50.3	83.6	85.0	72.0	2.5	-1.5
Smithland	39.1	58.5	91.2	89.9	81.4	2.5	-1.1
L/D 52	45.9	63.0	101.4	98.2	91.8	2.3	-1.0
L/D 53	43.3	53.6	87.8	87.9	85.3	2.3	-0.3
Ohio River	126.8	160.7	225.7	235.8	236.5	2.1	0.6
Ohio River System	163.1	200.5	260.3	263.5	271.8	1.7	0.5

SOURCE: USACE Waterborne Commerce Statistics

TABLE 4-11
1994 - 2004 Ohio River System Traffic by Project
(Ktons)

Project	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Annual Rate 1994-2004
Emsworth	24,272	23,075	23,424	23,201	23,153	23,561	22,334	21,729	23,687	19,211	18,791	-2.5%
Dashields	25,602	24,551	24,765	24,452	24,563	24,528	23,230	22,839	24,516	20,012	19,679	-2.6%
Montgomery	27,313	25,515	27,132	26,480	26,866	26,560	25,974	25,555	26,709	21,093	20,260	-2.9%
New Cumberland	37,272	36,745	36,584	35,564	35,425	33,906	34,062	33,854	35,251	32,189	31,478	-1.7%
Pike Island	43,643	43,309	43,729	41,345	43,027	41,276	41,460	41,682	43,634	39,062	38,912	-1.1%
Hannibal	47,783	42,783	46,596	44,812	47,627	47,258	48,344	49,476	51,200	48,884	50,101	0.5%
Willow Island	45,802	44,534	43,932	42,299	44,766	44,320	45,635	46,975	48,422	46,592	48,123	0.5%
Belleville	48,641	47,122	47,869	45,511	48,688	47,983	49,201	49,243	51,118	49,482	51,380	0.5%
Racine	49,845	48,000	48,933	46,644	49,517	48,646	50,022	50,239	51,764	50,625	52,308	0.5%
R.C. Byrd	56,079	58,649	59,406	56,337	57,855	55,970	57,879	58,108	54,898	53,164	57,775	0.3%
Greenup	68,695	67,573	67,262	69,891	70,635	70,044	71,713	70,563	65,915	62,135	64,502	-0.6%
Meldahl	64,627	63,376	61,270	62,246	63,739	62,784	63,391	63,813	57,771	53,222	55,262	-1.6%
Markland	60,011	57,757	54,680	55,090	55,119	54,850	56,062	55,807	49,625	45,248	50,050	-1.8%
McAlpine	61,943	57,609	53,980	52,823	52,857	54,835	55,790	56,170	51,893	49,482	52,753	-1.6%
Cannelton	64,257	59,513	56,782	56,240	54,386	56,650	55,786	56,653	55,841	54,002	56,888	-1.2%
Newburgh	76,779	72,052	68,300	65,407	64,131	64,509	64,433	66,527	64,200	62,475	67,151	-1.3%
J.T. Myers	85,718	82,108	77,603	76,218	74,151	71,393	72,447	75,290	68,961	62,655	67,880	-2.3%
Smithland	93,337	89,145	85,077	84,931	84,606	82,115	82,610	85,915	79,040	72,305	77,020	-1.9%
L/D 52	101,267	97,467	94,052	94,770	97,695	95,125	94,687	96,715	93,382	87,420	94,954	-0.6%

Source: LPMS Data.

SECTION 5
AFFECTED ENVIRONMENT

This section provides a description of the Ohio River's resources, ecosystems and human communities. Information presented in this section is summarized from material in the Environmental Appendix. For more detailed discussions of each section, refer to the corresponding section in the Cumulative Effects portion of the Environmental Appendix. A brief summation of the material presented in this section begins at section 5.11.

5.1 GENERAL DESCRIPTION

1. The study area includes the mainstem Ohio River, which extends from the junction of the Allegheny and Monongahela Rivers at Pittsburgh, Pennsylvania, to near Cairo, Illinois where the Ohio joins the Mississippi River. This area includes 981 miles of commercially navigable channel and a total drainage area of 204,000 square miles. The drainage area encompasses all or portions of fourteen states, including Alabama, Georgia, Kentucky, Indiana, Illinois, Maryland, Mississippi, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. Year-round navigation is provided by a system of 20 locks and dams. Within the Ohio River basin, the Corps has also constructed and operates and maintains 82 reservoirs, primarily for flood control, water supply, and recreation. Releases from these reservoirs during periods of drought aid navigation; however, those benefits are ancillary to authorized project purposes. Navigation is also provided on eight tributaries to the main stem Ohio River (see Fig. 2-1). However, navigable reaches outside the main stem Ohio River are not part of this study.

2. The study area for the ORMSS is defined as the Mainstem Ohio River from Pittsburgh, PA to Cairo, IL. However, in conducting the cumulative effects analysis (CEA), larger areas had to be considered. In fact, the impact area considered in the CEA varies among resource categories according to characteristics of each resource. Therefore, while geographic boundaries for the CEA were generally set the as the Ohio River and Floodplain (i.e., the area most likely to be affected by navigation related actions), we reserved the flexibility to adjust these boundaries as resource conditions dictated. Boundaries for each resource category are described in the CEA Section of the Environmental Appendix.

5.1.1. Endangered Species Consultation

Specific consultation under section 7 for the recommended actions contained in this report was not undertaken[1]. The purpose of this document is to recommend future navigation

[1] Concurrent with the preparation of the ORMSS PEIS, the Lakes and River Division agreed to undertake separate consultation with the US Fish and Wildlife Service under Section 7 of the Endangered Species Act for O&M Actions on the Ohio River Mainstem and its navigable tributaries. The Corps completed and submitted an initial draft Biological Assessment (BA) to the Service in October 2004. After a number of revisions in response to comments from the Service, the Corps completed a final BA and transmitted it to the Service in the spring of 2009. This BA considers all O&M actions undertaken by the Corps and the

needs to maintain a viable system for the next 50 years. The alternatives considered in this report are generic in nature and do not provide enough detail for an adequate assessment. 40 CFR 1502.20 addresses tiering of NEPA documents. A programmatic document is written to "eliminate repetitive discussions of the same issues and to focus on the actual issues ripe for decision at each level of environmental review". The Corps determined during preparation of the PEIS, in consultation with the US Fish and Wildlife Service, that Section 7 compliance would be more meaningful if it occurred during development of site specific project reports. The Service agreed to this in the Final Coordination Act Report by stating that "as specific projects and opportunities occur in the future, we expect the Corps to involve the Service, States, and others in determining how each project will or may impact trust resources…" It was agreed that at the site specific level potential impacts to endangered species will be better understood and "ripe for decision".

5.2 AQUATIC ECOLOGICAL RESOURCES

5.2.1 Water Quality and Sediments

See Environmental Appendix, CEA Chapter 3 for an expanded discussion of Water and Sediment Quality.

The following information on conditions of selected water quality indicators has been obtained from several sources. Data included results of more than 60 years of sampling, using a variety of assessment methods, at locations throughout the length of the Ohio River.

5.2.1.1 Historical Conditions

5.2.1.1.1 Dissolved Oxygen

1. Dissolved oxygen (DO) has long been a parameter of primary concern, and this is especially true on the Ohio River. Monitoring and research on DO in the Ohio River dates back to surveys and model development of Streeter and Phelps (1925). DO concentrations in the Ohio River are influenced by several factors, including water temperatures biochemical oxygen demand (BOD), photosynthesis by algae, travel and mixing times of pollutants, and daily fluctuations (Wellner and Dinger 1989). Sufficient dissolved oxygen levels, expressed as mg/L, are critical to support most aquatic life.

2. Historically, DO levels along the Ohio River were depressed by the biochemical oxygen demand (BOD) of raw or insufficiently treated sewage discharges. In 1936, Congressman Brent Spence testified at a congressional hearing on the pollution of navigable waters that "the Ohio River is a cesspool." At that same hearing the State Health Commissioner of Kentucky added "the Ohio River, from Pittsburgh to Cairo, is an open sewer" (USEPA 2003). About 1948, advances in cooperative management, which

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endangered species known or suspected to exist within the geographical area. The BA also developed a suggested list of Reasonable and Prudent Measures that could be implemented by the Corps to minimize potential impacts. With the assumption that these suggested Reasonable and Prudent Measures would be implemented, the BA concluded that O&M activities may affect but are not likely to adversely affect the identified species. A response by the Service is pending.

including signing of the Ohio River Valley Sanitation Commission (ORSANCO)[2] compact, began the process of improving water quality conditions in the Ohio River.

3. Prior to effective wastewater treatment, low DO values were typically recorded downstream from the three major population centers of Pittsburgh, Cincinnati and Louisville. Until the late 1960s and mid 1970s, substantial DO sags occurred downstream of these population centers. During October and November of 1963, for example, HydroScience (1969, cited in US EPA 2003) carefully documented the degree and extent of the DO sag in the Ohio River downstream of Cincinnati (approximately RM 460-480). At the normal bottom of the sag between miles 495 and 500, DO concentrations during this period did not exceed 2.0 mg/l. Zero DO concentrations were recorded at both miles 455 and 505.

5.2.1.1.2 pH/Acidity/Alkalinity

1. Tributary waters to the Ohio River, especially the upper reaches, have historically experienced extreme variations in pH, acidity, and alkalinity. While pH values in excess of pH 9.0 maximum criteria have been observed, values depressed below pH 6.0 minimum criteria were most typical. Also, although massive dumps of acid metal pickling liquors and other episodic events have been documented, chronic acid mine drainage (AMD) from high-sulfur bituminous coal mines were primarily responsible for low pH conditions in the river.

2. As early as 1912, the Pittsburgh Flood Commission identified AMD as a severe economic problem responsible for the corrosion of pipes, pumps, boilers, and navigation structures. By 1914 the U.S. Public Health Service had documented episodic acidification of the Ohio River as far downstream as river mile 172. Data collected by the U.S. Geological Survey and the Pennsylvania Department of Forests and Waters (White 1951) provide a record of conditions between October 1947 and September 1949, when total acidity at Ohio River mile 17 ranged from 5 to 8.6 and averaged 30 mg/l as $CaCO_3$. The pH of the Ohio River ranged from 6.6 to 3.65 and averaged 5.3. Between 1940 and 1965 pH measurements of less than 5.0 (often less than 4.0) were commonly recorded in the upper 100 miles of the Ohio River. Below river mile 100, pH values usually increased gradually to mean values of 7.2 to 7.8 between Cincinnati and Cairo, river miles 463 and 981, respectively. During this same period, unusually high pH records of between 9.0 and 10.0 were occasionally seen in all reaches of the river, probably due to undocumented industrial discharges.

[2] The Ohio River Valley Water Sanitation Commission (ORSANCO), was established on June 30, 1948 to control and abate pollution in the Ohio River Basin. ORSANCO is an interstate commission representing eight states and the federal government. Member states include: Illinois, Indiana, Kentucky, New York, Ohio, Pennsylvania, Virginia, and West Virginia." "ORSANCO operates programs to improve water quality in the Ohio River and its tributaries, including: Setting Waste Water discharge standards; performing biological assessments; monitoring for the chemical and physical properties of the waterways; and conducting special surveys and studies."

5.2.1.1.3 Fecal Coliform Bacteria

The presence of fecal coliform bacteria indicates water has been contaminated with human or other animal wastes, generally from the overflow of domestic sewage or nonpoint sources. Fecal coliforms also serve to indicate potential health risk to humans through consumption or contact with water may have been contaminated by pathogens or disease producing bacteria or viruses. Typhoid fever statistics presented by Drake (1931) for the period between 1873 and 1930 show that human health in the ORV was severely threatened by fecal pollution. In 1907, for example, Pittsburgh typhoid fever case and death rates were 1,119.2 and 125.2 per 100,000 inhabitants per year, respectively. Filtration systems for river sources of public water supplies were constructed between 1907 and 1914, and by 1914 typhoid case and death rates dropped dramatically to 64.5 and 15.4 per 100,000, respectively. By 1930 typhoid case and death rates had further declined to 11.2 and 1.5 per 100,000, respectively. However, filtration treated only intake waters. Bacteriological pollution of the river later declined with improved wastewater treatment described in the previous section.

5.2.1.1.4 Turbidity and Total Suspended Solids

1. Turbidity and total suspended solids (TSS) both indicate the amount of solids suspended in water, whether mineral (e.g. soil particles) or organic (e.g. algae). TSS is measured by weight of material per volume of water (mg/L) while turbidity is measured as the amount of light scattered by a water sample, with more suspended particles causing greater light scattering. Turbidity is reported as nephalometric or Jackson turbidity units (NTUs or JTUs), depending on the measuring instrumentation. ORSANCO has no specific standard for TSS.

2. High concentrations of particulate matter in water can cause increased sedimentation and siltation, which, in turn, can damage habitats for fish and other aquatic life. Further, suspended particles provide attachment sites for other pollutants such as heavy metals and bacteria. Turbidity and TSS of the Ohio River are largely influenced by erosion characteristics of native soils and geology. Human activities (including clearing, draining of wetlands, agriculture, and development) accelerate soil loss and runoff to waterways. Qualitative reports from the 19th century describe the Ohio River as naturally clear except for the higher turbidities of the spring “freshes” (periods of flooding). Pearson and Krumholz (1984) note that Mark Twain and others described the Ohio as naturally the clearest of the three major arms of the Mississippi River system.

3. From 1953-1985, ORSANCO observed a decreasing trend in turbidity, coinciding with the construction of numerous flood control reservoirs on major Ohio River tributaries. These impoundments trap sediments and release clearer water. According to Pearson (1992), the range of turbidities to which Ohio River fish are exposed in modern times is probably not significantly greater than in prehistoric times, but the mean turbidities are higher now.

5.2.1.1.5 Nutrients

1. Nitrogen and phosphorus are nutrients that stimulate growth of algae and aquatic plants that provide food for most other forms of aquatic life. Nitrogen and phosphorous

occur naturally in water. Major sources of these nutrients entering rivers include municipal and industrial wastewater, septic systems, agricultural runoff, and atmospheric deposition. Nitrate and phosphate are the forms of these elements most readily available for plant growth. Normally concentrations of nitrate and phosphate in river water are low because plants rapidly take up both ions (Hynes 1970).

2. There are few data on historic nitrate and phosphate concentrations in the Ohio River. However, considering that virtually no sewage treatment or runoff controls existed prior to the 1970s, it can be concluded that high levels of both nutrients were present in the mainstem and tributaries.

5.2.1.1.6 Sediments

1. The natural bottom substrate of the Ohio River is mainly sand, gravel or clay overlain, especially in near shore or other sheltered areas, with silt and/or organic detritus. In 1971, Mason et al. described the combinations of these materials in different parts of the river as follows:

- Upper river - characterized by many bottom deposits covered by an oily muck with small coal particles interspersed with sand and gravel
- Middle river - predominately a pasty clay overlain with sand, rubble or fine leaf detritus
- Lower river below Louisville - predominately mud overlain with different grades of sand and leaf detritus

2. Fine-grained sediments are usually found at the mouths of tributaries, on riverbanks and near lock and dam structures ORSANCO (1996). Ohio River sediments are generally highly mobile and dynamic because high proportions of surficial bottom materials are replaced with every storm event.

3. Heavy metal contamination in the Ohio River has resulted from various sources, including coal mine drainage (iron and manganese) and industrial activity, particularly the iron and steel industry of the upper Ohio River valley. Bottom sediments are natural "sinks" for many toxic and persistent pollutants that enter waterways. These deposits represent potential sources of contaminants that may reenter the water column through stream scouring, anaerobic release, and bioaccumulation, as well as through dredging for channel maintenance (Youger and Mitsch 1989). Even with increasing control of point and nonpoint pollution sources, sediments contaminated with heavy metals and other pollutants may continue to adversely affect overlying waters and food chains for years (Lyman 1987).

4. Steel mill slag can influence the quality of the Ohio River. Massive slag fills have been used as a foundation material for extensive riverfront industrial developments in the upper ORV (Josephson et al 1949 and USACE 1982 and 1989). Slag has also been used extensively for placement of highway shoulder berms, driveway and parking lot fills, stream bank protection, and as railway grade ballast. Steel mill slags can produce mineralized and extremely alkaline leachates. In the late 1960s, when coal field drainage still significantly acidified the Allegheny and Monongahela Rivers, Shapiro et al (1967) found that the Ohio River became net alkaline after flowing past the steel manufacturing

complexes near Pittsburgh. Koryak et al (2002) proposed that slag leachate products contributed to this large, unexplained, alkalinity load.

5.2.1.2 Recent Conditions and Trends

5.2.1.2.1 Dissolved Oxygen

1. Following passage of the 1965 Federal Water Quality Act, the Ohio River Valley Sanitary Commission (ORSANCO) adopted stream water quality recommendations. In 1970, ORSANCO Pollution Control Standard I-70 made secondary level treatment the minimum requirement for wastewater treatment plants. As a result, BOD effluent loading decreased significantly, even as influent volume continued to grow with population increases. Massive Federal cost sharing construction grants to local authorities from 1972 to 1995 helped support planning, design, and construction of wastewater plants to meet minimum treatment requirements. Corresponding to decreasing levels of pollutant loading, DO available in the river to support aquatic life increased substantially (USEPA 2000).

2. Since the completion of secondary sewage treatment facilities at most major cities in the late 1970s, few low oxygen events occur unless wastewater treatment facilities are temporarily shut down for repairs, maintenance or emergencies (Pearson and Krumholz 1984). By 1987, Wellner and Dinger actually found elevated DO concentrations up to a mile downstream from major wastewater treatment plants, indicating the general effectiveness of wastewater treatment reaeration on DO.

3. ORSANCO's current minimum DO standard for the protection of aquatic life is an average of at least 5.0 mg/L for each calendar day with the minimum concentration not less than 4.0 mg/L. During the April 15 - June 15 fish spawning season, a minimum concentration of 5.0 mg/L is to be maintained at all times (ORSANCO 2003). These ORSANCO DO standards are consistent with standards of the states along the Ohio River. A classic study of DO concentrations and aquatic life conducted in the Ohio River established the notion that 5 mg/L DO was the boundary condition between little fish life and a reasonably productive community of mixed warmwater fish species (Brinley 1944 as cited in US EPA 1986).

4. Under the Clean Water Act (CWA), antidegradation guidance (USEPA 1983) has already been applied to management of minimum DO concentrations along the Ohio River. In applying this antidegradation policy guidance to hydropower development in the Ohio River basin, a minimum DO criterion of 6.5 mg/L was established as a lower boundary for no significant adverse impacts to warmwater fisheries. At present, there are no hydropower facilities operational on the Ohio River upstream of Hannibal Dam.

5.2.1.2.2 pH/Acidity/Alkalinity

1. During the 1960s and 1970s, much progress was achieved in reducing AMD pollution in the upper Ohio River Basin. The success of these efforts can be seen in the annual reports of ORSANCO for the period 1974-1980. In most of these years 100% compliance with established standards for pH was achieved at all monitoring stations in the

Ohio River (Pearson and Krumholz 1984). ORSANCO's current pH standard to protect aquatic life is between 6.0 and 9.0 standard units (ORSANCO 2003).

2. While it would appear that AMD problems in the Ohio River have been under control for the past several decades, much of the progress in the abatement of AMD has been achieved by mandatory treatment of the effluents of active coal mines. Treatment of these mine discharges was supposed to continue in perpetuity. However numerous mining operation bankruptcies have recently occurred, and will probably continue to occur in the future. Huge underground mining complexes have been abandoned, and are now flooding. Without intervention, these abandoned mines will eventually again discharge AMD to the waters of the upper Ohio River Basin. As of the time of this document preparation, no plan of action has been developed to deal with the potential problem.

5.2.1.2.3 Fecal Coliform Bacteria

1. With ORSANCO's requirement that all municipal wastewater treatment facilities provide secondary treatment, coliform bacteria levels in the Ohio River were expected to decline. This decline did not occur throughout the entire river, although decreases did occur in the upper 100 miles. In 1976, ORSANCO adopted the new federal drinking water standard of 2000 fecal coliforms/100mL, a standard that has remained to date. By 1978-79, ORSANCO reported nearly 100 percent compliance in the lower two-thirds of the river and compliance about 75 percent of the time in the upper 100 miles, where problems had previously been most acute (Pearson and Krumholz 1984).

2. After reviewing bacterial data through the 1980s, Pearson (1992) noted that the largest decreases in coliform bacteria in the Ohio River mainstem apparently occurred after primary sewage treatment facilities became operational, with the most dramatic declines reported in the upper 100 miles. Nevertheless, throughout the 1980s, most violations of the drinking water standard occurred in the upper river. The primary contact recreation standard of <200/100 mL, established for full-body exposure recreation (e.g. swimming and water skiing), also was violated frequently (Pearson 1992).

3. More recently, primary water born entric human diseases of concern include giardiasis and cryptosporidiosis. Also, amoebic meningoencephalitis from thermophilic *Naegleria fowleri* is a unique potential health problem in the thermal discharges, receiving waters, and cooling towers of the numerous power plants along the Ohio River (Sykora et al 1983).

5.2.1.2.4 Turbidity and Total Suspended Solids

Current agricultural practices, reforestation and runoff controls from construction sites help minimize sediment losses and reduce turbidity and TSS in water. ORSANCO's 2000 Pollution Control Standards include no specific turbidity or TSS standard for protection of aquatic life, but generally state that discharges to receiving waters be free from materials that will settle to form objectionable sludge deposits or suspended materials that will be unsightly or deleterious. Sewage must be treated so as not to exceed the TSS arithmetic mean in monthly samples of 30 mg/L or a weekly arithmetic mean of 45 mg/L. Although control programs have achieved some success in reducing turbidity and TSS, increased nutrient loads and runoff from impervious surfaces as a result of continued

development causes increases in algal productivity and pollutants attached to soil particles in water.

5.2.1.2.5 Nutrients

1. An ORSANCO study of long-term water quality trends from 1977 through 1987 indicated a strongly decreasing trend in ammonia nitrogen and a decreasing trend in total nitrogen, primarily related to wastewater treatment plant improvements and stringent discharge permit requirements (ORSANCO 1990). A strongly decreasing trend in total phosphorus observed basinwide during ORSANCO's 1977-1987 study was attributed to the switch to phosphate-free detergents.

2. Recent phosphorus data were collected between November 1996 and September 1999. No samples exceeded 1.0 mg/L from Hannibal L/D (RM 126.4) upstream and only a few samples exceeded that level downstream to Markland L/D. Numerous recordings above 1.0 mg/L occurred downstream from Markland L/D, primarily during the first half of 1997 (ORSANCO 2000a). These higher levels may have been related to increased runoff of agricultural chemicals.

3. Concerns about the effects of algal blooms on aquatic life and drinking water quality have led U.S. EPA to direct states to adopt water quality criteria for nutrients by 2004. Of specific concern are depressed oxygen levels in the Northern Gulf of Mexico (a condition known as Gulf Hypoxia), attributed to heavy nutrient loads in the Mississippi River. As a major tributary to the Mississippi, the Ohio River is a contributor to this problem. Algal blooms have not harmed aquatic life in the Ohio River, but drinking water suppliers have reported increased algal activity, which may result in taste and odor problems. Data from ongoing algal and nutrient analyses of Ohio River water supplies should assist in the development of appropriate nutrient criteria (ORSANCO 2001).

5.2.1.2.6 Sediments

1. Youger and Mitsch (1987) conducted a sediment study at 11 sites on the Ohio River, primarily upstream of navigation locks between Pittsburgh and Louisville. Concentrations of heavy metals generally decreased with distance downstream, paralleling a trend found in 1977 by ORSANCO. Lower concentrations of most metals, including cadmium, chromium, copper, iron, lead, nickel and zinc, were associated with a dramatic decrease in the iron and steel industry in the upper river from 1977 to 1987. With the exception of cadmium and zinc, a slight upturn in concentrations of all metals usually occurred at RM 531 immediately upstream from Markland Dam, illustrating the effects of past and present discharges from the Cincinnati metropolitan region. Youger and Mitsch found concentrations generally were well above background and, therefore, may be a source of contamination in the river for years to come.

2. Results of a 1980 study showed a tendency for sediments to not release priority pollutants to the water column with vigorous mixing (USACE 1981). Rather, there was a tendency for eluted sediments to adsorb to priority pollutant metals and remove them from the water column. This was consistent with findings of a study by Brannon et al (1976), which stated "no relationship existed between trace metal concentrations in the standard elutriate and total metal concentration in the sediments. This held true even though some

sediments were apparently highly contaminated with some trace metals. This clearly suggests that sediments can be a stable sink or repository for some contaminants."

3. Other studies, however, have demonstrated that it is possible for some sediment contaminants to be remobilized under some hydrologic conditions. In one example, severe episodic shock loads of phenols were being experienced at the Wheeling, West Virginia water intake during the 1980s. Since the shock loads were mostly associated with rising water levels during winter high flow periods, resuspension of river sediments was suspected to be contributing to the problem. The results of a 1988-1989 study (USACE 1989) confirmed this to be the case. Nichols et al (1983) pointed out that fluid mud (an intermediate stage between mobile suspend material and mud) is chemically important because it is a reservoir for potential toxics and a medium for chemical transfer.

4. A biological indicator of sediment quality, burrowing mayflies spend most of their life in fine grained sediment deposits, which are those most likely to be contaminated. These organisms were absent from the upper Ohio River (the area most severely degraded by industrial contaminants) for many years. Their failure to recolonize the upper river in the 1970s, after water quality substantially improved and numerous fish species returned, suggests lingering adverse impacts from legacy sediment contamination. During the 1990s, however, small to moderate numbers of burrowing mayflies were observed in the upper five pools of the Ohio River. First in 2001, and then again in 2002, mass emergences of burrowing mayflies occurred as far upstream as Pittsburgh.

5.2.1.3 Attainment of Ohio River Designated Uses

1. Section 305(b) of the Federal Clean Water Act requires biennial water quality assessments of the degree to which surface waters are attaining their designated uses. The Ohio River has four designated uses: warm water aquatic life, public water supply, fish consumption, and contact recreation. Three classifications are used to describe use attainment:

- fully supporting (good water quality)
- partially supporting (fair water quality) and
- not supporting (poor water quality).

2. In 1996, ORSANCO further divided the partially supporting use classification into three categories to provide additional descriptions: substantially supporting, moderately supporting, and marginally supporting. However, after two water quality report cycles, use of these subcategories was discontinued.

3. Attainment status for each designated use is described in sections 5.2.1.3.1 through 5.2.1.3.4.

5.2.1.3.1 Warm Water Aquatic Life

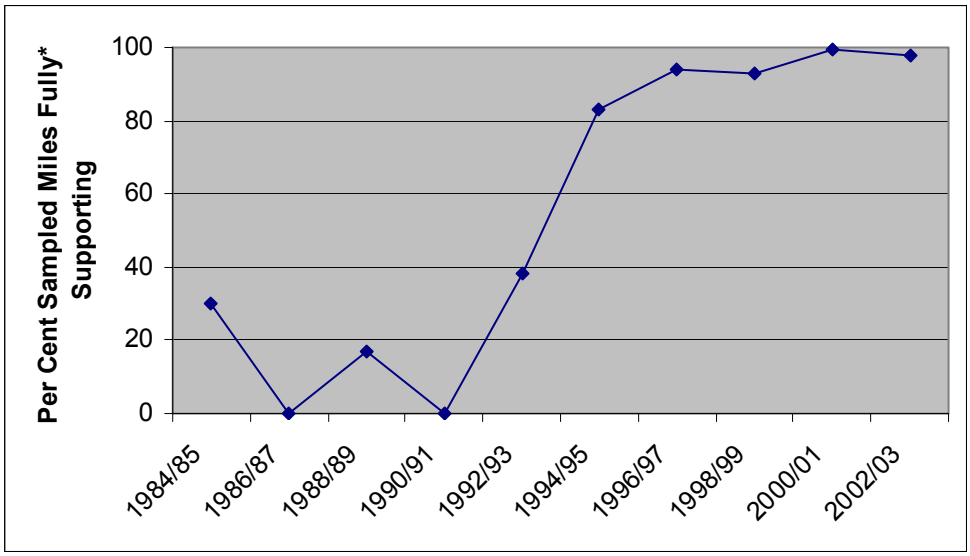
1. ORSANCO assesses Ohio River warm water aquatic life support based on chemical water quality data and measurements of fish communities using the recently developed Ohio River Fish Index (ORFIn). Dramatic increases in the number of Ohio River miles fully supporting warm water aquatic life have occurred since the mid-1980s as

Figure 5-1 illustrates. During the assessment for water years 2000-2001, 974 miles (99.3 percent) of the Ohio River were classified as fully supporting aquatic life.

2. Aquatic life use attainment in the Ohio River from 1984/85 through 1992/93 was probably higher than indicated in Figure 5-1. By the mid-1980's, biological assessments indicated that significant recoveries of fish and other aquatic life forms were occurring throughout the Ohio River. However, chemical assessments that routinely reported low level concentrations of total recoverable metals resulted in classification of these waters as "partially supporting" aquatic life use. Additionally, areas not attaining due to metals analysis did not appear to correlate well with areal distributions of recovering aquatic life forms.

3. Beginning in the 1994/95 monitoring period, several steps were initiated to develop assessment criteria that more accurately reflected aquatic life conditions in the river. The first step involved expanding the "partially supporting" category into 3 levels: substantially, moderately, and marginally supporting. A "weight of evidence" procedure was introduced to strike a balance between low-level findings of total recoverable metals and Modified Index of well being (MIwb) scores from fish population studies. For these monitoring periods, summation of the fully supporting and substantially supporting categories total 83% of sampled miles in 1994/95 and 94% in 1996/97.

FIGURE 5-1
Ohio River Aquatic Life Use Attainment



Note: represents "fully" plus "substantially" supporting for 1994/95 and 1996/97, represents "fully supporting" for all other years

4. Also during this time frame, ORSANCO initiated development of the ORFIn, expanding upon the MIwb to more accurately reflect fish communities and habitat conditions in the Ohio River.

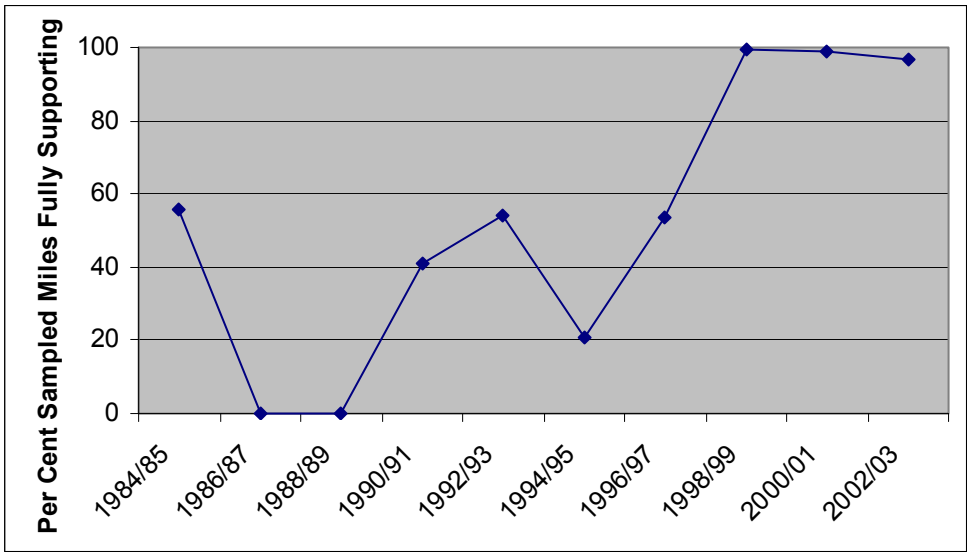
5. Beginning in the 1998/99 period, analysis for total recoverable metals was replaced with analysis for dissolved metals, which provided a better reflection of toxicity to aquatic life. This resulted in all of the "substantially supporting" miles being elevated to "fully supporting", for a total of 93% of sampled miles in this category. During the 1998/99 period, 61 miles remained in the "moderately supporting" category while 5.1 miles were downgraded to "marginally supporting", due to repeated fish kills from unknown point source contamination.

6. In the 2000/01 monitoring period, improved habitat conditions resulted in only 7 miles classified as "partially supporting". During this period, use of subcategories for "partially supporting" was discontinued. In the 2002/03 monitoring period, 'partially supporting" areas expanded to 16 river miles. This classification resulted from ORFIn scores that were below expected values (ORSANCO 2004b).

5.2.1.3.2 Public Water Supply

1. **Figure 5-2** illustrates that the number of Ohio River miles fully supporting public water supply use have also increased since the mid-1980s. Public water supply use is assessed based on chemical water quality data collected from ORSANCO's bimonthly sampling program, bacterial monitoring, and impacts on Ohio River drinking water utilities caused by source water conditions.

FIGURE 5-2
Ohio River Water Supply Use Attainment



2. Large and/or frequent industrial spills in the upper river and pesticide contamination from agricultural runoff in the lower river were the principle sources of public water supply impairment from the mid-1980's up to 1996/97. During the 1992/93 monitoring period, the upper 531 miles of river attained 'fully supporting" classification, while the lower 46% of the river attained "partially supporting" status due to pesticides (primarily atrazine) from agricultural runoff.

3. During 1994/95, a major spill of ethylene dibromide at river mile 203 contributed to a "partially supporting" classification for the entire downstream reach of the river. During 1996/97, detection of dioxin between river miles 237-317 and atrazine downstream from mile 607 resulted in a "partially supporting" rating on 46% of the river and "fully supporting" on the remaining 53%.

4. For the 1998/99 monitoring period, the assessment methodology for atrazine was changed from previous assessments. For this assessment, Ohio River atrazine levels were identified as a source of impairment when additional nonroutine treatment was required to meet the atrazine MCL (3.0 ug/L) in finished drinking water. The previous standard had been when atrazine concentrations in the Ohio River exceeded half of the finished drinking water MCL (1.5 ug/L). As a result, 997 miles were classified as "fully supporting". A segment of 4.4 miles in the lower river was classified as "partially supporting" due to point source contamination from1,2-dichloroethane.

5. Only relatively short stretches of the Ohio River have been classified as "partially supporting" for Public Water Supply in recent years. In both 2000/01 and 2002/03, approximately 10.5 miles from RM 161.7 though 172.2, were classified as partially supporting because the criterion for phenolics of 0.005 mg/L was exceeded in more than 10 percent of bimonthly samples at the Willow Island, WV, sampling station (ORSANCO 2004b, 2002). In 2002/03, an additional 22 miles of impairment were based on violations of bacterial stream criteria for the protection of public water supplies (ORSANCO 2004b).

5.2.1.3.3 Fish Consumption

During both the 2000-2001 and 1998-1999 assessments, all 981 miles of the Ohio River were classified as partially supporting fish consumption use (ORSANCO 2002, 2000c). Fish consumption use support is based primarily on the states' issuance of fish consumption advisories and ORSANCO fish contaminant data. The partially supporting designation is due to state advisory restrictions for PCBs; the majority of river miles were also partially supporting due to consumption restrictions related to mercury. Dioxin and chlordane have historically been fish tissue contaminants of concern. Chlordane has recently been removed from the list of substances impairing fish consumption; however, dioxin impaired 618 RM in 2000-2001 and 412 RM in 1998-99.

5.2.1.3.4 Contact Recreation

Contact recreation use support is assessed from data collected from May through October at ORSANCO's six recreation season monitoring stations on the mainstem downstream of urban centers with large combined sewer systems. Combined sewer overflows and other nonpoint sources, including animal waste handling practices, have been identified as significant causes of bacterial problems in the Ohio River, particularly during heavy rains. During the 2000-2001 contact recreation assessment, data from all monitoring stations indicated impaired contact recreation use. Approximately 40 miles (4 percent) of the Ohio River were classified as partially supporting contact recreation use and 136.5 miles (14 percent) were classified as not supporting. The remaining approximately 804 miles (82 percent) were not assessed. During the 1998-99 contact recreation assessment, 21 miles (2 percent) were classified as fully supporting contact recreation, 158 miles (16 percent) as partially supporting and 197 miles (20 percent) as not supporting. The remaining 605 miles (62 percent) were not assessed.

5.2.1.4 D evelopment of Total Maximum Daily Loads (TMDLs) for Various Pollutants in the River

1. Under USEPA regulations promulgated in 1992, states are required to identify water bodies that are not meeting water quality criteria established for specific designated uses (discussed above). For each impaired water body, a state must determine how much pollution reduction is needed to bring waters into attainment with their designated uses. The mechanism established to accomplish this is development of Total Maximum Daily Loads (TMDLs) for various pollutants. The TMDL program originated from Section 303(d) of the Clean Water Act. Present emphasis on TMDL program implementation has been driven by: 1) the realization that point source controls alone are insufficient to attain the nation's water quality goals and 2) citizen lawsuits forcing EPA to develop guidance for the TMDL program (CGER 2001).

2. Total Maximum Daily Load (TMDL) refers to the maximum amount of a pollutant that a water body can receive and still meet water quality standards. Consequently, a TMDL represents the sum of allowable loads of a single pollutant from all contributing point, nonpoint, and natural sources. TMDLs currently are being developed for the Ohio River. In 1995, ORSANCO initiated its Ohio River Watershed Pollutant Reduction Program to investigate specific pollutants on a watershed basis. The resulting

pollutant-specific data have been valuable to TMDL development for dioxin and polychlorinated biphenyls (PCBs) in the Ohio River (ORSANCO 2001). Proposed TMDLs undergo technical review and public comment before being submitted to USEPA for final approval.

3. The dioxin TMDL was developed in 2000 and applies to the Ohio River from Racine L/D (RM 237.5) to the Big Sandy River (RM 317). Related data indicated that dioxin levels must be reduced from the Kanawha River and Upper Ohio in order to meet water quality standards. ORSANCO is conducting sampling of fish tissue, water sediments and air to further identify sources of dioxin. A TMDL for PCBs is to be completed for the West Virginia/Ohio portion of the river (RM 40 through RM 317) during 2002 (ORSANCO 2001).

5.2.2 Biological Resources

5.2.2.1 Fish

See Environmental Appendix, CEA Chapter 4 for an expanded discussion of fish of the Ohio River Mainstem

Fish of the Ohio River represent a highly visible and important environmental component; they have been studied more than any other biotic group in the river. The fish communities of the Ohio mainstem include a wide range of species, feeding levels and reproductive conditions that reflect varying degrees of environmental change. Factors important to sustaining viable fish populations include adequate water quality, habitat with stable substrates, adequate depth, suitable current and sufficient food supplies. Also important are reproductive viability and the capacity to tolerate disturbance caused by invasive species and river traffic.

5.2.2.1.1 Historical Conditions

1. A total of 159 species of fish have been reported for the Ohio River mainstem since the early 19th century. Reports prior to 1920 list 111 species; those from 1920-1969 list 121; and those from 1970-1988 list 140 species. Many human activities affected the river's environment before 1920, including clearing of forests and draining of wetlands leading to siltation, turbidity and habitat loss. After about 1900, species tolerant of siltation and turbidity increased in numbers, including black bullhead, goldeye, skipjack herring, gizzard shad and spotted bass. Before completion of the wicket dams in the early 20th century, large river species such as shovelnose sturgeon, paddlefish, muskellunge and blue sucker had declined. Rapid growth of human populations in the Ohio basin during the first half of the 20th century, led to larger inputs of domestic sewage, industrial effluents and acid mine drainage. Historic large river species continued to decline and gizzard shad, emerald shiner, freshwater drum and the introduced common carp became dominant. The fish communities of the more populous, industrialized upper river particularly declined.

2. The earlier wicket dams and the present system of high lift dams have altered aquatic habitats by converting the Ohio River from a free-flowing waterway to one of relatively constant width and a minimum maintained channel depth of 9 feet. The modern navigation system, combined with land use and flood control practices in the watershed, has resulted in the inundation and siltation of extensive areas of gravel bottom substrates,

which are preferred by important fish species, particularly in the lower half of the river. At the same time as reductions in migratory species related to high-lift dams have occurred, nearly 80 embayments in creek mouths adjacent to the mainstem have been created in the upper half of the river. Slow-moving waters of these embayments offer important habitat for basses and other sunfishes, which are fish more typical of lake-like conditions.

5.2.2.1.2 Current Trends

1. Actions by the Ohio River Valley Water Sanitation Commission (ORSANCO), an interstate Ohio River improvement organization founded in 1948, and the implementation of the Clean Water Act helped reverse declining trends such that an upward trend in fish diversity in the upper Ohio has been documented in the last 20 years. Many species that disappeared from the upper river during the worst decades of pollution have returned to portions of the river approximating their historical ranges. Between 1984 and 1989, range extensions of mainstem fishes included 12 species in an upstream direction, 14 species in a downstream direction and six species both upstream and downstream. Further, improved water quality improvements are reflected in an ORSANCO list of the most abundant species captured during river surveys. Pollution tolerant common carp and bullheads have been replaced by bluegill, temperate basses and other fishes less tolerant of pollution. ORSANCO has recently developed a tool, the Ohio River Fish Index (ORFIn) which incorporates distinctive ecological characteristics and 13 attributes of Ohio River fish communities to evaluate their ecological health.

2. In spite of continued research and measurable improvements related to fish communities, stability of Ohio River native fishes is now a concern related to introduction within the last decade of four species of Asian carps (grass, silver, bighead and black). These species have little sport value, but can aggressively compete with native fishes for food and space. The impacts of Asian carps on Ohio River native fishes are still undetermined. The American Fisheries Society published a book entitled "Black Carp: Biological Synopsis and Risk Assessment of an Introduced Fish" (Nico, et al, 2005) that should be useful in developing strategies to consider in the Ohio River system for black carp management.

5.2.2.1.3 Recent Studies

1. During the past and into the present, many studies have been conducted to determine the effects of various human activities on fishes of the Ohio River. Key observations from these studies follow:

- A recent study on upstream fish passage at Ohio River dams, undertaken to examine the importance of longitudinal connectivity between navigation pools in sustaining migratory fishes, suggested that upstream fish passage opportunities generally occur during open-river rather than controlled conditions at dams. Open river conditions occur when dam gates have been lifted clear of the water and are no longer controlling water levels behind dams. Therefore, at open river the surface water elevation immediately upstream and downstream from a dam are nearly equal. An analysis of historical water elevation data at Ohio River mainstem dams revealed that the frequency of open river by calendar week (hence, the potential for fish passage) varied spatially along the river by dam and temporally

with discharge. The general spatial pattern of open river indicated the potential for fish passage decreases from downstream to upstream. In general, open-river conditions were more frequent during winter and spring and generally were nonexistent during summer and fall, coinciding with the low-flow period. The study suggests that because large river fish populations evolved under conditions less restrictive to between-pool movement than presently exist, conditions created by mainstem dams probably affect the distribution, abundance and productivity of migratory species by imposing limitations on reproduction and genetic exchange among localized fish populations.

- Additional studies undertaken for ORMSS related to fish movement and passage in the Ohio River supported some findings of the upstream fish passage study above and are briefly summarized below:

    1) A fish passage direct observations study, conducted at Winfield L/D on the Kanawha River, showed that large river migratory fishes (e.g. white bass, skipjack herring, sauger) were more common in tailwater areas than in the lock chambers, while species typical of more lakelike conditions (e.g. channel catfish) were more common in the lock chambers. This finding supports ORSANCO observations that fewer large river species are collected in traditional lock chamber surveys than expected based on their overall abundance in the river. Further, results of the direct observation study led to the reasoning that many migratory species are not attracted to flow conditions in lock chambers and, therefore, miss opportunities to pass through lock/dam complexes during typical navigational lockage operation.

    2) A fish tagging and recovery study, conducted in nine tailwater areas along the Ohio River, supported the findings of the fish passage direct observations study and indicated that migratory fishes' attraction for flowing waters inhibits them from entering lock chambers. Instead, their interpool movement appears to be facilitated by more open river conditions, which occur more frequently at some L/Ds than at others.

    3) A recreational fish survey of more than 8,500 angler trips at eight tailwaters and covering all seasons found that the number of anglers fishing for "any species" exceeded the number targeting a single species or group and totaled 33 percent of anglers on the river overall. Geographic differences also were observed in species sought; for example, fishes in the perch family were sought in more upstream tailwaters while catfish were sought more frequently in downstream tailwaters. Consumption advisories may explain that fewer fish were kept by anglers in the more industrialized upper river than in the more rural lower river.

- Studies on the effects of towboat operation on large rivers indicate that propellers of commercial towboats can cause abrupt changes in hydraulic patterns, including increased turbulence and water velocities that cause injury or mortality of adult fish, eggs and larval stages. Field investigations of these effects have been limited, in part because of the difficulty of sampling organisms in turbulent water behind large vessels. Two recent studies prepared for the Corps on the Upper Mississippi

River-Illinois Waterway may be applicable to the Ohio mainstem. First, a study of larval shovelnose sturgeon, larval lake sturgeon, eggs and larvae of paddlefish, juvenile common carp, and larval blue sucker (all species recorded for the Ohio mainstem.) found that larval mortalities varied by size and species, with higher tolerances by larger individuals and by species adapted to higher velocity habitats. The study concluded that shear stress created by propellers can be a major source of larval fish mortality. A second study, in Pool 26 of the Upper Mississippi and Alton Pool in the Illinois River, concluded that high annual tow traffic can yield high estimates of annual losses.

- The ORMSS project did not undertake a study on the effects of recreational boating on fish and habitat, but a literature review by the North American Lake Management Society emphasizes that impacts of recreational boating on fish and other aquatic life are most pronounced in shallow waters and are compounded by the coinciding of peak boating activity with critical life stages of aquatic organisms during warmer months. Wave action by high-speed watercraft can disturb or destroy spawning nests, promote shoreline erosion, smother fish eggs and habitat, and lead to gill damage causing decreased growth rates and lower fish biomass overall. Most studies cited in the literature review focus on lakes and reservoirs and fish species that typically inhabit them. Because scant information exists on the effects of recreational boating on large rivers, it remains a topic ripe for additional research.

- A study of winter habitat used by fishes in the Ohio River, conducted during two recent winters in the Belleville and Smithland Pools, found that during both winters and in both pools, fish communities and abundances differed among habitats. For example, in Smithland Pool, habitats adjacent to the main channel appeared to be important for fish during the winter, including island backwaters, submerged boulders at the channel border, and deep scours created by artificial structures. Tributaries in Smithland Pool only appeared to provide important winter habitat when temperatures were low and when tributaries areas were connected to the main channel and not blocked by silt. In Belleville Pool, tributaries and an embayment area appeared to be important for wintering fishes, although such areas may cool more than the main channel during snow melt, stimulating fish to move into warmer main channel areas. The unique opportunity to conduct parallel research projects in two Ohio River pools during the same winters provided several insights into the potential effects of increased navigation fish: 1) Tributary habitats are clearly important to wintering fish; reduced connections between tributaries and Smithland Pool likely compromises the success of many species. 2) Artificial sites such as wing dikes in Smithland Pool create scours used by river fishes. 3) Island backwater areas appear particularly important for fishes during winter. In the Ohio mainstem, quantity and availability of winter refuge may well determine the relative survival and abundance of resident fish populations. Therefore, river habitat management that maintains or enhances accessibility to these areas should be beneficial to wintering fish in the Ohio River.

- Studies on the effects of cooling water intake structures on fish have been undertaken along the Ohio River since the 1970s in conformance with Section 316(b) of the Clean Water Act. In accordance with new and proposed regulations

related to §316(b), U.S. EPA recently evaluated entrainment and impingement rates at nine power plants on the Ohio mainstem between RM 53.9 and 560. The main fish species the study found to be at risk were emerald shiner, freshwater drum, gizzard shad, sauger, white bass, white crappie, and white sucker. Several of these species have floating eggs or larvae that make them more vulnerable to damage from water intakes. Further §316(b) studies at several power plants along the Ohio River are anticipated as additional phases of the revised 316(b) program are implemented by U.S. EPA in the coming years.

2. Finally, a tool to evaluate river traffic impacts on habitat for fish and other aquatic life current has been developed by the USACE – Louisville District to evaluate aquatic life. Called the Navigation Predictive Analysis Technique (NAVPAT), the tool is a habitat model that links tow movements to possible biological effects by considering 15 life-stages of fishes typical of various fish groups and habitats in the Ohio River system. Although refinements to NAVPAT continue, the model has been used to evaluate environmental effects near Olmsted L/D and McAlpine L/D.

5.2.2.2 Mussels

See Environmental Appendix, CEA Chapter 5 for an expanded discussion of Ohio River mussels

Because of limited mobility, mussels are subject to a variety of environmental factors that can restrict their distribution and reproductive success. Payne and Miller (1999) found that long-term stability of Ohio River mussel beds depends on clay, silt and sand, which are deposited during seasonal low flows, being removed by high flows without eroding underlying gravel and cobble. Other factors important to sustaining viable mussel communities include adequate water quality; availability and distribution of fish hosts for colonization by young mussels (glochidia); and restricting the introductions and abundance of non-native, invasive species.

5.2.2.2.1 Historical Conditions

1. As long ago as the late 1800s, freshwater mussels had begun to decline in the Ohio River, primarily from direct habitat disturbances, as well as indirect effects of siltation, pollution and contaminants associated with construction, industry and agriculture (Taylor 1989). In the 19th Century, harvesting of freshwater mussels for button manufacture began in the Ohio River. Harvesting mussels for the button industry continued through the mid-20th century until the advent of plastic buttons, which are cheaper and more easily manufactured. Mussel harvesting along the river, however, continued beyond the 1950s in response to the cultured pearl industry's demand for small mussel pellets to stimulate pearl growth. As late as the 1980s, 22 active commercial mussel harvesters were operating on the Ohio and Tennessee Rivers (Williams and Schuster 1989).

2. Construction of dams on the Ohio River further affected native mussels. First they impounded water and inundated mussel habitats. Second, the dams formed barriers that separated and isolated the populations of mussels. These barriers also affected the distribution of fish species that serve as hosts to the larval phase (glochidia) of the mussel. This affected the ability of certain mussel species to recolonize areas of suitable habitat.

Third, changes in current velocity and direction associated with high-lift dams have had impacts on mussel beds. High-lift dams are the newer generation dams constructed by the Corps. High lift dams created deeper pools than the first generation of "low-lift" dams. As current velocity diminishes upstream of dams, deposition of silt seems to particularly affect younger mussels. Younger mussels are small enough to sink into the silt and suffocate. When lower lift dams were in place, in many areas the current followed the shoreline washing mussel beds free of silt and mud. With the completion of high-lift dams, current patterns changed, allowing greater deposition of silt (Williams and Schuster 1989).

5.2.2.2.1.1 Mussels in the Upper Mainstem River

1. This section describes historical factors affecting freshwater mussels and conditions of the mussel community from Pittsburgh (RM 0) to Meldahl Lock and Dam (RM 436). Mussels were completely extirpated from the upper portion of the Ohio River during the early 20th Century. Arnold Ortmann (1919), in his classic monograph of the *Naiades* of Pennsylvania, reported the total demise of the mussel fauna of many tributaries of the upper Ohio River, mostly from the impacts of acid drainage from bituminous coal mining. However, in 1919 he was still able to document either the presence, or relatively recent occurrence, of a diverse assemblage of at least 39 species of mussels in the Pennsylvania portion of the mainstem of the Ohio River.

2. The degree, extent, and duration to which previous water quality conditions adversely affected survival of mussels along the upper Ohio River cannot be precisely determined from historical data. However, as early as 1914, the U.S. Public Health Service documented episodic acidification of the Ohio River extending as far as 170 miles downstream of Pittsburgh (U.S. Public Health Service 1924). Data collected by the U.S. Geological Survey and the Pennsylvania Department of Forests and Waters (White 1951) provide a good picture of Ohio River water quality conditions (at a station 17 miles downstream of Pittsburgh) during the late 1940s. The pH of the Ohio River ranged from 3.65 to 6.6 and averaged 5.3 (pH of 7.0 is neutral). Other water quality factors affecting mussels in the upper river included low DO, high turbidity and suspended solids, and high concentrations of contaminants (e.g., metals and organic compounds).

5.2.2.2.1.2 Mussels in Other Mainstem Reaches

Mussel communities from Mehldahl Lock and Dam (RM 436) to the confluence of the Ohio and Mississippi Rivers (RM 981) were less affected by historical water quality conditions than were mussels of the upper Ohio River. This is due in large part to the upper river reach being more heavily industrialized than the rest of the river. Although mussels were definitely affected by water quality factors from upstream sources, major influences along the middle and lower reaches were from low DO, high turbidity and suspended solids, and contamination of sediments.

5.2.2.2.2 Recent Conditions and Trends

1. With the enactment of the Federal Water Pollution Control Act Amendments in 1972, water quality conditions began to improve on the mainstem Ohio River and throughout the Nation. As water quality improved, mussel resources began to also

improve. However, by this time, many of the modern, high lift locks and dams on the mainstem Ohio River were in place. Presence of these dams restricts fish movement among pools and has slowed reestablishment of freshwater mussel populations. Another major factor setting back mussel recovery was introduction of the non-native zebra mussel in the Ohio River around 1990. Zebra mussels negatively affect native mussels primarily by smothering siphons, preventing valve opening and closure, and interfering with normal feeding and burrowing. Further, living freshwater mussels are a preferred substrate for zebra mussels (Ricciardi et al. 1995).

2. Several federally listed threatened or endangered species of freshwater mussels that were once found in the Ohio River are considered to be extirpated from the mainstem, including the white wartyback, cracking pearlymussel, rough pigtoe, winged mapleleaf, northern riffleshell and catspaw. The ring pink may be present but no live specimens have been collected in recent years. The tuberculed-blossom pearlymussel may be extinct. Although historical records indicate the dromedary pearlymussel once occurred in the Ohio River, definitive data are not available (USFWS 2000). Five federally listed endangered native mussel species, however, are currently known to exist in the Ohio River mainstem. These are the fanshell, pink mucket, orangefoot pimpleback, clubshell, and fat pocketbook.

3. Two additional historic Ohio River mussels are listed by the USFWS as candidate species – the sheepnose mussel (*Plethobasus cyphus*) found as recently as 1994 in the Newburgh and Markland pools and the spectaclecase (*Cumberlandia monodonta*) which may be extirpated from the Ohio River. Candidate species are organisms for which the USFWS has sufficient information on their biological status and threats to propose them as endangered or threatened under the Endangered Species Act (http://endangered.fws.gov/candidates/).

5.2.2.2.2.1 Mussels in the Upper Mainstem River

1. Studies conducted since 1991 indicate that some species of mussels are recolonizing the upper to middle Ohio River mainstem, reflecting in large part the revitalization the river has undergone in recent years due to more stringent water quality standards (ESI 2000, Cavanaugh and Mitsch 1989). As recently as 1980, Taylor found only sub fossil shells and no living mussels in the Pennsylvania reach of the Ohio River. However, the OSU compilation of mussel records revealed two records of mussel occurrence (1979 and 1984) in the Montgomery pool. It appears that recolonization of Emsworth, Dashields, and Montgomery Pools by mussels is a very recent phenomenon.

2. ESI 2000 concluded that the present fauna of the upper Ohio River appears to be a mix of historical species and new species that have recently colonized the study area from tributaries and downstream pools. Researchers have recently found evidence of 54 species, including 35 species that historically appeared in this portion of the river and 19 new species that have recently become established in the upper river. This considerably expands the number of species reported for the upper Ohio River by Taylor (1989). Of the 54 species for which evidence was found (including weathered and sub fossil shells), one species is presumed extinct, eight species are considered extirpated from the study area and the status of two species is unknown. Ten species thought extirpated from the upper river, however, were found live or as freshly dead shells. Indications of recent recruitment were observed for 15 species, including five species previously thought extirpated. There are no

recent records of live specimens of any federally listed threatened or endangered species in the Ohio River mainstem upstream from the Willow Island Dam, although Watters (2003) suggests the fanshell probably occurs in Dashields pool.

Patterns in the ESI data suggest that recolonization is occurring primarily from downstream as evidenced by:

- decreasing species richness and abundance in more upstream pools, and
- opportunistic habitat use in upstream pools.

3. Mussel beds (defined as areas where mussels are consistently found in greater abundance than in surrounding areas and where several species and young animals are present) occur as far upstream as Willow Island Pool (ESI 2000). However, recruitment in recent years was only apparent in a few areas in Willow Island Pool and density was low (<5 mussels /m^2). Density was still low to moderate (<10 mussels /m^2) between Belleville and Meldahl Pools, but species richness increased and recruitment was good in many areas sampled.

4. Increasing trends of total mussel species and rare mussel species (those species comprising <1% of the total collected) from upstream to downstream pools in the upper river further illustrate the recolonization pattern of Ohio River mussel fauna.

5.2.2.2.2.2 Mussels in Other Mainstem Reaches

1. Williams and Schuster (1989), whose studies somewhat geographically overlap the ESI database, reported a net loss of 18.6 linear miles of mussel beds between RM 317 and RM 981 since 1967. The most drastic change was the complete absence of mussel beds in 51.8 miles of the Ohio River above McAlpine L/D. In the interval between 1967 and 1982, within the study area, four new high-lift dams (Cannelton, Newburgh, John T. Myers and Smithland) replaced wicket dams. Other high-lift dams completed during the 1960s had been operational for nearly 20 years.

2. The non-indigenous Asiatic clam (*Corbicula fluminea*) appears to have no adverse effects on native mussels in the Ohio River. Since 1993, Asiatic clam populations have greatly declined; however, zebra mussels (first appearing in the Ohio River in 1991) have replaced Asiatic clams as the non-indigenous bivalve of primary concern. Zebra mussel density near Olmsted L/D was 49,000 individuals per square meter in 1994, but was reduced to 5,000 per square meter in 1995. High zebra mussel densities in 1994 resulted in reduced growth of native mussels, but did not cause major declines in density of native mussels such as have occurred in the Great Lakes. It remains to be seen if zebra mussels can sustain sufficiently high abundance in the lower Ohio to have drastic effects on native mussels.

3. Intensive mussel surveys have been conducted since 1983 in the lower Ohio River near Olmsted, Illinois, to assess the ecological effects of construction and operation of a new lock and dam at RM 964.4 that will replace existing Locks and Dams 52 and 53. Upon completion, the new Olmsted Dam will increase water levels by a maximum of 10 ft. in the pool above the dam during periods of normal and low flow (approximately 42 percent of the year). A mussel bed is located upstream of Olmsted Dam near the Post

Creek outlet at RM 956.5 (Payne and Miller 2002). In addition to changes in the upstream pool area, navigation traffic patterns and river currents immediately downstream of the new dam will be altered. These projected changes are of special interest with respect to their possible impacts on a dense, diverse mussel bed that occurs from approximately RM 966.7 to 969. Mussel studies near Olmsted Lock and Dam are anticipated to continue until the project has been in operation for several years.

5.2.2.3 Other Aquatic Life

See Environmental Appendix, CEA Chapter 3 for an expanded discussion of Ohio River phytoplankton and macroinvertebrates

All aquatic organisms, from minute microscopic plankton to the largest fish, reflect the water quality of their environment and, thus, potentially can serve as biological indicators of water quality conditions and trends. Smaller organisms, especially algae and macroinvertebrates, have most often been studied in this regard, in part, because of their relative ease in field collection and laboratory processing. Bioassessments in general may be used within a planning and management framework to prioritize water quality problems for more stringent assessments and to document "environmental recovery" following control action. Characterization of water quality has been the primary motivation for the biological surveys which have been conducted along the river by ORSANCO since 1957.

5.2.2.3.1 Phytoplankton of the Ohio River Mainstem

Algae form a basis of the food chain and are a foundational component of the Ohio River ecosystem. Algae in running waters may occur as attached forms on all types of solid objects including macrophytes and as films on mud and silt surfaces. Algae also occur as free floating or planktonic forms. Ohio River researchers have confirmed that phytoplankton communities are very important in the Ohio River. Monitoring has to a large degree been motivated by a history of water supply taste and odor problems and public health concerns. In recent years these concerns have expanded to include control of cryptosporidious disease by filtration of the oocysts of the protozoan *Cryptosporidium parvum* during algae blooms (USACE 1994).

5.2.2.3.1.1 Ohio River Plankton Studies - 1957 to 1960

Between October 1957 and January 1960, Jackson and Weise (ORSANCO 1962) collected 210 plankton samples along the Ohio River. Over the length of the river, they concluded that diatoms generally dominated the phytoplankton community. While species composition was similar along the length of the river, there were quantitative longitudinal variations, with generally depressed concentrations of phytoplankton in the polluted upper portion of the river. They suggested that acid mine drainage pollution contributed by the Monongahela River depressed phytoplankton abundance in the upper river. A number of algae bloom events were documented at various locations between river miles 307 and 642, typically involving diatoms and blue-green algae.

5.2.2.3.1.2 Ohio River Plankton Studies - 1974 to 1975

The U.S. Army Corps of Engineers (1975) sampled phytoplankton along the upper Ohio River between RM 1.0 and 129.2 in 1974. Similar to the findings of Jackson and

Weise (1962), they observed that the microflora of the Ohio River was dominated by diatoms and green algae,. Blue-green algae were conspicuously absent from the upper Ohio River, even during late summer. Since blue-green algae are very sensitive to acid conditions, it was speculated that the influence of acid mine drainage may have limited blue-green algae growth in the upper river at that time. Phytoplankton concentrations in near surface samples were generally elevated in the lower sections of navigation pools where velocities are low, and were reduced downstream of navigation dams where velocities and turbulence increase as water passes the dam.

5.2.2.3.1.3 Ohio River Plankton Studies during the 1990s

1. No published plankton data from the 1980s are available. However, during the 1990s, Wehr and Thorp (1997) conducted a study of the effects of navigation dams, tributaries and littoral zones on phytoplankton communities in a reach of the Ohio River that extended roughly from Cincinnati to Evansville. Their study demonstrated that the Ohio River supports diverse, substantial phytoplankton communities, with densities comparable to other large rivers in North America. They observed 134 algal and cyanobacteria taxa, with about 60% of the species diversity contributed by diatoms. As with previous and subsequent investigations, cyanobacteria and green algae attained their greatest prominence in the summer while diatoms were most prominent during the cooler months.

2. Wehr and Thorp concluded that Ohio River phytoplankton densities increased with temperature and decreased with current velocity. Tributaries to the study reach of the river appeared to have few effects on either phytoplankton or zooplankton, probably because of the considerably higher flow of the Ohio River relative to its tributaries in this reach. Consequently, the plankton community of the Ohio River would appear to consist of "true" resident populations.

5.2.2.3.1.4 Distribution and Abundance of Phytoplankton along the Ohio River in 2002

1. In July 1999, the Ohio River Valley Water Sanitation Commission (ORSANCO), in cooperation with the University of Cincinnati, Northern Kentucky University and ten major public water supply utilities, initiated an ambitious program to monitor phytoplankton and chlorophyll along the Ohio River. Organisms are identified and enumerated at the genus level from samples collected twice per month, year round, at each of the ten water supply intakes. The most recent complete year with available organized sampling data is 2002. Data from that year showed a tendency for concentrations of both chlorophyll and phytoplankton to increase in a downstream direction in the Ohio River.

2. The percentage of phytoplankton organisms capable of producing taste and odor problems and the percentage of organisms which were blue-green algae were less in the upper river than in the middle or lower portions of the river. Conversely, the percentage of diatoms was highest in the upper river. The percentage of organisms generally considered to be tolerant of pollution was lowest in the lower river. Factors which might contribute to these spatial trends are the increasing size and lower relief of the river as it flows along its 981 mile long course, the longer navigation pools towards lower portions of the river, and warmer water temperatures in the more southerly lower reaches of the river. Seasonal

patterns apparent in the ORSANCO data show that phytoplankton is least abundant during the higher flow and colder winter months and most abundant during the lower flow and velocity warmer summer months.

3. The composition of the Ohio River phytoplankton community is complex, containing over a hundred genera. However, some generalizations can clearly be made:

- Overwhelmingly, the phytoplankton community of the river was dominated by diatoms.
- The green algae *Chlamydomonas* and *Chlorella,* and *Cryptomonas* were also occasional dominants.
- Despite the concerns related to blue-green algae blooms, blue-green algae were only dominant in 2.8% of the Ohio River samples collected in 2002.

4. The recent ORSANCO length of river, year round sampling study initiative is by far the most ambitious and comprehensive attempt to monitor and characterize the phytoplankton community of the Ohio River. From the data available to date, the results of this effort appear to be generally consistent with Hynes' (1970) characterizations of large temperate zone rivers, as well as the results of previous Ohio River phytoplankton investigations. An apparent decline in pollution tolerant and potential taste and odor causing phytoplankton organisms suggests possible improving water quality and ecological health along most of the Ohio River. Continued monitoring will allow for verification of potential trends.

5.2.2.3.2 Aquatic Macroinvertebrates of the Ohio River Mainstem

1. In addition to their intrinsic values and importance as food for fish and other forms of aquatic life and often non-aquatic life, benthic macroinvertebrate communities are also highly responsive indices of water quality. Macroinvertebrate quality evaluations are based on the principle that invertebrate communities of non-degraded streams are composed of many different types of organisms, including pollution intolerant taxa such as mayflies, stoneflies, and caddisflies (Ephemeroptera, Plecoptera, and Trichoptera, or EPT organisms). The invertebrate communities of polluted streams, on the other hand, are dominated by a small number of pollution tolerant taxa such as sludge worms and bloodworms (Annelida and Chironomidae, or AC organisms). Between the extremes are numerous organisms with intermediate tolerances.

2. The following discussion of Ohio River macroinvertebrates excludes freshwater unionid mussels, which are discussed in **Section 5.2.2.2.**

5.2.2.3.2.1 Ohio River Macroinvertebrate Studies - 1957 to 1960

1. Between October 1957 and January 1960, ORSANCO (Jackson and Weise 1962) collected invertebrate samples along the length of the Ohio River. They found that invertebrate communities of rocky substrates along the main channel of the Ohio River did not include any species which are indicative of unpolluted water. The invertebrate communities of soft substrates nearer to shore were even more depauperate, consisting only of very pollution tolerant tubificid worms and a few specimens of the bloodworm chironomid *Tendipes* sp.

2. More intensive sampling near the intake of the Louisville Water Company at RM 600 confirmed that the distribution of benthic organisms in the Ohio River was related to its substrate type. Similarly, Thorp (1992) demonstrated that invertebrate taxonomic richness and density in the Ohio River is significantly influenced by substrate composition, and also references numerous supporting studies from other locations. Samples of different types of bottoms and from various depths revealed fewer organisms on bottoms of sand or sand and silt than on bottoms of silt alone.

3. Jackson and Weise also emphasized that only a few specimens of Ephemeroptera (mayflies) were found in the Ohio River during their 1957 to 1960 study period. Ephemeroptera are generally considered to be indices of good water quality. Due to water quality improvements over the more than four decades since completion of the Jackson and Weise survey, burrowing mayflies have gradually returned to the entire Ohio River. Huge, newsworthy, emergences of burrowing mayflies finally returned to the Pittsburgh reach of the Ohio River only in 2002/2003.

5.2.2.3.2.2 Ohio River Macroinvertebrate Studies - 1963 to 1967

The results of an intensive Ohio River cooperative aquatic macroinvertebrate monitoring effort, conducted between 1963 and 1967, were published by U.S. Environmental Protection Agency in 1971 (Mason et al.). This effort used artificial substrate sampling (rock baskets) to eliminate the variable of bottom substrate. Important conclusions developed by Mason et al were that artificial substrate sampling techniques tended to collect more diverse samples than dredge samples and that during the five year study period the abundance and diversity of macroinvertebrates increased at stations along the lower and middle reaches of the Ohio River, but not yet in the upper reach of the river near Pittsburgh. Throughout 1963-67, dredge samples from the upper part of the river contained only pollution-tolerant sludgeworms and a few bloodworms.

5.2.2.3.2.3 Invertebrate Community Condition Scores - Patterns and Trends

Invertebrate community condition score and metrics for 2002 ORSANCO data were plotted against 1967 condition scores. The results clearly demonstrate that dramatic improvements have occurred along the previous severely impaired upper reach of the Ohio River since 1967, but less so or not at all along the moderately to slightly impaired middle part of the river. Notwithstanding the progress to date, results for the upper and middle river, compared to the higher condition scores for the lower river, suggest that there is still considerable room for improvement along the upper and middle reaches of the Ohio River.

5.2.2.3.2.4 Invertebrate Signature Species

The extensive ORSANCO Ohio River aquatic macroinvertebrate data file is a valuable large river ecosystem information resource with the potential to yield numerous important insights into the ecology not only of the Ohio River, but also perhaps of other large temperate regulated rivers. While the examination of the file should be considered cursory, some characteristics of the fauna are evident. Among these is the presence of certain organisms, which because of their ubiquitous distribution and/or abundance might be considered to be Ohio River invertebrate signature species. One candidate example is

the almost uniquely large river habitat caddisfly *Cyrnellus fraternus*, present in 88% of the rock basket samples examined. and comprising fully 58.1% of the total number of all invertebrate organisms collected from the Ohio River in 1967, and 39.4% of all 2002 organisms. Identification of important system specific taxa, such as the crustacean *Gammerus minus* and the mayfly *Baetis flavistriga* in urban drainage in the upper Ohio River Valley (Koryak et al 2003), can also be used to help refine rating metrics.

5.2.2.3.2.5 Influence of Navigation Dams on Invertebrate Communities

Characteristics of invertebrate rock basket communities from samples collected by ORSANCO upstream and downstream of Ohio River navigation dams in 2002 show that taxa richness and mean condition scores were somewhat higher downstream of the dams. However, other parameters demonstrated slightly more negative values downstream of the dams and the data is probably inconclusive. If there are more diverse and healthier invertebrate macroinvertebrate communities in the tailwaters of the dams than within their pools, the composition of these communities is probably correlated with natural substrate. The artificial substrate sampling techniques used would not reflect such natural variations in the substrate of the river.

5.2.2.3.2.6 Influence of Islands on Benthic Macroinvertebrate Communities

Thorp (1992) demonstrated linkages between islands and benthos in the Ohio River, with implications for riverine management and aquatic ecosystem restoration opportunities. He found islands to have significant positive effects on invertebrate density and diversity that appeared to be related to changes in physical habitat characteristics. He also noted that islands interrupt the deepwater regions of the Ohio River ecosystem by providing shallow-water habitats and access to different forms of food. Jahn and Anderson (1986) also found that the macroinvertebrate fauna in large rivers shows significant spatial variation among different habitats within the same pool. Thorp specifically recommends island preservation and construction to foster aquatic habitat heterogeneity, and notes that island construction has been employed in several large rivers, such as the Mississippi, with consistently satisfactory results.

5.3 LAND USE

See Environmental Appendix, CEA Exhibit D for an expanded discussion of land use patterns along the Ohio River mainstem corridor

5.3.1 Historical Conditions

Land use changes occur as a result of population increases or decreases in localized areas. Economic development and infrastructure projects can also lead to direct changes in land use as well as associated changes in population density. River-related land use applies these concepts to address how human use of the Ohio River has shaped or influenced associated land use patterns and what land use changes may be anticipated in the foreseeable future.

5.3.1.1 Pre – 1920

1. Pioneer settlement within the Ohio River valley prior to the 1790's was constrained by French and British interests in maintaining their claims of sovereignty within the region. Following the American Revolution, colonization of the area was accomplished by awarding lands in the Northwest Territories to veterans of the war. However, Native American resistance (often supported by British influences) continued to minimize colonial settlements in the area. It was not until Anthony Wayne's victory at the Battle of Fallen Timbers in northwestern Ohio in 1794 and the conclusion of the Treaty of Greeneville in 1795 that the threat of Indian attacks on Upper Ohio River settlements was eliminated and the development of towns and communities in the river valley could proceed unimpeded (ACE_c pg. 3-8). The population within the Ohio Valley grew from 125,000 in 1790 (the first Federal Census) to 850,000 in 1810 (ACE_c 3-55).

2. The decades of pre-settlement military activity necessitated establishment of fortifications along the Ohio River or its tributaries and these often became the sites of the earliest settlements within the region. The most notable example is Pittsburgh, located at Fort Pitt (circa 1758), other examples include fortifications preceding the establishment of towns at Marietta, OH and Wheeling and Point Pleasant, WV (ACE_c 3-8). Other factors contributing to the initial location of towns along the Ohio River generally included the availability of high ground for a town site above the flood zone, connectivity between the town and a productive hinterland, and certain 'port development opportunities' such as the Falls of the Ohio at Louisville or location of the national road crossing at Wheeling. Initial settlements within the region tended to cluster along the Ohio River because the river was the primary access to the region.

3. A variety of factors influenced the subsequent growth and decline of Ohio River towns from 1830's to 1920's. Some early riverfront settlements subsequently prospered as hubs or service centers to interior regions accessed through these towns. As the hinterlands developed, the river towns continued to grow as ports for the assembly and shipping of the region's produce. During the early decades of this period, the Ohio River provided the primary mode of transportation, both for immigration of new settlers and for transport of regional products. The earliest flatboats and keelboats mostly provided one-way transport downstream, necessitating shipment of produce through New Orleans and coastal shipping to reach eastern markets. The arrival of steamboats around 1815 permitted two-way traffic and greatly reduced travel times (ACE_c 3-60). However, the Ohio River itself remained largely unimproved prior to the 1920's, and the ability to move produce was constrained by the seasonal availability of high water flows sufficient to support navigation. Development of the Ohio River in the 1800's included the removal of snags, completion of the initial canal and locks around the Falls of the Ohio at Louisville in 1833, and completion of the first wicket dam (Davis Island, Pittsburgh) in 1885.

4. The latter part of this era includes the period of heavy industrial development along the middle and upper Ohio River. This development centered on the iron and steel industry in Pittsburgh, with its convergence of proximity to raw materials, coal, river water, and rail and river transportation to move materials and produce into and out of this center. An almost continuous band of industrial development became established along the Ohio River floodplain from Weirton to Pittsburgh. To compensate for the limited availability of high ground within this corridor, industries built up elevation of the

floodplain for their developments. The steel industry typically used large quantities of slag as fill material (Rieger, personal communication).

5.3.1.2 Settlement and Development Patterns 1920 to Present

1. Construction of the system of wicket locks and dams ultimately revitalized the Ohio River as a major transportation corridor. Following construction of the first project in 1885 (Davis Island) the next lock and dam was not finished until 1904. Six lock and dam projects were completed between 1904 and 1910, 23 were completed between 1911 and 1920, and the entire system of 50 lock and dam projects was completed by 1929. The original design for a navigation depth of six feet was modified in 1910 to provide for a nine-foot depth.

2. Even as construction of the slackwater system continued, river traffic declined. In 1917, cargo carried on the river reached a low of about 4.6 million tons, a nadir caused largely by the abrupt halt of coal shipments from Pittsburgh to New Orleans. The turning point for the slackwater system was during World War I. Wartime shipping overburdened the country's land transportation system and by 1920, cargo volume on the Ohio River had risen to almost 9.4 million tons, a total that increased further to 10.8 million tons in 1924 (Froggett 1926a), 16 million tons by 1925 (Froggett 1926b), and 22.3 million tons by 1930 (Robinson 1983:28-29; USACE-ORD 1979:22). Where traffic once consisted primarily of coal and steel products moving downstream, new products were being added as the century progressed. Freight soon included petroleum and its products, iron and steel, dry and liquid chemicals, grain, cement, and a variety of other items (Gaum 1970:487), and upstream traffic substantially increased in volume.

3. Commerce on the river grew steadily through the 1930s and 1940s while development of diesel towboats and larger barges created opportunities for larger scale, more efficient movement of commodities. Designed for about 15 million tons of commerce annually, the old locks and dams handled more than 70 million tons in 1954; in addition, traffic moving upstream on the Ohio had nearly equaled that moving downstream. Plans to improve system efficiency and accommodate the larger tugs and barges called for reducing the number of dams by building high-lift projects with larger capacity locks. The final plan, approved in 1954, envisioned a total of 19 high-lift projects with dual lock chambers and began with the construction of Greenup and New Cumberland L&Ds, although construction of Emsworth, Dashields, Montgomery and Gallipolis L&Ds during the 1930s had already replaced some old locks and wicket dams on the upper river. Olmsted, which will complete the 1954 modernization plan, is currently under construction and will replace L&D 52 and 53 (Johnson, 1992).

4. During this era of sustained urban growth, the demands of industrial and commercial development outpaced the availability of land within some of the rapidly growing riverfront urban centers. Within the Huntington and Louisville Districts, a series of levee and floodwall projects were completed during the 1930s and 1940s to protect existing properties against flooding. Rapidly growing cities also expanded beyond the river floodplain to higher ground, utilizing mass transit (light rail, bus) and automobiles to connect their expanding fringe with the urban riverfront core.

5. The availability of reliable, inexpensive electric power contributed significantly to the industrial and commercial growth of the Ohio Valley. Construction of the wicket dams contributed to bulk transport of the region's coal and provided stable pool elevations. Over the years, availability of abundant supplies of cooling water and economies of river transport of coal have favored development of the very large power plants that are now a part of the riverfront landscape of the Ohio Valley.

5.3.2 Present Descriptions

5.3.2.1 Pittsburgh, PA to Steubenville, OH; river mile 0 to 62 (Pittsburgh, PA)

1. The floodplain is very constricted, with the river at ordinary high water typically accounting for 30 to 60 per cent of total area of the floodplain (defined as approximately level terrain between steeper bluffs). Low and high-density urban uses (commercial, industrial, high-density residential and low-density residential) dominate all the floodplain, including islands in the upper half of the river reach. Deciduous forest dominates bluffs or steep areas adjacent to the river outside urbanized areas, whereas low-density residential or deciduous forest dominates bluffs within the urbanized areas. Eight islands are presently located in this stretch of river (*see Environmental Appendix, CEA Chapter 6, Table 6-10)*.

2. Low and high-density urban uses dominate upland areas in the eastern half of the area (Pittsburgh area) and also in Beaver, PA, and East Liverpool, OH. Deciduous forest and pasture are the principal land uses outside of the urbanized areas. Only a few small areas of cropland or mixed forest (mixed deciduous and evergreen forest) are visible.

5.3.2.2 Steubenville, OH to Parkersburg, WV; river mile 62 to 187

1. The floodplain is very constricted. Significant low and high-density urban uses occur along the full length of this reach and are the dominant land use within the floodplain upstream of Moundsville, WV. The floodplain is primarily in row crops or pasture outside of the urbanized areas, with only a few small areas of deciduous forest. Deciduous or mixed forest dominates bluffs or steep areas adjacent to the river. Twenty-three islands are located in this reach.

2. Deciduous forest dominates land use in the upland areas, with pasture as the secondary use. A few urban patches are scattered through upland areas upstream of Moundsville but are confined to upland areas adjacent to the river in communities downstream to Parkersburg. Patches of mixed forest occur throughout the uplands. Only a few small areas of row crop use are visible, some mining or transitional surface use is also visible.

5.3.2.3 Parkersburg, WV to Ironton, OH; river mile 187 to 323

1. The floodplain is very constricted, widening somewhat in the Huntington to Ironton area. The reach between Huntington and Parkersburg is primarily rural, with only a few small urban areas visible at Gallipolis/Point Pleasant, WV, Cheshire, OH, and Pomeroy, WV. Land use in the floodplain in this section is a mixture of pasture and row crop. Urban land uses dominate the floodplain between Huntington and Ironton. Seven islands remain within this segment of the Ohio River.

2. Deciduous forests dominate Upland areas, with pasture the secondary land use. Patches of mixed forest and areas of mining or transitional surface use occur throughout the uplands along with a few small areas of row crops.

5.3.2.4 Ironton, OH to Foster, KY; river mile 323 to 439

1. The floodplain remains wider from the Ironton/Huntington area to west of Portsmouth, OH, then gradually returns to the constricted configuration of the upper river. Land use within the floodplain is primarily row crops with some pasture and a few small areas of wooded wetlands. Vegetation on the bluff areas adjacent to the river is primarily deciduous. Urban land use within the floodplain is found at Ironton/Greenup, Portsmouth, and Maysville. Three islands are located along this segment of the river.

2. Upland areas are predominately deciduous forest in the eastern and central portions of this area, but give way to mixed pasture and row crops in the western third. Significant row crops are also evident in the broad floodplain of the Scioto River above Portsmouth and significant wooded wetlands occur in floodplains of the Little Sandy River southeast of Portsmouth. Areas of mining or transitional use are scattered through the eastern portion of this area.

5.3.2.5 Foster, KY to Ghent, KY; river mile 439 to 537

1. The floodplain remains constricted through the eastern portion of this reach, with the river surface typically accounting for 40 to 60 per cent of the floodplain area. Downstream of the confluence with the Great Miami River, the floodplain broadens somewhat, with the river surface typically accounting for 20 to 40 per cent of the floodplain area. Low and high-density urban use dominates the floodplain in the Cincinnati/Covington/Newport area. Urban use is also visible west of Cincinnati at Cleves, Oh and Lawrenceburg and Rising Sun, IN. Land use in the floodplain east of Cincinnati is primarily a mix of row crops and pasture. Row crops dominate land use in the broader floodplain west of Cincinnati, with some pasture and a few small areas of wooded wetlands. Only one island remains in this reach.

2. Urban uses dominate upland areas adjacent to the Cincinnati area and also occur in scattered patches north, east and south of Cincinnati. Non-urban areas throughout the region include a mix of row crop, pasture, and deciduous forest, with significant row crop areas in the Great Miami floodplain and several areas of wooded wetlands in the floodplains of tributary streams in Kentucky.

5.3.2.6 Ghent, KY to West Point, KY; river mile 537 to 630

1. The floodplain returns to the more constricted form, with river surface accounting for 40 to 60 per cent of the floodplain area. Low and high-density urban use dominates the floodplain in the Louisville/Clarksville/Jeffersonville area. Urban use is also visible east of Louisville at Madison, In, Carrolton, KY, and Vevay/Ghent. Floodplain use outside of urban areas includes a mix of row crops, pasture, and some wooded wetlands. Deciduous forest dominates bluff areas adjacent to the river. Six islands occur within in this reach.

2. Urban uses dominate upland areas surrounding Louisville and are also visible as smaller patches throughout the area. Non-urban areas throughout the region include a mix of row crop, pasture, and deciduous forest use, with significant areas of wooded wetlands in tributary floodplains northeast of Louisville and scattered patches of mixed forest in Indiana. The Indiana Army Ammunition Plant is a large commercial/industrial area north of Louisville.

5.3.2.7 West Point, KY to Lewisport, KY; river mile 630 to 737

1. The floodplain gradually widens from east to west through this reach of the river, with river surface accounting for 20 to 40 per cent of floodplain area in the western area. Urban land use within the floodplain is restricted to a few small centers, including Tell City, IN and Brandenburg, KY. Row crops and pasture are the dominant land uses within the floodplain, with a few small areas of wooded wetlands. Deciduous forest is prominent along bluffs adjacent to the river. There are four islands in this reach.

2. Upland areas include deciduous forest (dominant in the central area) and mixed row crop and pasture (dominant in the east and west portions of the area). Significant urban use is located in the Fort Knox area and significant wooded wetlands are located in bottomlands of the Salt River on the east side of Fort Knox.

5.3.2.8 Lewisport, KY to Wabash River, IN; river mile 737 to 848

1. The floodplain continues to widen from east to west through this reach of the river, with river surface accounting for 10 to 20 per cent of floodplain area near the Wabash River confluence. Limited urban land use occurs in floodplain areas of Evansville, IN and Henderson and Owensboro, KY but the majority of urban area for these cities is located on adjacent uplands. Extensive areas of row crop agriculture dominate floodplain land use, with significant secondary areas of wooded wetlands and some pasture and deciduous forest. Deciduous forest is also prominent along bluffs adjacent to the river. This reach includes seventeen islands.

2. Row crop agriculture and pasture (including significant row crop agriculture in the Wabash River floodplain) dominate land use in upland areas, with lesser tracts of deciduous forest and some significant areas of wooded wetlands along tributary floodplains. Several areas of mining activity, scattered tracts of mixed forest, and a few urban centers (Morganfield and Sebree, KY) are also visible.

5.3.2.9 Wabash River, IN to Cairo, IL; river miles 848 to 981

1. The floodplain is narrowed somewhat near Shawnee National Forest southwest of the Wabash River but returns to a broad floodplain configuration from Paducah to the confluence with the Mississippi River. Limited urban land use occurs in floodplain areas of Paducah, KY, and Metropolis and Cairo, IL. Row crop agriculture is the dominant floodplain land use, with significant secondary areas of wooded wetlands and some pasture and deciduous forest. Deciduous forest is also prominent along bluffs adjacent to the river. Twenty-four islands are found here.

2. Upland land use includes a mix of row crop agriculture, pasture and deciduous forest, with significant areas of wooded wetlands in tributary bottomlands and some fairly large blocks of mixed forest. Significant urban land use is visible in areas adjacent to Paducah and at Calvert City, KY.

5.3.3 Trends

1. With respect to statewide trends, all six states along the Ohio River mainstem are showing significant increases in the amount of developed land. Additionally, the rate of development has increased in all six states. Cumulatively for the six states, 0.6 percent of total land area was developed from 1982 to 1987, 0.8 percent was developed from 1987 to 1992, and 1.2 percent from 1992 to 1997 (double the 1982-1987 development rate). The total area of developed land within the six states increased by 32 percent during the 15 years covered by these data. This compares closely to the national increase of 34 percent during the same period. Nationally, an average of 1.4 million acres per year was developed from 1982 to 1992. This increased to an average of 2.2 million/year from 1992 to 1997.

2. It seems likely that the accelerating rate of development illustrated above continued from 1997 to 2002 (the latest year for which data were considered). Housing construction did not slow, partly because of federal interest rate reductions that contributed to record low mortgage rates. A conservative estimate would set land developed from 1997 to 2002 as equal to the total developed from 1992 through 1997, or 1.2 percent of total land within the six states. Thus it is estimated that 11.7 percent of total land area within the six states was developed for urban/commercial/industrial use as of 2002.

5.4 RIPARIAN/FLOODPLAIN ECOLOGY

See Environmental Appendix, CEA Chapter 6 for an expanded discussion of Riparian/Floodplain Ecology for the Ohio River Mainstem

1. Riparian/floodplain resources include terrestrial habitats, wetlands, soils and geology, islands, and floodplain hydrology. The following definition for "riparian", which was developed by the National Research Council (2002), encompasses the above components and related processes:

2. Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients of biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect waterbodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral stream, lakes, and estuarine-marine shorelines (NRC 2002).

3. Further, riparian areas include portions of the channeled system and associated features (gravel bars, islands, wood debris); a vegetated zone of varying successional states influenced by floods, sediment deposition, soil-formation processes and water availability; and a transitional zone to the uplands of the valley wall – all underlain by alluvial aquifers. Although they occupy only a small portion of the total land base in most watersheds,

riparian areas are regional hot spots for biodiversity and exhibit high rates of biological productivity in contrast to larger landscapes (NRC 2002).

4. Each of the identified components and related processes are influenced by both natural processes and man-induced stresses. For example, compounding the influence of natural processes are changed floodplain hydrology and characteristics resulting from development projects or other human induced changes in land use. These influences include dams and other instream developments, activities along the riverbank or within the riparian zone, and upstream activities throughout the watershed. The floodplain hydrology resulting from the combination of natural and human influences, subsequently, affects the full spectrum of riparian features. It also significantly affects the suitability of the riparian zone for various human activities such as agriculture, recreation, transportation, housing and commerce.

5. For purposes of describing the affected environment, the following components, processes, habitats and species are addressed: physiography and geomorphic considerations, floodplain descriptions, soils and sedimentation, hydrological considerations, corridors, riparian habitats, wetlands, bottomland hardwood forests, riparian edge/shoreline areas, embayments, islands, upland and unique habitats, wildlife, and invasive exotic species.

5.4.1 Historical Conditions

1. Based on average annual discharge, the Ohio River is the second largest river in the United States, surpassed only by the Mississippi River, below its confluence with the Ohio (USGS streamflow data, cited in USEPA 2000). The Ohio River is formed by the confluence of the Allegheny and Monongahela rivers in Pittsburgh, Pennsylvania, and flows 981 miles in a southwesterly direction to join the Mississippi River at Cairo, Illinois. The elevation of the Ohio's riverbed drops 429 feet from the headwaters to its confluence with the Mississippi River (USEPA 2000). The mainstem's major tributaries, from upstream to downstream, include the Muskingum, Kanawha, Guyandotte, Big Sandy, Scioto, Licking, Great Miami, Kentucky, Green, Wabash, Cumberland, and Tennessee rivers. The 203,940 sq.-mi. Ohio River basin encompasses several physiographic provinces, but the Ohio mainstem is primarily influenced by four provinces: Appalachian plateau (RM 0 to RM 380), central lowlands (north of the Ohio River from central Ohio through Indiana and Illinois), interior low plateau (RM 380 to RM 928), and coastal plain (RM 928 to RM 981). Due to the broad scale of these physiographic and geomorphic considerations, the historical and recent conditions are essentially the same, thus no trends are noted.

2. The dimensions of the Ohio River floodplain in various river reaches are influenced by the erodibility of the rocks forming the valley. The floodplain is narrow upstream (e.g. 0.8 mi. at Pittsburgh) as it flows through a relatively flat-laying sequence of sedimentary rocks. By Vanceburg, KY (RM 380) the floodplain has broadened to 1.6 miles, but then remains fairly narrow almost to Louisville, because the valley walls are formed by relatively resistant shaly limestone. From above Louisville to West Point, KY (RM 630), the floodplain widens where more erodible soft shales form the valley walls. Downstream from West Point, however, the river enters an area of more resistant limestone and the valley narrows for approximately 90 miles. Near Hawesville, KY (RM

724), the valley enters soft shale and sandstone and, consequently, broadens. The valley narrows again near Shawneetown, IL (RM 858) where more resistant sandstones occur, then broadens near the confluence with the Cumberland River (RM 920), where the floodplain consists of soft unconsolidated sediments of the Mississippi Valley (USACE 2000). Due to the broad scale of the floodplain along the mainstem, the historical and current conditions are essentially the same. However, localized changes in the floodplain have occurred along the mainstem as a result of both local and upstream land use changes, as well as a consequence of river flow pattern changes from upstream dams and locks operations.

3. Riparian soils are highly variable in structure, particle size distribution, and other factors that occur not only horizontally across a riparian area but also vertically within a soil profile. Such variability results from interactions between streamflow patterns and sediment transport in conjunction with variations in local geology, channel morphology, and streamside vegetation. Sediments deposited on floodplains undergo biogeochemical changes that occur over time to transform flood-deposited sediment into riparian soils which, because of their high levels of nutrient and organic matter, are some of the most productive agricultural soils in the nation. The alluvial sediments along the upper River valley consist of glaciofluvial fill or medium to coarse-grained sand and gravel of Wisconsin Stage and post-glacial terrace deposits mainly of the "point-bar" type of river sediment. These glaciofluvial deposits are as much as 125 feet thick. The downstream floodplains commonly consist of thick sections of sand, silt, and clay that are commonly referred to as loams.

4. Regarding hydrological considerations, riparian areas receive water from direct precipitation, groundwater discharge, overland and shallow subsurface flow, from adjacent uplands, and from the Ohio River by various pathways. It is estimated that 4,500 billion gallons of water is stored in the mainstem's alluvial aquifer, with more than 70% being in the lower third of the River. Due to the shallow depth of this aquifer, this aquifer is also sensitive to pollution. The quality of the groundwater is characterized by relatively high hardness and dissolved solids concentrations.

5.4.2 Recent Conditions and Trends

1. Many ecological functions along the Ohio River have been lost, as riparian areas have become hydrologically disconnected from their adjacent stream channels. Such disconnections occur, for example, when local topography and soils are altered by agricultural activities or by development and its associated infrastructure. Floodplain and instream sand and gravel mining also potentially modify riparian hydrology, influencing groundwater levels, overbank flow, bank stability and the character of riparian vegetation. Impoundment of the river for navigation has elevated the water table and has significantly affected Riparian/Floodplain Resources. Deepwater habitats of navigation pools have replaced the varied habitats of islands, gravel bars, riffles, and channel wetlands, while some new habitats have been created in embayments.

2. The USWFS (2000) analyzed aerial photos to estimate the miles of riparian habitat remaining along the Ohio River. The analysis used 1800 as a benchmark year and assumed that at that time, the entire river corridor was forested, therefore, encompassing 1,962 linear miles on both banks of the river. The length of the remaining intact riparian

forested areas along each riverbank was calculated by examining aerial photographs from randomly selected 20-mile stretches of river in the Pittsburgh, Huntington and Louisville Corps districts. Intact riparian forested areas were defined as having stable, undeveloped banks that support mature native riparian vegetation of sufficient width to provide some habitat value and/or provide buffering from mainland development. The percent forested riparian areas for each evaluated reach was calculated and extrapolated to determine the total number of riparian habitat miles remaining. The analysis indicates that slightly more than 50% of all types of riparian habitat along the Ohio River have been lost since 1800. Additionally, disproportionate losses in the upper and middle river are consistent with historic patterns of settlement and development.

3. Bottomland hardwood forests are temporarily or seasonally flooded areas that usually occur along streams and rivers, usually in mineral soils. They represent the natural climax community of the Ohio River floodplain. Industrial, residential and agricultural development, draining, and construction of dams and navigation pools have eliminated much of this habitat type. In fact, between 1800 and 1970, approximately 1,235,000 acres (65%) of the Ohio mainstem's forested floodplain habitat was lost or converted to other uses (Ohio River Basin Commission 1978). Prior to development, a typical floodplain habitat was a matrix of bottomland forest interspersed with components of other wetland types, including sloughs and oxbows. The remaining riparian area is often less than a few hundred feet wide (USFWS 2000).

4. Riparian edge/shoreline areas are physical, chemical and biological transition zones between terrestrial habitats and open water. Such areas are important for a variety of birds, mammals, amphibians, reptiles and fishes, dependent on this limited habitat type. Rooted aquatic plants or macrophytes, however, represent a conspicuous group of organisms primarily found in riparian edge/shoreline areas, as well as in embayments. Nine species of submerged plants have been observed along the Ohio River and backwaters, including eelgrass and water nymphs. Further, a total of 24 species of emergent plants have been noted, including water willow, lizardtail and duck potato.

5. Most remaining shallow water and wetland habitats in the Ohio mainstem floodplain occur in the embayments – the tributary mouths inundated by backwaters from the impounded Ohio River (USFWS 2000). Major wetland habitat types in embayments include riverine open water, riverine emergent, riverine aquatic bed, palustrine open water, palustrine emergent, palustrine scrub/shrub, and palustrine forested.

6. In summer, during the height of the growing season, the diversity of the wetland plants and habitat types in Ohio River embayments provide excellent food and cover for migratory and resident wildlife. The shallow water habitats are important feeding areas for wading birds such as great blue herons, great egrets and black-crowned night herons, which nest in heronries nearby and feed in the embayments while raising their young. After fledging, juvenile herons concentrate in the embayments as well. Wood ducks, mallards, and Canada geese nest and raise their broods in the embayments and along the mainland wetlands in summer.

7. The most comprehensive assessment of embayments and wetlands along the Ohio River has occurred in the Ohio River Islands National Wildlife Refuge's planning area, which encompasses approximately 400 Ohio River miles from the Montgomery to

Mehldahl pools. More than 5,400 acres of relatively undisturbed embayments and mainland wetlands are affected by Ohio River backwaters and have some significance for wildlife.

8. Recently, the Ohio River Islands National Wildlife Refuge (ORINWR) office completed a comprehensive assessment of the number and acreages of islands lost from the Ohio River since 1900. Of 124 islands present according to 1911-1914 navigation charts, 31 islands have disappeared, including 20 from the upper river. While some islands in the lower river have increased in size since 1900, the overall acreage gain of 1,094.8 is far outweighed by the 12,001.3 acres lost. The ORINWR analysis indicates an overall loss of 43.1 percent of historic island acreage, due primarily to pool raises, construction of high-lift dams on islands and dredging (USFWS, undated).

9. Historically, the Ohio River floodplain was primarily forested habitat, with scattered prairies, canebrakes and wetlands in the floodplains of the main river and its tributaries. Scattered remnant unique habitats such as dry forest glades, post oak flatwoods and clay barrens may still be found. Bluffs bordering some areas of the Ohio River shoreline provide habitat for a number of species of concern. Most of this area has been settled, cleared, drained, farmed and developed, resulting in the outright loss of habitat, and the fragmentation of that which remains. Significant wildlife use of upland forests in the study area includes the endangered Indiana bat and gray bat, raptors (including nesting bald eagles) and neotropical migrant songbirds.

10. The varied riparian habitats along the Ohio River support a diverse assemblage of wildlife. Birds are an especially important component of wildlife along the river and are conspicuous by their numbers, visibility and overall species diversity. Riparian areas' diversity in plant species and variations in vertical and horizontal structure provide an array of niches for birds. Riparian areas along the Ohio River mainstem afford important habitat for breeding birds, stopover habitat for migratory birds and wintering habitat for birds that live in North America year-round. The Ohio River corridor is poised on the boundary between the Atlantic and Pacific Flyways, and is a major migration route for birds.

11. Over 25 species of waterfowl (ducks, geese, swans, mergansers) utilize the Ohio River corridor. The majority of these species are migratory, using riparian habitats as feeding and nesting areas. Numerous shorebirds (e.g. lesser and greater yellowlegs, spotted sandpipers, semipalmated plovers, ruddy turnstone, common snipe, American woodcock, solitary sandpiper, least sandpiper, semipalmated sandpiper and killdeer) utilize the Ohio River corridor during spring and fall migration. Important areas include mudflats and emergent wetlands. The USFWS (2000) notes that before the Ohio River was extensively altered, its floodplains and tributaries provided numerous sandbars, mudflats and oxbows that were ideal habitat for shorebirds.

12. The great blue heron and green-backed herons are the most commonly observed wading birds along the Ohio River. Both species feed and roost in shallow water zones, fringe wetlands and interior wetlands along the river and islands. Wading birds also include the interior least tern, listed as federally endangered due to low numbers and loss and degradation of nesting islands. The bald eagle, formerly an threatened species under the Endangered Species Act, also occurs in the Ohio River corridor although in 2007 it was

delisted. This species is still protected under the Bald and Golden Eagle Protection Act, the Migratory Bird Treaty Act and the Lacey Act. The USFWS (2000) indicates bald eagles are more abundant along the Ohio River in winter than at other times of the year, as they shift south from frozen lakes and rivers in the north.

13. More than 25 mammal species occur along the Ohio River mainstem, including furbearers such as mink, beaver and muskrat. These species are noticeably more abundant along back channels and wetland habitats of embayments than along the main channel/navigation sides of islands (USFWS 2000). Somewhat less conspicuous are the endangered Indiana bat and gray bat that roost along the river during summer. Although not as conspicuous as birds or mammals, most amphibians and many reptiles are intimately associated with riparian areas and their waterbodies. Many species of amphibians and reptiles are found in Ohio River riparian zones, although most have not been well studied. However, the 15 species of reptiles and amphibians documented as of 2000 for the Ohio River Islands National Wildlife Refuge (USFWS 2000) might be considered to be representative of the typical herpetofauna common to the Ohio River riparian zone.

14. The only Federally endangered, threatened, proposed or candidate species of reptile or amphibian listed in the USFWS's Ohio River Valley Ecosystem Team website for counties contiguous with the Ohio River mainstem is the copperbelly water snake (*Nerodia erythrogaster neglecta*), found in several counties in Southern Illinois. In Indiana and Ohio the copperbelly water snake is threatened in the northern part of its range, but is not listed in these states in the southern part of its range near the Ohio River. However, Conservation Agreements have been signed between USFWS and the Illinois, Indiana, and Kentucky Departments of Natural Resources, other state agencies, and a number of coal companies as a means of protecting and enhancing habitat for the copperbelly water snake in the southern portion of its range.

15. Invasive exotic plant species have become an extremely serious problem along the Ohio River floodplain. In fact, the USFWS considers invasive exotic plants second only to direct habitat losses as a threat to native species (USFWS 2000, and Morrison 2003). Along the RM 0 to 437 river reach considered within the scope of the Ohio River Islands National Wildlife Refuge's management strategy, one of the greatest obstacles to efforts to restore and protect wildlife habitat is invasion by non-native plants such as Japanese knotweed, mile-a-minute, and multiflora rose. The riparian corridor along this reach of the Ohio River includes a diverse assemblage of about 500 species of plants. Of these, 39 species are considered rare, 100 species are considered exotic, and 35 species are problematic invasive exotic species.

5.5 AIR QUALITY

See Environmental Appendix, CEA Chapter 7 for an expanded discussion of Air Quality within the Ohio River corridor

Air pollutant emissions are broadly classified as originating from two types of sources, stationary and mobile. Stationary sources generally include facilities such as industrial plants and electrical power generating plants, whereas mobile sources include automobiles, trucks, trains, boats, and any other equipment that is not at a fixed location.

5.5.1 Historical Conditions

1. Extensive and diverse industrial development in the ORV began in the 1800s and, up to about 1970, occurred without substantive regulation of air emissions. In addition, rapid highway development occurred from 1945 through 1970, which contributed to the growing popularity of the automobile as well as development of an extensive commercial trucking industry. As was the case with industrial sources, emissions from automobiles and trucks were unregulated up through at least 1970.

2. Gasoline and diesel fuel from mobile sources added lead, Volatile Organic Compounds (VOC), Carbon Monoxide (CO), Nitrous Oxides (NOx), Particulate Matter (PM) and other pollutants to the air. USEPA estimates that national emissions of NOx increased 690 percent between 1900 and 1970. During the same period, VOC emissions increased 260 percent and Sulfur Dioxide (SO_2) increased by 210 percent. Air quality trends in the ORV probably approximate these national trends with the exception of SO_2, which was very heavily concentrated in the ORV due to the amount of coal burned in the region.

3. Many local air pollution problems are the result of population centers and local weather patterns that concentrate pollutants over a period of several days. The most obvious localized impacts of smog, PM, and lead attracted much public attention during the two decades of debate that preceded passage of the Clean Air Act and finalization of Federal air quality regulations in the early 1970's. Long-range transport and atmospheric chemical interactions that contributed to acid rain, formation of Ozone (O_3), and other impacts were less obvious. However, the earliest legislation established monitoring and research programs that led to better understanding of these processes.

4. One of the earliest programs to improve air quality focused on the automobile. Beginning in the mid-1970's, all new vehicles sold in the U.S. were required to have catalytic converters, which reduced emissions and enabled the vehicles to operate on unleaded gasoline. Additional engine design and performance standards also contributed to reduced emissions of VOC and CO. Subsequent fuel efficiency standards reduced emissions by increasing the number of miles traveled per gallon of fuel consumed. Significant progress towards improved air quality was gradually achieved over about 15 years as the previous generation of leaded vehicles was gradually replaced.

5.5.2 Recent Conditions and Trends

1. In general, regional conditions in the ORV reflect the national pattern for overall improvement in air quality. Between 1970 and 1999, total emissions of the six National Ambient Air Quality Standards (NAAQS) pollutants have decreased by 31 percent. These advances were achieved in concert with significant economic and population growth. During the same time period, U.S. Gross Domestic Product increased 147 percent, vehicle miles traveled increased 140 percent, and the U.S. population increased by 33 percent. Since 1970, emissions from all of the NAAQS pollutants have decreased, with the exception of NOx. Between 1970 and 1999, emissions of NOx increased 17 percent. The majority of this increase is due to heavy-duty diesel vehicles and coal-fired power plants.

2. VOCs combine with NOx to form O_3. Substantial progress has been made in the control of this class of pollutants; however, future gains will be more difficult to achieve. For this region, sulfates are the primary precursor to the formation of $PM_{2.5}$, accounting for over 50 percent of particulate composition at monitoring stations east of the Mississippi River. NOx is an important secondary precursor. The acid rain program, regional NOx programs, and NOx vehicle initiatives are the primary activities that will contribute to reduced $PM_{2.5}$ emissions in the ORV. In addition to the national acid rain program, three regional programs are in effect that will further reduce NOx emissions from power plants and other industrial sources in the Midwest and northeast. In this region, NOx shares principal contributor status with VOC for local ozone problems, with SO_2 for acid rain, and is a secondary contributor to the formation of $PM_{2.5}$.

3. Overall compliance with air quality standards is indicated by whether an area is designated to be in attainment with requirements for various pollutants. Achievement of attainment status for O_3 in the seven county Cincinnati and Northern Kentucky area and for SO_2 in Gallia County reflects the trend towards attainment status for numerous localities in the ORV. However, revised standards for O_3 and $PM_{2.5}$ seem likely to place numerous localities into nonattainment status for one or both of these NAAQS. Some localities will have to continue or reinstate air quality programs from earlier periods of noncompliance status (e.g. Cincinnati and Northern Kentucky), while others will be required to implement programs for the first time. Programs for both pollutants would primarily focus on transportation management, public education, and emergency procedures. In some cases, nonattainment localities may acquire the authority to impose stricter emission limits for NOx, SO_2, VOC, and $PM_{2.5}$ from stationary sources such as printers, distilleries, dry cleaners, industrial boilers, and related sources.

4. For areas that are nonattainment for O_3 in the ORV, as well as for communities trying to maintain their attainment status, transportation management is one of the primary strategies at the local level. Vehicle inspection programs are a fundamental means of assuring that owners perform routine maintenance to keep their vehicle emissions in compliance. Communities can also require the use of reformulated fuels that burn more efficiently and emit fewer pollutants. Support of mass transit programs is motivated, in part, to reduce vehicle emissions.

5. Local program efforts are supplanted with emergency procedure approaches when local air quality threatens to exceed compliance thresholds. Local authorities may encourage or require reduced activities by public agencies, local industries, area sources, and individuals until air quality improves.

5.6 HUMAN HEALTH AND SAFETY

See Environmental Appendix, CEA Chapter 8 for an expanded discussion of Health and Safety within the Ohio River corridor

Health and safety (H&S) considerations are primarily related to human communities rather than resources and ecosystems. However, some H&S measures may impact resources or ecosystems. The H&S VEC consists of:

- Worker health and safety – This refers to construction workers and workers related to lock and dam operation, assemblage/ disassemblage of barges in tow, operation of tows and helper boats, and barge loading/unloading.

- General population health – This refers to chemical or bacteriological exposures to the human population using the Ohio River as a water supply, or using the river for body contact recreation (swimming and/or water skiing) or consuming fish from the River.

- Recreational boater safety – This refers to accidents experienced by those persons engaged in recreational boating on the Ohio River.

- Noise refers to the ambient sounds audible in an area or environment, comprised of sounds from varying distances. Both workers and the general population may be subject to noise impacts.

5.6.1 Historic Conditions

5.6.1.1 Hazardous Industries, Waste Sites and Spills

Industrial activities located or conducted in proximity to the river have posed one or more types of public risk. These included pollution point sources, production and disposal of hazardous wastes, and spills of potentially hazardous or polluting materials associated with transfer, storage and use of the materials. Past industrial activities also contributed to the creation of contaminated sites and landfills that pose ongoing threats to groundwater, surface water or public health. Raw materials, products, and wastes associated with river oriented industrial activity were transported locally and regionally by barge, rail, and truck. These materials were subject to spillage while in transit and especially at material transfer points.

5.6.1.2 Recreational Boating

Recreational boating on the Ohio River was subject to higher levels of risk than normally encountered on inland lakes and streams. Strong currents, water level fluctuations and the presence of barge traffic were more prevalent on the Ohio River than in other settings. Recreational boating on the Ohio River resulted in a number of injuries, fatalities, and associated property damage. Boating and other river oriented recreational activities grew significantly over the past several decades in conjunction with improving water quality (see Env. App. CEA Chapter 9, Recreation).

5.6.1.3 Water Quality

Poor water quality limited recreational activities prior to recent improvements brought about by the Clean Water Act and associated enforcement starting in the 1970s. Industrial contamination adversely affected fish populations and led to imposition of fish consumption advisories all along the river. Temporary impacts following wet weather worsened conditions by increasing fecal coliform counts in urban areas. Major spills of oil or chemicals threatened drinking water supplies.

5.6.1.4 Noise Impacts

Noise impacts have historically been associated with general industrial activities such as mining activities, coal utilities, and other river-oriented industries that produced significant, ongoing or frequent noise impacts. Additional noise sources may include construction activity at large project sites such as lock extensions, dam rehabilitation, various other Corps activities, and major construction activity conducted by others. In all cases, the potential importance of noise impacts is a function of the population, including sensitive groups, living in close proximity to the source of the noise.

5.6.2 Recent Conditions and Trends

5.6.2.1 Hazardous Industries, Waste Sites and Spills

1. Certain industrial activities, waste sites, and spill locations have been recorded in one or more databases. These include activities such as hazardous waste generators or underground storage tank operators that require a permit to operate, contaminated sites such as Resource Conservation and Recovery Act (RCRA) listed sites, and sites where reportable spills of oil or hazardous materials have occurred. To obtain a perspective on the distribution of such sites along the full length of the Ohio River, the Corps collected information from all available databases. All records occurring on or within one mile of either bank of the river were selected and mapped.

2. This survey identified 3,579 mapped sites. Most sites are listed by more than one database. For example, site 950 in Pittsburgh includes records for a past leaking underground storage tank, current registration of underground tanks, and a reported spill. As expected, sites are concentrated in urban and major port areas, but numerous sites are present along the length of the river. (See Env. App. CEA Chapter 8, Health and Safety, for an overview of mapped areas, an example detail map, and records for an example site (#950).)

3. The availability of funding for redevelopment of brownfields and other former hazardous waste sites is contributing to reutilization of some formerly abandoned sites. Limited availability of undeveloped land within some areas of the floodplain further reinforces the reuse of formerly developed sites. These abandoned or underutilized sites are representative of historic urban/commercial development patterns and are an important component of many redevelopment programs. Successful redevelopment of such sites should include removal or stabilization of buried contaminants, thus contributing to reduced public health risks.

4. Spills of hazardous or toxic materials are an ongoing problem associated with commercial navigation and river-oriented industry. Activities and areas of particular concern include vessel fueling operations (including midstream), barge loading/off-loading operations, queuing areas and river reaches with heavy debris. Short to long-term impacts are associated with exposure of spills and public drinking water intakes. Spills also may damage or contaminate shoreline areas.

5. Spill records from the Emergency Response Notification System (ERNS) were collected for the period 1990 – 2000 (see Env. App. CEA Chapter 8, Health and Safety).

This database produced 1,700 non-duplicate records for the Ohio River that located the spill event by river mile. These spill events were not randomly distributed along the 981 miles of river, but, as expected, were concentrated in the major port and industrial areas. The 1,700 spill records correspond to just 56 discrete river mile (RM) point locations, ranging from a low of 4 records at Clarksville, IN (RM 605) to a high of 190 at Louisville, KY (also at RM 605). By clustering points that were close together (e.g. RM 602 – 608 for Louisville), spill events could be summarized as just 36 locations along the river. The most frequent spill locations correspond to the

- Follansbee, WV area (75 spills, RM 71-75),
- Yorkville, OH to Wheeling, WV (75 spills, RM 85-90),
- Point Pleasant, WV area (79 spills, RM 265-270),
- Kenova, WV/South Point, OH/Catlettsburg, KY area (182 spills, RM 316-318),
- Cincinnati, OH area (129 spills, RM 468-473),
- Louisville, KY area (234 spills, RM 602-608),
- Owensboro, KY (66 spills, RM 757)
- Paducah, KY (107 spills, RM 935)

5.6.2.2 Recreational Boating Accidents

1. All boating accidents for the six states along the Ohio River totaled 4,955 events for the period 1995-2001 and accounted for 8.8% of all boating accidents nationwide. Accidents occurring on the Ohio River during the same period totaled 295 records, or 4.7% of all boating accidents in the six states. For Ohio River boating accidents, collision with another vessel was the most common event, accounting for 80 accidents or 34% of the total. Other collisions (floating/sunken objects, docks, etc.) or groundings accounted for 47 events (20%), flooding/swamping, or capsizing the vessel accounted for 25 events (11%), and falling overboard or within the vessel accounted for 21 events (9%). Other types of accidents included fire/explosion (8%), sinking (7%), victims in water struck by boat or prop (4%), skier mishaps (3%), and miscellaneous other (4%).

2. The limited years of available data reveal no apparent trend in the annual average number of accidents on the Ohio River. Annual numbers vary widely, from a low of 21 in 1998 to a high of 50 in 1999. Anecdotal comments suggest that high water conditions during peak weeks of the boating season (mid-May through mid-September) significantly reduces the total amount of boating activity and may likely contribute to similar declines in number of accidents in such years. This high annual variability, combined with the relatively small number of annual accidents on the Ohio River, makes it difficult to determine any trends over a limited period of time.

3. Recreational boating activity and reported boating accidents on the Ohio River are highly concentrated on warm season weekends. The months of June through August account for 71.1% of all accidents, while May through September account for 89.7%. Saturday or Sunday accounts for 62% of all accidents.

5.6.2.2.1 Boating Accidents and Barge Traffic

1. Reported recreational boating accidents for the Ohio River from 1995 through 2001 included 9 events out of 235 that involved a commercial vessel. The 9 accidents all involved recreational boats and barge/tow combinations that were underway at the time of the accident.

2. Three of the accidents resulted in 8 fatalities, including one accident that produced 6 deaths. The principal cause of this most serious disaster was listed as restricted vision due to fog and darkness. Improper loading was listed as a secondary factor; the six victims were sharing a 16 to 18 foot open motorboat. The barge/tow was not cited for contributory factors in this case.

3. For the nine accidents, alcohol use was cited as the primary cause of three events and a secondary factor in two additional events. Careless/reckless operation and operator inexperience were each cited as the primary cause of two accidents, while machinery failure and restricted vision were each identified for one accident. Operator inattention was recorded as a secondary factor in three cases and no proper lookout (attributable to the barge operator) was recorded for two cases. Six of the nine cases occurred at night. No case indicated that crowded conditions on the waterway contributed to the accident.

5.6.2.3 Water Quality Health Risks

5.6.2.3.1 Bacteria Contamination and Monitoring

1. To protect human health associated with contact recreation, ORSANCO monitors six urban areas (Pittsburgh, Wheeling, Huntington, Cincinnati, Louisville, and Evansville) five times per month from May – October for both fecal coliform and *E. coli.* A total of 19 stations are monitored near the six urban areas. Additionally, nine water supply utilities perform analysis for fecal coliform bacteria on their raw intake water and provide these results to ORSANCO monthly, bringing the total to 28 stations monitored for fecal coliform.

2. No violations of the stream criterion to protect public drinking water supplies occurred during calendar year 2001(the latest year available). During May through October 2001, however, all six urban areas recorded one or more violations of the contact recreation standards. Of the 28 urban stations monitored, 22 stations exceeded stream criteria to protect human health associated with contact recreation.

3. Records for 2001 reflect the recent pattern for bacteriological exceedances in Ohio River urban areas. Exceedances occur annually in most urban areas and are generally associated with high flow conditions. Combined sewer overflows, leakage and overflow from sanitary sewer collection systems, and urban stormwater runoff are considered the primary sources of these biological contaminants.

5.6.2.3.2 Fish Consumption Advisories

. All six states bordering the Ohio River have consumption advisories in place for certain species of fish from the river. These advisories primarily focus on the potential

presence of certain contaminants and are derived from results of fish tissue sampling conducted by ORSANCO. An advisory committee comprised of state health and environmental quality personnel is convened to discuss the data and assess the need for fish advisories. Fish advisories are then issued, removed or modified by state agency personnel. ORSANCO also facilitates communication among the states to minimize differences in advisories issued for Ohio River fish.

5.6.2.4 Noise Impacts

As stated in section 5.6.1.4 under historic conditions, construction activity in close proximity to sensitive populations, riverfront industrial operations, and highway and rail bridges that concentrate vehicular traffic are ongoing sources of noise impacts. Regulation of construction and industrial activities minimizes most potential conflicts. However, changes in riverfront recreational and residential patterns could be impacted by pre-existing noise sources.

5.7 RECREATION AND AESTHETICS

See Environmental Appendix, CEA Chapter 9 and Exhibit C for an expanded discussion of recreation.

The Ohio River has long been the setting for a wide variety of river-based and shoreline recreational activity. Such activities have contributed to the demand for and continuing development and maintenance of a spectrum of recreation-related facilities, including boat launching ramps, riverfront parks, trail and greenway corridors, marinas and mooring facilities, and floating restaurants. More recently, riverfront settings have become popular locations for sports stadiums, museums, concert venues, casinos, on-shore dining-shopping-entertainment complexes, hotel and convention centers, and residential developments. The limits on recreational opportunities related to the Ohio River do not appear to have been reached, as further enhancement of recreation and tourism oriented facilities still figure prominently in all riverfront planning by individual communities as well as by public/private regionally focused groups along the river. Aesthetics, as a resource, is nebulous to define since it is subjective and changes with the viewer. This report combines aesthetics and recreation since these two resources are so closely related for many recreational activities. Aesthetics as a stand-alone resource, however, is not easily discussed at this level of study particularly since this study does not recommend any structures be moved to new locations. Since the recommendations contained in this report pertain only to rehabilitations and new construction in existing locations, there will be no aesthetic disruptions on a system-wide basis. A more detailed look at aesthetics will be considered at the project-level analysis when recommendations contained in this report are implemented.

5.7.1 Historic Conditions

1. Popularity of the Ohio River as a setting for recreational activity dates back to well before 1920, the beginning date for this assessment. One of the most visible early recreational uses of the Ohio River accompanied the advent of steamboat transportation in the early 19th Century, which introduced luxury travel on the Ohio River for those that could afford it. Later, some steamboats were converted for use as floating entertainment

centers, which offered dining, music, theater and vaudeville, for over a century. The last vestige of this era is the showboat *Majestic*, built in Cincinnati in 1923, (Baldwin, 1981). Now moored at the Cincinnati Public Landing, the *Majestic* still offers a summer theater series on the river.

2. Commercial steamboat transportation declined through the mid 19th century due to competition from the railroads, but the entertainment value of traveling by steamboat survived. Although expensive, vacation travel on steamboats has remained popular into the 21st century. In addition to overnight travel, numerous excursion boats began operating on the river during the 19th century and several continue to offer short dining and sightseeing trips on the river.

3. By the turn of the 20th century, individual and family oriented activities such as pleasure boating, fishing, swimming, and picnicking were all highly popular pastimes on the Ohio River. Before completion of the low-level navigation dams (1929 or earlier, depending on location), summer low water in many areas along the river revealed miles of smooth sandy beaches. On weekends, such beaches were popular sites for family outings, where people could boat, fish, swim, and picnic (Roberts, 1981).

4. As completion of the low-level dams progressed through the 1920s, several factors began to influence recreational activities on and around the river, with changes varying by location along the river. Along the heavily industrialized reaches from Pittsburgh through Wheeling, for example, steel mills, other industries, and railroad lines crowded out residential and commercial uses of the floodplains while also discharging industrial effluents to the river. The combination of pollution and restricted access eliminated most recreational activities and contributed to negative perceptions of the river's recreational potential that persisted well into the 1970s (Muller, 1989). Downstream from the industrialized reaches, acidic discharges from coal mining impaired aquatic life and rendered much of the river unusable for recreation. By contrast, significant recreational activity in the Cincinnati area persisted well into the 1930s and began to recover concurrent with improving water quality during the 1960s. Downstream from Cincinnati and Louisville, rural stretches of the river historically were less impacted by pollution and seemed to persist with less disruption.

5. The river's navigation dams have had mixed impacts on recreation patterns. The low water beaches were flooded and fisheries associated with shallow riffles became restricted to tailwater areas immediately downstream of the dams. Changes in water quality, however, have stimulated the most dramatic impacts to recreational activities. Coordinated efforts to clean up the Ohio River, beginning with the establishment of ORSANCO in 1948 and continuing with the implementation of the Clean Water Act and other important environmental legislation, have contributed to reestablishment of traditional recreational uses of the river, a trend that began in the mid-1960s. This period roughly corresponds to the development of the high lift lock and dam projects that replaced the earlier wicket dams Thus, particularly for the upper and middle reaches of the river, the recovery and expansion of river oriented recreation occurred in the relatively stable environment of the long pools behind the high lift dams rather than in the free-flowing river.

5.7.2 Current Recreational Practices

1. Currently, the Ohio River is a popular setting for a broad spectrum of recreational activities. People living in counties adjacent to the river tend to view this resource as an important contributor to their quality of life and a significant portion of their recreational activity is oriented to the river. In urban areas, interests in the river have contributed to the provision of a wider range of opportunities, including riverfront parks and landings, large marinas, special events, and riverfront dining, shopping, and related entertainments. Almost every large and small community along the river provides some type of facility and event oriented to the river. Urban, small town, and rural settings along the river also serve as regional recreation and tourism destinations.

2. Events that draw large crowds and activities with large numbers participating attract a lot of attention, but solitude and quiet relaxation also are some of the most important values associated with recreation on the Ohio River. People living in urban areas especially appear to value the river as a convenient way to escape and relax.

3. Recreational activities on the Ohio River have grown steadily concurrent with improved water quality and economic prosperity. The primary factors affecting current trends in recreational activity are acceptable water quality, accessibility, maintenance of recreation facilities, and expanding choices.

4. Existing parks and access facilities along the urban pools are heavily used, and new facilities are readily discovered and utilized. Access points and other resources in some rural areas appear to be less crowded. A variety of public agencies and private organizations are actively engaged in development of new riverfront parks, greenways, trailways, boating access, and mixed use urban riverfront projects.

5. The most heavily used areas along the river also are those areas most directly impacted by operation and maintenance of the navigation system. To reflect influences of the navigation system in the context of broad economic forces, as well as to maintain consistency with the scope of other chapters (e.g. Land Use, Health and Safety), counties adjacent to the Ohio River mainstem were defined as the geographic focus for impacts related to recreational activities. Three variables that contribute significantly to recreational activities in a local or regional setting were explored: opportunity, availability, and experience.

6. Employment and income statistics are indicative of socioeconomic trends that contribute to recreational opportunity within a given population. For example, a population with better than average employment and income has more opportunity for recreational activity than a population that is less affluent. Over time, population growth in combination with economic prosperity will contribute to expanding opportunities for recreational activity.

7. Accessibility generally refers to ease of access to a given recreational resource. Individuals living close to the Ohio River have easier access than individuals living an hour's travel time away. The presence of boat launch ramps, community parks, or public access to shoreline fishing sites provides improved access in comparison to areas without

such facilities. The type of facility provided may also differentially benefit certain groups (e.g., boat ramps likely provide little value to hiking/biking interests).

8. The quality of experiences directly influences future recreational choices. Not only are individuals more likely to repeat pleasurable recreational experiences, but they are likely to encourage others through word-of-mouth. The collective activity and experiences of a given population thus can provide a good indicator of both future activity and how the population will respond to changes in the recreational resource.

9. Over the past 30 years or more, the popularity of the Ohio River as a setting for recreational activities has experienced tremendous growth in numbers of participants and scope of activities. Most readily available studies of Ohio River recreation have focused on boating and fishing activities. These studies include recent trends that may be applicable to analysis of the broader spectrum of recreational activities.

5.7.2.1 Recreational Boat Lockage Data

1. The Corps of Engineers maintains records of all boat traffic that utilizes its locks on the Ohio River, including recreational vessels. Lockage records do not directly reflect all boating activity on the river because the relatively large size of Ohio River pools and general availability of access and boater services makes ‘same pool’ boating a feasible option.

2. Total recreational boat lockages at all 20 Ohio River lock and dam projects for the past six years of record indicate that the lock receiving the greatest recreational use is Meldahl, with Markland a close second. Cincinnati is located approximately midway between these projects and the population base there likely contributes to the high recreational use of these locks. By contrast, McAlpine lock and dam is located in downtown Louisville, apparently allowing boaters to launch either above or below the dam and thus minimize use of these locks. The high numbers of lockages at the upper four projects (Emsworth, Dashields, Montgomery, and New Cumberland) reflect boating activity in the Pittsburgh area. Pools at these locations are also much shorter than downstream pools, which contributes to more frequent lockages. Lockage patterns also generally reflect annual variations in recreational boating opportunity associated with weather and water conditions during the May-September peak season.

3. When aggregated for the entire river and tracked for the long term, recreational lockages reflected a steady growth trend for boating on the Ohio River from 1980 through 1988 and almost no growth from 1988 through 2001. The rapid growth of lockage activity from 1980 to 1988 may reflect renewed interest due to improved water quality while the trend from 1988 to 2001 could be influenced by a variety of factors, including annual variations in river water levels, changes in boating travel patterns, or improved availability of launch ramps (which could reduce the need to lock through from available ramps to preferred pools). The latter trend may also reflect that boaters in the region are aware of opportunities on the river and the level of interest has stabilized.

5.7.2.2 Studies of Boat Registrations and Boat Owners

1. Recent annual boat registration data (1996-2001) for states in the Ohio River region generally reflect both the national average boat registrations per capita and the recent national trend towards a slower rate of growth, with an average annual growth for the region of 1.1 percent during the past six years. Growth rates for individual states range from a low of –0.04% for Indiana to a high of 2.8% annually for West Virginia.

2. The Ohio Department of Natural Resources, Division of Watercraft (OHDW) has completed two boating studies that help to illustrate boater activity on the Ohio River (Husak 1999 and ODNR 2003). Although details of these studies are found in CEA Chapter 9, major findings applicable to the Ohio River are presented below:

- The 1999 study showed that of the all boating trips within Ohio, about 8.3 percent occurred on the Ohio River during the study period.

- On the Ohio River, 50% of overnight boats traveled alone while 50% traveled in small groups of two to five boats. The most important destination features for overnight travel include 'suitable draft for boat' and experiencing a 'back to nature atmosphere'.

- Of Ohio boaters in general, Ohio River boaters were least likely to report a need for speed limits with about 58 percent reporting 'no need'. Those reporting 'no need' on other waterways ranged from 15 to 52 percent.

- Ohio River boaters reported a lower satisfaction with the availability of launch ramps compared to boaters using other Ohio waterways.

- Finally, proportionally more Ohio River boaters (48.3%) reported negative impacts from accumulation of silt and natural debris in the waterways.

5.7.2.3 Boating/Fishing Studies

1. The most recent Ohio River boating/fishing studies for which data are available were a 1992-1993 survey conducted by the Ohio DNR, Division of Wildlife (Schell et al., 1996), a 1992 survey near Pittsburgh (TES, Inc. 1996), and a 1981 survey by the West Virginia DNR (Pierce et al. 1983).

2. The primary objective of both the Ohio DNR and West Virginia DNR surveys was to provide direction and prioritization in developing fisheries strategies, resource protection, recreational facilities development, and public perceptions of the resource. Both studies employed aerial and shoreline surveys and were coordinated to insure comparability of findings. Consequently, comparisons can be made for several types of activity on the eight pools addressed by both surveys. One finding of both studies was related to historic water quality and indicated that fishing may require a somewhat higher level of water quality than pleasure boating. Boating and fishing data collected by the ODNR survey in 1993 suggests that urban boaters may be somewhat less likely to include

fishing in their boating activities. The popularity of fishing in the Meldahl pool, located upstream from Cincinnati, may be due in part to boat anglers desire to avoid crowds.

3. The study near Pittsburgh examined and interviewed recreationists on 40 miles of the Ohio River, 14.5 miles on the Allegheny, and 23.8 miles on the Monongahela. The purpose of this study was to characterize and quantify the various recreational uses of the rivers in the study area for planning and managing the future recreational development of the rivers. Among the study's findings were that the relative proportion of boat fishing activity in the Pittsburgh study, 12.7 percent of all boating, may be comparable to the 14.5 percent found on Cincinnati's urban pool by the ODNR study in 1993.

4. Recreational activity on rivers in the Pittsburgh study area was strongly influenced by seasonal weather with about 67 percent of all boating and 55 percent of all fishing activity occurring during the June-August summer season. Despite fairly high catch rates averaging just over three fish per hour, anglers near Pittsburgh generally rated fishing quality as 'poor' (about 38%) or 'fair' (28%), primarily due to water quality concerns.

5.7.2.4 Riverfront Enhancement Trends.

1. Measurable improvements in the water quality of the Ohio River mainstem have led to the rediscovery of the river as an asset to communities along the entire river corridor. During the earlier water quality recovery phase (1970s and 1980s), specific sites began to be developed for recreation and entertainment, for example, riverfront parks, major league stadiums, and riverboat restaurants. Within the past decade, however, riverfront projects have become much more comprehensive in scope. Large and small-scale efforts to integrate residential and commercial development, shoreline and river recreation, heritage tourism, and ecological protection/restoration are underway in many communities along the Ohio mainstem.

2. All three of the river's major metropolitan areas have organizations dedicated to regional visions for the river corridor:

- River Fields, Inc. (www.riverfields.org), the oldest such organization, promotes management, protection and development of land and water resources along both sides of a 50-mile reach of the river near Louisville.

- The Ohio River Way (www.ohioriverway.org), based in Cincinnati, focuses on a 150-mile reach of the river from Maysville in Mason County, KY (RM 408-409) to Madison in Jefferson County, IN (RM 558-559).

- The Pittsburgh Riverlife Task Force (www.pittsburghriverlife.org) was founded in 1999 to develop a compelling vision for the city's waterfront, an area encompassing portions of the Ohio, Allegheny and Monongahela rivers. Concurrently, the Western Pennsylvania Field Institute (www.wpfi.org) supports a program promoting outdoor recreation of all types on and along Emsworth Pool (Ohio RM 0-6.2).

3. Several smaller communities along the river have developed comprehensive planning processes or have implemented plans that combine recreation, heritage tourism

and economic growth. Such efforts have occurred in Wheeling, WV, Marietta, OH, Evansville, IN, Paducah, KY and Southwestern Illinois. Further, many other smaller communities along the river are developing docking facilities, rejuvenating their downtowns, and hosting river-based festivals focusing on regional music, art, food, and other local attractions (e.g., the Superman festival in Metropolis, IL). Widespread Internet access has become increasingly important in publicizing recreation and entertainment offerings of smaller river communities.

4. The Ohio River Scenic Byway (www.byways.org/browse/byways/2286) connects communities and points of interest along the 943-mile north bank of the Ohio mainstem through the states of Ohio, Indiana, and Illinois. Like other routes in the National Scenic Byways system, the Ohio River Scenic Byway markets and promotes all types of recreational, natural, scenic, and cultural features within at least one to two miles of the route.

5. The growth and diversification of recreational activities on the Ohio River have created demands for a variety of support facilities and services. Informal and qualitative data suggest that steady growth is occurring in riverfront dining, camping, marinas, shopping, launching ramps, parks, and related services in response to this demand. Numbers of marinas and public boat launching ramps can be tracked from Corps of Engineers' Navigation Charts for the Ohio River. A review of these charts has shown a 200% growth in the number of ramps between 1976 and 2003.

5.8 TRAFFIC AND TRANSPORTATION

See Environmental Appendix, CEA Chapter 10 for an expanded discussion of Ohio River transportation.

This section considers development of traffic and transportation, especially river related aspects, along the Ohio River. As emphasized in Section 4, the Ohio River is an important artery of the nation's inland waterway system, providing for commercial navigation in the eastern third of the country. To reiterate, the entire Ohio River navigation system consists of the Ohio mainstem and navigable portions of eight tributaries, including the Allegheny, Monongahela, Kanawha, Big Sandy, Kentucky, Green, Cumberland, and Tennessee Rivers. The mainstem serves as a collector of system traffic for distribution points within and outside the Ohio basin. Through interconnections with the Mississippi River and its tributaries, the Ohio River navigation system also has access to midwestern states and deep-draft ports on the Great Lakes and the Gulf Coast. While this section focuses primarily on water transportation, it also summarizes intermodal links with the Ohio River that extend the influence of commerce on the Ohio mainstem far beyond the Ohio basin.

5.8.1 Historic Conditions

Section 5.3 (Land Use) related much of the history of land use patterns to the Ohio River as a primary transportation mode. Therefore, information presented in section 5.3 is summarized herein.

5.8.1.1 Transportation Patterns during the 19th and Early 20th Century

1. Bigham (1998) refers to the Ohio mainstem as the nation's first interstate highway, bringing goods and people to the first western frontier. During the early decades of settlement, the Ohio River provided the primary corridor of transportation, both for immigration of new settlers and for the shipment of regional products**;** consequently, initial settlements within the region tended to cluster along the Ohio River mainstem. Some early riverfront settlements subsequently prospered as hubs or service centers to interior regions accessed overland by horse and wagon, thus representing an early form of intermodal transportation.

2. Development of the Ohio River in the 1800s was limited to the removal of snags, completion of the initial canal and locks around the Falls of the Ohio in 1833, and completion of the first wicket dam at Davis Island, near Pittsburgh in 1885. Inland canals provided the first significant alternative or supplement to river transport, beginning in 1825 with completion of the Erie Canal from Buffalo to New York City. In contrast to conditions of inland rivers of that era, canals provided nearly year-round transportation and the ability to ship products more directly to eastern markets instead of overland from Upper Ohio, Allegheny, or Monongahela ports. On balance, canal development probably supplemented river traffic more than it competed with or replaced river traffic. Steamboats hauled goods to canal terminals on the Ohio River, creating another early form of multimodality.

3. Railroads provided a far more significant level of competition to river transport than did canals and quickly became the primary means of commercial transportation in the region. They provided true year-round transport capabilities, greatly reduced transport times, and could be quickly built to serve any point-to-point opportunity. **T**he first railroad in the Middle Ohio River Valley was completed in the 1840s, connecting Lake Erie with the Ohio River. By 1855, there were 1247 miles of track in the Ohio Valley, virtually saturating rail transport opportunities in the region. (Carlisle & Mulligan 2001). Railroads almost immediately rendered canals obsolete, sometimes laying track beside or over the abandoned canals.

4. Commercial river transport declined at a slow but steady pace in competition with railroads. Inland cities with good rail connections grew substantially. To a large degree, the early river port towns along the Ohio River either prospered or perished with the railroads, depending on their ability to attract rail service. Subsequently, further prosperity came to most towns able to establish railroad bridges across the Ohio River.

5. The latter decades of the 19th century and early decades of the 20th century included the period of heavy industrial development along the middle and upper Ohio River. This development centered on the iron and steel industry in Pittsburgh, with its convergence of raw materials, coal, river water, and rail and river transportation to move materials and produce into and out of the region. During this time, the Ohio River stimulated a variety of transportation and technological strategies that pushed expansion westward and added to the nation's overall prosperity (Bigham 1998).

5.8.2 Transportation Patterns from the 1920s to the Present

1. Commerce on the river grew steadily through the 1930s and 1940s while development of diesel towboats and larger barges created opportunities for larger scale, more efficient movement of commodities. Designed for about 15 million tons of commerce annually, the old locks and dams handled more than 70 million tons in 1954; in addition, traffic moving upstream on the Ohio had nearly equaled that moving downstream. By this time, construction of Emsworth, Dashields, Montgomery and Gallipolis L&Ds during the 1930s had already replaced some old locks and wicket dams on the upper river.

2. Plans to improve system efficiency and accommodate the larger tugs and barges called for reducing the number of dams by building larger dams, referred to as "high-lift" because they created greater pool elevation differentials. Along with the high-lift dams, the Corps added locks with larger chambers adequate to pass larger tows. (Details of the modernization plan, which will be completed when Olmsted becomes operational, are included in Section 4.3.)

3. During the 20th century era of sustained urban growth, rapidly growing cities expanded beyond the river floodplain to higher ground, utilizing mass transit (light rail, bus) and automobiles to connect their expanding fringes with urban riverfront cores.

5.8.3 Current Conditions and Trends

5.8.3.1 Locks and Dams

5.8.3.1.1 Current Design

1. The current configuration of the river, as modified by the pool levels behind the system of high-lift dams, generally provides for navigation of commercial tows as long as 1200' long by 108' wide, although some tows on the lowermost reaches of the Ohio operate in a double-wide configuration of 30 barges (5 long x 6 wide), typical of the larger tows on the lower Mississippi River. Section 4.4 includes additional detail of barge configurations and navigation conditions in the lower river.

2. Section 4.4 also presents details concerning the three broad classifications of the current lock and dam facilities: 1) the 60+ year old upper three structures (Emsworth, Dashields, and Montgomery L&Ds) just downstream of Pittsburgh, 2) the thirteen modernized lock and dam structures constructed between 1954 and 1979, plus R.C. Byrd L&D, where new locks were completed in 1995, and 3) the locks and dams with dual 1200'x110' lock chambers which include Smithland, McAlpine, and Olmsted (under construction). WRDA 2000 Sections 101 (14) and (15) authorized the Corps to extend the current auxiliary chamber at J.T. Myers and Greenup L/D from 600 feet to 1200 feet. These efforts are currently in design stage.

3. Significant delays occurring at various Ohio River locks and dams are linked to lock maintenance closures rather than a lack of total capacity to efficiently accommodate traffic. Lock maintenance closures are scheduled, and shippers receive closure notices well in advance, thereby allowing them to adjust deliveries. Scheduled maintenance

closures typically last from 30 to 60 days and occur mostly on a five- to ten-year maintenance cycle. Unscheduled chamber closures can occur with little or no advance notice, usually when a component of the lock fails, forcing chamber closure. In these situations, shippers have few options other than wait their turn to transit through the auxiliary lock. Both types of closures are disruptive to traffic on the river and result in build up of tows (queuing) upstream and downstream of the L&D. Often, tows may have to wait several days in queue before their turn to lock through the auxiliary chamber and continue their trip.

5.8.3.1.2 Commodities Transported

1. Inland waterways carry 11 percent of commodities nationwide, but account for only 1 percent of freight costs, making inland shipping the cheapest freight mode in terms of average transportation cost per ton-mile (Wilson 2001, cited in Transportation Research Board 2002). Barge transportation also is the most energy efficient mode for carrying large quantities of bulk commodities. A typical jumbo barge (195' x 35') can transport as much coal or grain as 15 rail cars for one-fourth the energy per ton-mile (Huntington 2003). A typical 15 barge Ohio River tow carrying 22,500 tons is equivalent to 255 railcars (two 25 unit trains) or 865 semi-trucks.

2. Commodities transported on the Ohio River system are the products of coal mines, petroleum refiners, stone quarries, cement plants and farms and raw materials for construction companies, steel mills, electric utilities, paper plants, aluminum manufacturers and chemical companies – the foundation of the region's economy. Commodity traffic flow at a given lock and dam is largely determined by its geographic location. The commodity mix consequently influences barge type and tow configuration (USACE 2000).

3. Ohio River mainstem traffic is dominated by coal transport although market patterns have changed in the past several years. There was a 2.8 percent annual increase in coal traffic from 1965 through 2001, but coal traffic slightly declined (-0.3percent) from 1991 through 2001. To some extent, changes in the coal export market account for this decline, which has resulted from increasing competition from other exporting countries and the movement away from coal for environmental reasons.

4. In 2001, 87 percent of traffic within the Ohio River system moved on the mainstem as compared with the entire system, which includes navigable tributaries. Since 1990, growth on the Ohio mainstem has slowed somewhat from its rapid 1940-1990 pace, when it averaged 4.2 percent annual growth. The annual growth rate for the mainstem from 1990 to 2001 was 0.7 percent. Since 1996, total mainstem traffic has stabilized around 240 million tons per year.

5. The dominance of electric utility coal transport on the Ohio River and attention focused on coal by the government and the public are reflected in the Corps' most recent traffic demand forecasts. Because coal is such a dominant factor on the Ohio River, traffic forecasts place special emphasis on utility coal and the sorbent materials (lime and limestone) used for coal desulfurization. While other commodities and barge-served markets face uncertainty, none faces a more uncertain future than coal. Deregulation is affecting the electric utility industry, but environmental regulations, especially regarding

air quality, will be the dominant factor affecting future coal utilization and sourcing by the electric utility industry.

6. Recent trends in the other commodities reflect growth rates exceeding 4.0 percent annually in aggregates, grain, and iron. Aggregates consist primarily of crushed limestone, sand and gravel, and building stone. These comprised the second largest commodity group on the Ohio mainstem in 2001, accounting for 16.9 percent of the traffic. Grain traffic, consisting primarily of corn, wheat, and soybeans, composed 7.4 percent of Ohio mainstem traffic in 2001. In 2000, approximately 71 percent of the grain traffic on the Ohio River system was outbound, primarily for export markets.

7. The iron and steel industry has undergone massive changes in recent decades. Within the Ohio River system, only four integrated steel mills remain in operation. Most iron ore and iron and steel products currently moving on the Ohio River system move from Gulf Coast ports to the remaining integrated mills on the Ohio River system. Detailed traffic demand forecasts for all commodities are included in Attachment 3 to the SIP/PEIS Economics Appendix (USACE-Huntington 2003).

5.8.3.2 Rail

Rail transportation has been important in the growth of the Ohio River valley and is directly related to the availability of raw materials and natural resource commodities. As mentioned previously, rail transportation provides year round operability, which is an advantage to commerce. In some parts of the Ohio River basin, the current rail system lacks the necessary connections with other lines for cost effective transport of goods ,while in other parts rail transportation has been successfully integrated into an intermodal system. Information from the U.S. Department of Transportation's Freight Analysis Framework (FAF) indicated that in the six states bounded by the Ohio River, the amount of freight transported by rail is expected to remain constant or decrease slightly through 2020. West Virginia was the exception where rail transportation of goods is expected to remain dominant through 2020. The FAF also found that 50% of the river terminals have rail access but it is not entirely utilized due to lack of efficient connections.

5.8.3.3 Highway

Highway transportation consists of overland movement of goods and commodities (i.e., in trucks). The higher the value of the commodity, the longer the distances that the commodity is trucked. Raw materials and natural resources are economically transported in bulk via water transport. However, in many instances, highway transportation is utilized to transport the commodities to river ports and terminals and to other facilities after water transport has occurred.

5.8.3.3.1 Historical Conditions

Until the 1960s, rail and river transport were the main sources of transportation of goods and services. With the advent of the National Highway System, truck transportation became more feasible. Goods from river terminals and ports are transferred to other locations via truck transport for distribution.

5.8.3.3.2 Recent Conditions and Trends

1. The Appalachian Development Highway System has developed several highway corridors within the Appalachian region that provide access across and parallel to the Ohio River in West Virginia, Kentucky and Ohio and connections with other large interstate systems. The Appalachian Regional Commission currently provides grants and other monies to promote feasibility studies and construction of intermodal transportation networks, access roads from communities to the existing highway system and completion of the corridor system in Appalachia.

2. Information from the U.S. Department of Transportation's Freight Analysis Framework indicated that highway transportation of freight (i.e., by truck) is the leading mode of transport in the six Ohio River bounded states except in the state of West Virginia. In the agricultural regions of Ohio, Illinois and Indiana, grain transport is conveyed via trucks 95% of the time to other modes of transportation such as river terminals and ports. In the coal regions of Kentucky and West Virginia, over 40% of the overland coal transported to river terminals is accomplished by truck.

5.9 SOCIOECONOMIC PROFILE

See Environmental Appendix, CEA Chapter 11 for an expanded discussion of socioeconomic and environmental justice data for the Ohio River Corridor.

5.9.1 Demographics

5.9.1.1 Historical Conditions

1. Along the Ohio River, there are eight Metropolitan Statistical Areas (MSAs), each encompassing major population centers. The MSAs are: Pittsburgh, Steubenville/Weirton, Wheeling, Parkersburg/Marietta, Huntington/Ashland, Cincinnati Consolidated, Louisville, and Evansville. In addition, there are rural counties adjacent to the river but outside of these MSAs.

2. MSAs along the Ohio River upstream of Cincinnati experienced overall population growth from 1900 through about 1960. Most rural counties upstream of Cincinnati experienced population declines during the same period.

3. Beginning about Cincinnati and continuing downstream to Evansville, there was a consistent pattern of population growth within MSAs and population declines in rural counties over the first part of the 20th century. Rural counties downstream of Evansville experienced population declines throughout this period.

5.9.1.2 Recent Conditions and Trends

1. From about 1960 and continuing through 2000, MSAs upstream of Cincinnati all experienced population declines. With the exception of the area between Parkersburg-

Marietta and Huntington-Ashland, populations in rural counties also declined through this period.

2. Beginning about Cincinnati and continuing downstream through Evansville, total population, both within MSAs and in rural areas, grew overall in the last half of the 20th century. Rural counties downstream of Evansville experience a general decline in population during the same time frame.

3. In the two largest MSAs (Pittsburgh and Cincinnati), a noticeable pattern developed in the last part of this century. In both areas, populations in the central or core county declined. In both instances, there was evidence of population movement from the center to outer parts of the MSA. In Pittsburgh, this out-movement occurred in spite of overall population decline for the entire MSA.

5.9.2 Environmental Justice

1. Environmental justice (EJ) addresses the issue of disproportionate impacts on minority and economically disadvantaged populations. Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," provides that "each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations (EO12898)."

2. The geographic focus for EJ impacts includes those areas most directly impacted by operation and maintenance of the navigation system. In order to reflect influences of the navigation system in the context of broader business and economic forces, as well as to maintain consistency with the scope of other chapters (Land Use, Health and Safety, etc.), counties adjacent to the Ohio River mainstem are defined as the geographic focus for EJ impacts. Where such counties are part of a Census-defined Metropolitan Statistical Area (MSA), all counties in the MSA are included in the geographic focus for EJ impacts.

3. A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. For a detailed discussion of the public scoping process, see the Environmental Appendix, Cumulative Effects Assessment Report Chapter 2 and the CEA Exhibit A on Scoping.

4. Numerous federal agencies have published guidelines addressing EJ issues. Guidance from the General Services Administration (Fact Sheet, GSA) notes that “NEPA provides a major planning context in which EJ issues can be addressed, though such issues should be considered under other environmental review authorities as well (e.g., the National Historic Preservation Act and the Endangered Species Act). The Presidential Memorandum (Executive Order 12898) identifies four important ways to consider EJ under NEPA, which are summarized in the CEQ's EJ guidance (CEQ 1997) as follows:

- "Each Federal agency should analyze the environmental effects, including human health, economic, and social effects of Federal actions, including effects on minority populations, low-income populations, and Indian tribes, when such analysis is required by NEPA.

- Mitigation measures identified as part of an environmental assessment (EA), a finding of no significant impact (FONSI), an environmental impact statement (EIS), or a record of decision (ROD), should, whenever feasible, address significant and adverse environmental effects of proposed Federal actions on minority populations, low-income populations, and Indian tribes.

- Each Federal agency must provide opportunities for effective community participation in the NEPA process, including identifying potential effects and mitigation measures in consultation with affected communities and improving the accessibility of public meetings, crucial documents, and notices.

- Review of NEPA compliance (such as EPA's review under Section 309 of the Clean Air Act) must ensure that the lead agency preparing NEPA analyses and documentation has appropriately analyzed environmental effects on minority populations, low-income populations, or Indian tribes, including human health, social, and economic effects."

5. CEQ's guidance outlines several principles that should be addressed in the course of NEPA review to ensure consideration of EJ, which can be paraphrased (from Fact Sheet, GSA) as follows:

- Consider the human composition of the affected area - that is, its population and how it is used by human communities, and determine whether any such communities are characterized by low-income levels or high-minority composition. If so, determine whether there may be disproportionately high and adverse effects on such populations.

- Consider not only direct impacts on the health and environmental quality of EJ communities, but indirect, multiple, and cumulative effects as well, including effects that are not within the control of or subject to discretionary actions of the reviewing agency.

- Recognize that the cultural, social, occupational, historical, and economic characteristics of an EJ community may amplify the environmental effects of an action. Such a population may be more sensitive to such effects and less resilient in adapting to them, than another community.

- Implement effective public participation strategies that seek to overcome linguistic, cultural, institutional, geographic and other barriers to meaningful participation, and that include active outreach.

6. The Ohio River region has very few counties that exceed state averages for minority populations. In many counties, the percent minority population is only 20 or 30 percent of the state average. Counties that do exceed the state average are generally metropolitan centers such as Cincinnati in Hamilton County, Ohio. Rural counties with above average minority populations include Pulaski County, Illinois; and Hardin, Mason, Meade and Union Counties, Kentucky.

7. Census records were also searched for Native American populations. Through 1980, state and county records identified very few individuals who identified themselves as Native American. The 1990 and 2000 Census appear to be identifying slightly larger populations, which may be the result of more sensitive measuring procedures.

8. Census records for 1970, 1980, 1990 and 1995 were reviewed for people of all ages in poverty, based on Census definitions for the periods studied. Counties were identified for occurrence of high poverty rates if the percent in poverty exceeded 1.5 times the state average or 1.5 times the regional average (average poverty rate for the six state region) for any two of the four periods measured. Counties that exceed twice the state or regional average are also noted. Statewide poverty rates for Kentucky and West Virginia in 1970 exceeded 1.5 times the regional average. Exceedance of poverty levels (state or regional) by 1.5 times was selected as an evaluation factor by the study team to indicate counties in which poverty would be considered severe.

9. Per capita incomes provide an alternative to Census poverty rates for comparison of states, counties and other subregions. Per capita incomes are calculated annually by the Bureau of Economic Analysis (BEA). For the six state region, the population weighted per capita income in 2002 represented 0.981 percent of the national per capita. All states in the region show fairly stable maintenance of their income status relative to the national average, with four states gaining, Ohio essentially unchanged, and West Virginia showing slight decline. Individually, Illinois and Pennsylvania consistently rank among states with the highest per capita incomes, Ohio steadily represents the midpoint among states, and Indiana represents the point at which 2/3rds of the states have higher per capita incomes. Despite significant gains for the past two decades, Kentucky remains in the bottom tier of states while West Virginia's declining incomes keep it very near the bottom for all states. Counties with higher than average per capita incomes along the Ohio River are almost exclusively associated with major urban centers. Of the 5 counties with per capita incomes above the national average, 3 are the core counties for the cities of Pittsburgh, Cincinnati, and Louisville while 2 are adjacent counties within the MSAs of Cincinnati and Louisville.

5.10 CULTURAL RESOURCES

See Environmental Appendix, CEA Chapter 12 for an expanded discussion of cultural resources within the Ohio River Corridor.

5.10.1 Past Conditions

Cultural resources along the Ohio River are rich and varied, reflecting human occupation and significant events in the Ohio Valley over many centuries. Both the prehistoric and historic cultural resources of the Ohio River point to the central role of the river as a transportation artery in sustaining permanent settlements. In both prehistoric and

historic times, human settlements developed along the Ohio River and its tributaries because its floodplains offered rich soils and the river offered food, water and opportunities for trade. Later, the Ohio River and its tributaries were used in relation to early industries, river transportation, and trade routes.

5.10.1.1 Prehistoric Cultural Resources

1. Aboriginal peoples have occupied the Ohio Valley for thousands of years. The earliest known dates for human occupation occur in the upper Ohio Valley where the archaeological records indicates human habitation at least 16,000 years ago (Carlisle and Adovasio, 1982). The prehistoric periods of human occupation of the Ohio Valley are listed in **Table 5-1** through the period of direct contact with Europeans.

TABLE 5-1
Prehistoric Periods through Contact Period in the Ohio Valley

Period	Dates	Hallmarks of Period
Paleoindian	11,000 – 9,000 BP	Highly mobile hunter-gatherers; primarily used stone tools. Clovis (fluted projectile) point is diagnostic.
Archaic	9,500 – 2,500 BP	Divided into early, middle, and late Archaic, with periods distinguished primarily by stone tools, the introduction of horticulture, and changes in burial practices and social structure. Early Archaic is characterized by highly mobile small bands of people, primarily exploiting watercourses.
Woodland	2,500 BP – AD 1650	Effects on the landscape were dramatic due to introduction of agriculture. Early Woodland associated with Adena culture, marked by use of pottery and construction of conical interment mounds. Middle Woodland included socioeconomic integration across regional boundaries via trade networks. Hopewell culture of Middle Woodland was characterized by elaborate geometric earthworks. Late Woodland was associated with large, densely occupied villages on high terraces overlooking the major rivers.
Late Prehistoric	AD 900-1650	Encompasses Fort Ancient, Mississippian cultures, and Late prehistoric occupations leading up to the period of European contact. These cultures were built on a very effective subsistence base. A relatively high density of Fort Ancient sites

		has been recorded in the middle Ohio River Valley.
Contact	AD 1500-1800	By early 16th c., the Ohio River Valley was populated by several sedentary aboriginal groups. It is assumed that even before European contact, human presence in the New World had affected the balance of the ecological system. The Fur Trade Wars (c. 1630-1680) dramatically altered distribution of animals and the Native American population.
SOURCE: *USFWS. 2000. Ohio River Islands National Wildlife Refuge – Draft Comprehensive Conservation Plan and Environmental Assessment., Northeast Region Office, Hadley, MA.*		

2. In addition to sites along the Ohio River, prehistoric artifacts have been found on Blennerhassett Island near Parkersburg, WV, and on other Ohio River islands. A 1998 archaeological and geological assessment of the Ohio River Islands National Wildlife Refuge classified the islands into three different types with regard to cultural resources: 1) islands with sediments having recent origins not likely to contain prehistoric archaeological sites; 2) islands with Holocene sediments likely to contain historic archaeological sites close to the surface and deeply buried prehistoric sites; and 3) islands which contain a core area of Pleistocene sediments overlaid by shallow Holocene age sediments, which are likely to contain prehistoric and historic resources closer to the surface (Diamanti 1998). Information on island formation is relevant to what kinds of prehistoric sites could exist on individual islands.

5.10.1.2. Historic Cultural Resources

1. Archaeologists have worked to reconstruct the cultural and historical threads that knit together the native cultures of the Late Prehistoric and early historic periods in the Ohio River Valley with the more familiar named tribes associated with the historic contact period. The Late Prehistoric peoples of the Fort Ancient Tradition, for example, were once numerous in the Ohio River Valley. However, the rare historical and even more limited archaeological data for the immediately succeeding Protohistoric period, just prior to the time of the first contacts between Native Americans and Europeans, indicate that by A.D. 1650-1700 few Native Americans permanently resided in the Upper Ohio River Valley. In fact, early European explorers and Euro-American settlers coming to the Ohio Valley in the mid to late 18th century found few Native Americans who had been long-time residents of the region. Only small hunting camps and a few villages were found. Hunting parties ranged throughout the area as wild game abounded. Near the headwaters of the upper Ohio, now Pittsburgh, early European surveyors, traders, and settlers encountered members of the Seneca, Delaware, and Shawnee tribes who used the area during hunting expeditions.

2. As the result of the initial exposure to Europeans and diseases from which the native peoples had no natural immunity, all these tribes suffered from disease during the 18th century, which not only disrupted their traditional way of life but also reduced their ability to resist incursions by European settlers (Carlisle and Mulligan, 2001).

3. Islands comprising the upper part of the Ohio River Islands National Wildlife Refuge figure prominently in the early explorers' accounts of prehistoric and contemporary Indians, George Washington's surveying expeditions, the settling of the Ohio River by pioneers and traders, strategic battles during the Civil War, and river exploitation for navigation and industry. Many islands were large enough to be permanently settled or industrialized. For example, Neville Island, about five miles downstream from Pittsburgh, became an active industrial site during the late 1800s.

4. Prehistoric mounds and mound complexes are important features of Ohio River archaeology. As early as 1780, a military party noted the large mounds at the mouth of the Muskingum River, at the site of the future Marietta, Ohio (Carlisle and Mulligan, 2001). Prehistoric mounds and mound complexes also once stood at the location of many other Ohio cities including Circleville, Chillicothe, and Cincinnati, though most were ploughed away in the early days of settlement (Jakle, 1977:71). Extant Ohio River mounds listed by the U.S. National Park Service as National Historic Landmarks include Grave Creek Mound (Moundsville, West Virginia), which dates to 500 B.C. representing the Adena culture and Angel Mounds (near Evansville, Indiana), which date to 1000-1600 A.D. representing the northeastern most extension of the Mississippian culture.

5. During the 18th century various explanations to account for Native American artifacts, trails, and earthen mounds were developed and debated. The architectural complexity and sophistication of the mounds and the numerous abandoned sites across the landscape provided a sharp contrast to the simpler, then current Native American condition, which was interpreted to be the result of a cultural disjunction. Early explorers and settlers were unaware that the comparatively simple bands of migratory native hunters and horticulturists of their own day were the products of more than a century of cultural upheaval, dissolution, and widespread geographical relocation that had been precipitated by the development of sustained European settlement on the eastern seaboard beginning in 1607 and by related socio-political changes within other Native American cultures (Carlisle and Mulligan, 2001).

6. French and British fur traders frequented the Ohio Valley early in the 18th century, but permanent occupation by Europeans did not begin until the mid-18th century when a few isolated military outposts were established in the valley. Three major factors delayed extensive settlement in the Ohio Valley during much of the 18th century: larger ongoing European political struggles; nearly constant hostility between settlers and Native Americans; and the American colonists' struggle for independence from Great Britain. Several cities along the lower Ohio River were founded by the late 1700's including Louisville in 1779 at the Falls of the Ohio, the most significant break in navigation on the river.

7. Following the Treaty of Paris (1783), formally ending the American Revolution, the Land Ordinance of 1785 provided for the administration and subdivision of land in the Northwest Territory, which consisted of land north of the Ohio River, west of Pennsylvania and east of the Mississippi, including all of present-day Ohio, Indiana, and Illinois and parts of Michigan and Wisconsin. Following the Land (Northwest) Ordinance, several important towns and cities were founded in the upper and middle Ohio Valley, including East Liverpool (1797), Steubenville (1798), Marietta (1788) and Cincinnati (1788) – all in Ohio. Wheeling, West Virginia, had been settled somewhat earlier (1770s),

while the communities of Parkersburg and Huntington, West Virginia, both remained small until well into the 19th century. The search for good agricultural land was the major impetus to westward migration and settlement of the Northwest Territory (Diamanti, 1998).

8. The Battle of Fallen Timbers (1794) near Maumee, Ohio and the subsequent Treaty of Greenville were key events leading to the cessation of hostilities between settlers and Native Americans in the upper Ohio Valley and opened the way for more extensive settlement. Other lower Ohio Valley communities were founded during the same era near the confluence of significant tributaries, including the Kentucky communities of Owensboro (late 1790s), Henderson (1797) and Paducah (1795). The second largest city on the lower Ohio for most of its history, Evansville, Indiana, was not founded until 1812. Another major event that opened the way for development of settlements in the lower Ohio Valley was William Henry Harrison's victory over the Shawnee at the Battle of Tippecanoe in Northern Indiana in 1811. The event was a turning point in British-inspired Indian problems since following that battle the confederation of the eastern tribes disintegrated.

9. The banks of the eastern Ohio River became the departure point for many settlers heading into the territory to the west. Flatboats were an important mode of transportation for settlers. The invention of the steamboat in the early 19th century also was highly significant in transforming the settlement of the entire Ohio Valley. Because steamboats were capable of two-way transportation of agricultural products and industrial supplies, they stimulated the economic growth of the region. Louisville became pivotal for the rapidly expanding trade between Pittsburgh and New Orleans, and all points in between, because the Falls of the Ohio remained an obstacle to navigation until a canal around the falls was completed in 1833.

10. Development of communities and trade during the early steamboat era transformed the Ohio Valley within a few decades. Consequently, by the middle of the 19th century, fine homes and public buildings were erected in communities all along the Ohio. Many 19th century buildings have been preserved in historic districts. Several of the finest surviving residences are on the list of National Historic Landmarks (NHL), which are considered to possess exceptional value or quality in illustrating or interpreting the heritage of the United States.

11. The 19th century also witnessed the construction of two suspension bridges over the Ohio that continue to be important as both historic and active transportation resources. The Wheeling Suspension bridge, begun in 1849, was the first bridge to cross the Ohio River, allowing the National Road (which became U.S. 40) to move forward.. An even longer suspension bridge was completed between Covington, Kentucky, and Cincinnati in 1867. Now named the John A. Roebling Bridge, after its designer, the bridge became Roebling's prototype for the Brooklyn Bridge (1883).

12. Throughout the 19th century and during the Civil War, the Ohio River was an important geographic and cultural boundary between slavery and free labor. With its islands, fords and lower water level, the pre-impounded Ohio River offered opportunities for slaves to escape to freedom. Many places on both sides of the Ohio River served as stations on the Underground Railroad.

13. During the 20th century, high-lift dams constructed along its length transformed the Ohio River itself. The decades-long construction process will be completed when the most downstream project, Olmsted Lock and Dam (replacing Dams 52 and 53), is completed in 2011. By raising the level of the river, high-lift dams have inundated fords, portions of islands and mouths of tributaries that were above water during prehistoric and early historic times (USFWS, 2000). The older locks and dams on the Ohio River are of sufficient age to now be eligible for placement on the National Historic Register, thus representing a new generation of cultural resources along the Ohio River's ever-changing mainstem.

5.10.2 Current Conditions and Trends

1. The number of National Historic Landmarks (NHL) and listings on the National Register of Historic Places (NR) for counties along the Ohio River ranges from only one in a rural county of West Virginia to approximately 500 listings in the Louisville region, Jefferson County, Kentucky. Not surprisingly, the highest number of listings on the NR is associated with the most populous areas. Numbers of listings by county also reflect local and state levels of interest, effort, and funding for historic preservation.

2. The National Register also includes the historic districts previously mentioned. Such historic districts have been designated in both small communities and large cities along the Ohio River. The metropolitan counties associated with Pittsburgh, Cincinnati and Louisville have dozens of listed historic districts while the smaller cities of Steubenville, OH (Columbiana County), Wheeling, WV (Ohio County), Parkersburg, WV (Wood County), and Evansville, IN (Vanderburgh County) each have five to 10 historic districts. Other smaller communities and counties that have listed historic districts include Beaver, PA (Beaver County), Belmont County OH (near Wheeling WV), Sistersville, WV (Tyler County), Marietta, OH (Washington County). Huntington, WV (Cabell County), Aurora, IN (Dearborn County), New Albany, IN (Floyd County), Henderson County, KY (Henderson County), and Paducah, KY (McCracken County). Downtown Madison, IN (Jefferson County) is the largest historic district along the Ohio River, encompassing over 1,000 19th century structures.

3. Section 110 of the National Historic Preservation Act requires federal agencies, including the Corps of Engineers, to assume responsibility for preservation of historic properties owned or controlled by them and to locate, inventory, and nominate all properties that qualify for the National Register. Consequently, many of the locks, dams, buildings and equipment originally built by the Corps of Engineers on the Ohio mainstem are themselves considered to be cultural resources. During 1999, the Corps evaluated 70 sites associated with the navigational system along the Ohio River in accordance with National Register criteria related to age of structures, historical importance, and site integrity These sites represent the 51 lock and dams constructed in the first part of the 20th century as well as the 19 replacement "high-lift" lock and dams.

4. To complement this inventory, the Corps evaluated the engineering associated with the lock and dam construction in the Ohio River Context Study (McVarnish 2001). This study described the Ohio River navigation system as a "living laboratory of 20th

century lock and dam technology and concluded that it clearly meets the National Register's Criterion C, which states that structures that embody the distinctive characteristics of a type, period or method of construction are eligible. Because of its extensiveness and complexity, the Ohio River Navigation System pioneered the evolution of several significant areas of engineering, including lock filling and emptying technology; cofferdam technology and; power generation in navigation complexes in the United States.

5.11 SUMMARY OF AFFECTED ENVIRONMENT DISCUSSION

1. The environment affected by the Ohio River navigation system and all other actions – past, present, and future – consists of resources, ecosystems, and human communities collectively referred to as Valued Environmental Components or VECs. Ten VECS were examined during this study, but six received greater emphasis: 1) water and sediment quality, 2) fish, 3) mussels, 4) riparian and floodplain resources, 5) health and safety, and 6) river-based recreation. The four VECS receiving lesser emphasis were 1) air quality, 2) transportation and traffic, 3) socioeconomics, and 4) cultural resources.

2. The thorough examination of the VECs was bounded by both time and space. Temporal boundaries for the study were generally the years 1920 through 2060. However, historical data and anecdotes preceding this time frame were evaluated and included, when appropriate, to provide a comprehensive perspective. The spatial area for ORMSS was defined as the mainstem of the Ohio River and associated 100-year floodplain from Pittsburgh, PA, to Cairo, IL – a distance of 981 river miles (RM). In actual fact, impact areas varied as resource conditions and, in some cases, available data dictated.

3. This brief summary considers the 10 VECs in the sequence as presented in the first paragraph above. However, to gain an accurate understanding of the affected environment, it is important to bear in mind that VECs do not exist in isolation, but are integrated with each other. Recognizing this, the overarching goal of ORMSS has been to provide a holistic assessment of the Ohio River.

5.11.1 The Six Major VECS

1. **Water quality** of the Ohio River has been directly affected by socioeconomic factors and land use, including industrial development and agricultural activities along the river. In turn, water quality has profoundly affected the river's biological resources and recreation. The late 1800s through mid-20th century witnessed a marked degradation of water quality that began to reverse with the establishment of ORSANCO, the implementation of the Clean Water Act and other landmark environmental legislation, and an array of programs and educational efforts that continue into the present. Regarding the river's attainment of designated permissible uses, in 2003, 80% of the river's miles fully supported aquatic life use and 97% of the river's miles fully supported public water supply use. Contact recreational levels are still impaired, attaining fully supported use on 27% of river miles, primarily due to wet weather impacts of combined sewer overflows and nonpoint source pollution. Site-targeted efforts to reduce bacterial pollution from CSOs are needed along with special surveys for legacy-contaminated sediments

2. The decline in **native fish species** numbers and abundances and increase in pollution-tolerant species that occurred through the mid-20th century reflected both adverse water quality conditions and physical changes that occurred as the river was transformed from a free-flowing river to a series of deeper, slower pools created first by wicket dams, then by the present generation of high-lift dams. Declines of fish resources were most severe in the more populous, industrialized upper and middle sections of the river. Fish populations began to recover concomitant with improved water quality such that all portions of the river now support active sports fisheries. Other positive signs for understanding and improving the fish resource include development of the Ohio River Fish Index (ORFIn), and recent research suggesting that dams may inhibit fish passage less than previously thought and that many fish species will use the lock chambers to move between pools. Fish passage research strongly suggests, however, that fish passage through the dams becomes more prohibitive as fish move up the river. There is a highly migratory fish assemblage, often referred to as the Great River Fishes, which has not recovered in much of the river. This group includes species such as skipjack herring, blue suckers, sturgeon species and paddlefish. Since it is uncertain whether the Great River Fishes use the lock chambers to move between pools, but are thought to move through gate openings of the dams to migrate, this assemblage may be disproportionately affected, especially in the upper river. Possibly negative and largely unknown impacts on Ohio River fishes include the recent invasion of Asian carp species, moving upstream from the Mississippi River and continuing threats to native mussels, an important food source for fish.

3. The existing condition of **mussels** of the Ohio River is perceived as so precarious that many activities in and along the river present concerns to their future sustainability. Presently, five Ohio River mussel species are listed as federally endangered and many more species merit special concern both federally and by states bordering the river. In addition to habitat changes caused by high-lift dams, dredging and siltation, and nonpoint pollution, native mussels have been impaired by invasive zebra mussels, inadvertently introduced during the 1990s, and also may be measurably impacted by Asian carp in the future. The ability of the native fishes to serve as the mussel host species, particularly the Great River Fishes, and for those host species to move between pools during the reproductive life stage of the mussel is also a significant issue. Further studies on the population dynamics of these invasive species are needed to ascertain impacts on native mussels. On the plus side is substantial interest and progress in mussel research, including studies related to habitat restoration and mussel propagation.

4. The lack of awareness of environmental services performed by **riparian/floodplain resources (RFR)**, coupled with ongoing floodplain development, especially in the upper and middle river, led to the loss and fragmentation of these valuable commodities along the Ohio mainstem before such resources could be well-documented. However, recent decades have documented an increasing awareness of riparian services, including now regulated wetlands. Establishment of the Ohio River Islands National Wildlife Refuge has focused attention on the disappearance of islands, another unique riparian habitat type. Growing awareness of environmental services performed by RFR, as well as increasing demand for river corridor enhancement and protection may help move RFR toward a more sustainable future. Much will depend upon the establishment and success of environmental regulations and institutional programs, including incentives on privately-owned land.

5. Prior to 1920 and continuing into the 1960-70s, **health and safety** issues on the Ohio River represented a broad spectrum of risk factors related to workplace conditions, spills and discharges from commercial navigation, river oriented industries, and untreated municipal effluent. Little information was available to advise the public of these health and safety concerns. Reduced risks related to these factors have made the Ohio River a safer place to work, live, and play. However, problems associated with exceedances of biological standards, certain contaminants associated with fish consumption, and mixed signals regarding fish consumption standards persist. Possible growth of commercial navigation, water recreation, industries, and other river uses represent continuing challenges. Important efforts required for continued improvement, such as rehabilitation of sanitary sewer systems or reduction of mercury emissions from coal combustion, will require significant long-term investments to achieve results.

6. Prior to 1920, and continuing up to about 1950, the popularity of **recreation** on the Ohio River declined in concert with a degrading environment due to largely untreated and uncontrolled pollution discharges from growing municipalities, mining activity, and various types of industries and land uses along the river. During the past several decades, water quality improvements, combined with increased economic prosperity, have increased the demand for and stimulated the development of marinas, ramps and other recreation facilities along the river that support fishing and boating. Recently, more integrated riverfront planning also has addressed land-based recreation needs along the river and has increased opportunities for an expanded spectrum of recreational choices. A recreation study conducted for ORMSS indicated that although the perception exists that increased participation could lead to overcrowding and competition for limited resources, that perception does not currently seem to be an overriding influence affecting people's decisions to participate in river-related activities.

5.11.2 Additional VECs

1. During the period of rapid population and industrial growth continuing into the 1970s, **air quality** in the Ohio River Valley was in a progressively degrading state due to largely untreated and uncontrolled point and nonpoint pollutant discharges from coal fired power plants, other types of industries, and vehicular sources. Since implementation of the Federal Clean Air Act of 1970 and subsequent amendments, the air quality in the region has shown a steady improvement. Future improvements to air quality will depend on effective air quality monitoring and management efforts, including efforts to establish effective limits for mercury and to continue analysis of the need to control other types of emissions.

2. River-based **transportation and traffic** from 1950 to the present have often been characterized by problems related to construction of new infrastructure, demands that exceeded system capacities at numerous locations, and the use of auxiliary locks during repair and maintenance periods. Because of the navigation system's aging infrastructure, further problems are anticipated unless investments occur. An important future question relates to the effect potentially marked increases in recreational boating may have on Ohio River navigation system operations.

3. After a past characterized by rapid conversion of natural resources and landscapes to meet the industrial and infrastructure demands of a rapidly expanding population and

related volatile patterns of explosive growth and recession cycles, **socioeconomic resources** in the Ohio valley are currently well-developed and stable. In recent decades, improved water quality has enhanced redevelopment interest for many riverfront neighborhoods. Projected slower growth patterns in the future may present opportunities to proceed with gradual and better planned processes of development and redevelopment serving the needs and interests of a stable and established population.

4. The **cultural resources** of the Ohio Valley are rich and varied, including prehistoric sites, historic homes and districts, and sites associated with significant events in American history. Despite the large number of cultural resources, many sites remain unsurveyed. Implementation of cultural resources legislation, including creation of the National Register of Historic Places and establishment of State Historic Preservation Offices (SHPOs), has heightened awareness of the need to preserve cultural resources along the Ohio River. Because of their engineering innovations and age, many components of the Ohio River navigation system are receiving consideration as historic cultural resources.

SECTION 6
OHIO RIVER PROBLEMS, NEEDS AND OPPORTUNITIES

This section begins with a description of the navigation and ecosystem sustainability problems and needs that exist, or that are expected to exist in the future, along the Ohio River mainstem. These problems and needs provide an opportunity to improve the balance of economic and environmental benefits of the system. Various measures to alleviate these problems and address needs are identified and examined. They include both nonstructural and structural measures for navigation, some of which have proven effective in the past and others that are considered to have the potential to address existing and future problems and needs. Also included are descriptions of problems, needs, and opportunities for improving ecosystem sustainability in and along the Ohio River. This section includes the identification of Planning Objectives and the associated planning assumptions and constraints that frame the formulation and evaluation of alternative measures for both navigation and ecosystem sustainability improvements in subsequent sections. This section addresses the first step of the plan formulation process (Section 2.4.1).

6.1 BACKGROUND

1. The Ohio River provides a significant link to the nations' transportation network while at the same time supporting valuable natural resources that should be sustained for future generations. This study strives to balance economic and ecosystem needs of the Ohio River for the overall benefit of the nation for the next 60 years.

2. Economic efficiency is the ability to perform a task in a timely and cost-effective manner. The efficiency of the Ohio River navigation system is measured in terms of the time and cost it takes a vessel to move between points on the river and the cost to operate and maintain the system. Inefficient lock operations are characterized by unnecessarily high delays and can result from insufficient capacity due to a chamber's physical dimensions or unreliability of the physical components.

3. A lock's capacity is largely determined by factors including lock chambers' dimensions; approach conditions, the percentage of empty barges, empty and fill times, and lock availability. Of these, chamber dimensions and lock availability are the most important. Larger chambers can process larger tows in single operations, or "cuts", leading to a greater throughput "capacity", typically measured in tons that could be moved through a project in any given year. Availability refers to the total time that a chamber is "open for business", including those times during a lockage or when sitting idle, or at all times except when the chamber is not available to lock vessels, or "closed". Availability is strongly influenced by lock component reliability (less reliable locks require more downtime for repairs, thereby decreasing availability).

4. Ecosystem benefits are not measured in dollars due to the non-monetary nature of environmental outputs. Rather, ecosystem benefits are more appropriately measured by changes in the ability of systems to function in a self-sustaining, natural manner. Ecosystem sustainability (ES) is determined by assessing the ability of the most sensitive resources to continue to function in a natural self perpetuating manner. As such, indicators of environmental sustainability are measured in terms of technically valid scientific measurements, regulatory thresholds or regulatory protection policies, and composite indices of ecological health. These indicators are specific to each type of resource being evaluated. Examples include measurement of water quality parameters (scientific), compliance with stream use designations (regulatory thresholds), and indices of biotic community health (composite). This study considers the overall results of indicators for each resource category and evaluates the historic, current, and future sustainability of that resource under both the Without-Project and With-Project conditions.

6.1.1 Chamber Dimension Considerations

1. All Ohio River facilities are currently operating with two lock chambers, a main chamber to lock most tows and an auxiliary (usually smaller) chamber available to process recreation vessels or small tows that can lock through in one lockage operation (or "cut") and to process all tows during closures of the main chamber.

2. At all Ohio River projects except the upper three, Emsworth, Dashields and Montgomery (EDM), the main chambers are large enough to process 1200' tows with a single passage. This length was determined in studies for the high lift system to handle the largest barge tows operating efficiently on the Ohio River and adopted for the main lock at each new project. Tows larger than this length sometimes transit the lower river and are forced to reconfigure to transit through the 1200' chambers in a single passage. However, the towing industry has adapted its typical Ohio River barge configuration to accommodate the 1200' chambers. The main chambers at Ohio River facilities typically processes over 90 percent of the commercial tonnage at times when both chambers are available to process tows, reflecting the fact that most tows (barges + tow boat) are larger than the auxiliary locks and are processed much quicker through the main chamber. Processing tows through a chamber smaller than the tow size requires multiple passages, which significantly increases the time to process the tow. The small size of an auxiliary chamber becomes critical when that chamber must be used to service all traffic when the associated main chamber is closed. During these times, lines of tows waiting their turn to lock through form in upstream and downstream approach areas. As the size of the auxiliary chamber at most Ohio River projects, as well as the main chamber at the upper three projects, is smaller than the maximum size tow, their adequacy through the planning horizon is a major emphasis of this study.

6.1.2 Lock Service Availability

1. Locks may be rendered inoperable due to a variety of reasons, including the following categories recorded in the Corps Lock Performance Monitoring System: collision/accident, debris, flood, fog, hardware malfunction, ice, vessel interference, other, rain, river current/out draft, snow, testing and maintenance tow detained by Corps or Coast Guard, tow malfunction or breakdown, tow staff elsewhere occupied, and wind. Many types of interruptions are beyond the control of the Corps, such as fog and other weather-related events[1]. However, closures due to maintenance of lock components typically produce the greatest disruption to service because they are typically the longest in duration.

2. A system of infrastructure as large as the Ohio River system of locks and dams requires frequent maintenance, ranging from small adjustments and repairs to major component replacements. Maintenance actions can be proactive – repair a component before it becomes inoperable (preventative maintenance), or reactive – repair or replacement after a component fails. It is also necessary to take lock chambers out of service and dewater locks at scheduled intervals to allow for inspection and/or to perform repairs or replacements of lock components such as filling and emptying valves and lock gate components. The goal of preventive maintenance is to avoid component failures and the need for lengthy unscheduled repairs. Unscheduled repairs that require closure of a main chamber can be very costly as repairs would be completed under emergency conditions and industry would not be able to prepare for the unanticipated impacts to their operations. There is a trade-off as preventative maintenance increases the up-front costs to operate and maintain a lock, but the payoff is a reduction overall repair costs and navigation delays.

3. Lock and/or dam maintenance, whether minor maintenance (over a few days) or more extensive work lasting several weeks or months to replace major components of the lock chamber, often requires work vessels and procedures that interfere with and delays the passage of vessels through the navigation system. The repair of some components, including concrete lock walls and miter gates, require chamber dewaterings that are not only costly in and of themselves, but incur additional and sometimes much higher costs to industry in the form of added delays when the main chambers must be closed for extended periods and all traffic forced to lock through the smaller auxiliary chamber of any facility. This is particularly critical at locks where the traffic levels exceed the capacity of the auxiliary chamber.

4. As any structure ages, the natural deterioration process dictates that maintenance requirements increase, resulting in more frequent and costly repairs and replacements. In other words, locks become more unreliable with age. Attendant with maintaining an increasingly unreliable lock is more frequent and longer closures of the main chamber. In addition to the costs to complete the work, significant costs in the form of added delays to

[1] The Pittsburgh District Corps of Engineers is partnering with the Port of Pittsburgh Commission on their "SmartLock" project by making lock facilities available at Emsworth, Dashields and Montgomery Locks on the Ohio River for installation of recently developed state-of-the-art navigation technology to assist safe navigation of the lock in low visibility conditions of darkness, fog, rain, and snow. For more info, see the Commission's web page http://www.port.pittsburgh.pa.us/home/index.asp?page=12
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the commercial towing industry are incurred during closures of the main chambers at any project. This has begun to occur on a more frequent basis for Ohio River lock chambers.

6.1.3 Structural Concerns and Reliability Issues

1. Reliability can be loosely defined as a measure of safety or assurance of adequate performance of a structural component. Structural strength properties may also be a function of time, usually in degrading fashion. Structural integrity is adversely impacted by factors including structural deterioration of members due to factors including corrosion and fatigue.

2. The age of a structure is not the only factor in the deterioration process, but the older a structure is the more operating cycles is has undergone, thus, fatigue also is an important determinant with corrosion in the reliability of the lock components such as miter gates, culvert valves, and operating machinery. Increasing age of any lock or dam component usually correlates to increasing levels of deterioration, depending upon prior maintenance levels and repair work. Other factors that impact component reliability include the level of preventative maintenance and repairs and the original design parameters incorporated into the original construction. It is necessary to repair or replace some of these major components at various points throughout the life of any project.

3. When lock and dam facilities deteriorate significantly and/or where opportunities arise to increase operational efficiency, Major Rehabilitation (MR) of the facility is usually considered. By regulation, a MR project:

- ☐ requires approval by the Secretary of the Army and construction **is** funded out of the Construction General (CG) Civil Works appropriation for the Corps of Engineers;
- ☐ requires a minimum of two Fiscal Years to complete;
- ☐ costs over $10.6 million in capital outlays **for inland navigation projects** (in Fiscal Year 200**6**) for reliability improvement projects or over $1.30 million in capital outlays (in Fiscal Year 2005) for efficiency improvement projects. These thresholds are adjusted annually by regulation; and
- ☐ reliability and efficiency improvement projects require, for inland locks, **construction is** 50/50 cost shar**ed** with the Inland Waterways Users Trust Fund (whereas other maintenance is 100% Federally funded from the Operations and Maintenance account).

4. The Corps' experience at Ohio River navigation projects has been that major lock and dam components become a reliability concern when those components are from 40-70 years old (reflecting the "50-year" design life typically ascribed to projects). The aging lock and dam infrastructure is a critical concern since one-third of the lock chambers (excluding L/D 52 and 53) will be beyond their design life as of 2010, the beginning of the study analysis period (based on years chambers became operational shown in **Table 4-2**). Furthermore, nearly all will surpass this design life early in the analysis period. When the reliability of components at a site degrades to the point that replacement is justified, the economics and practicality of "bundling" of multiple components together into a single

major rehabilitation project is considered if it meets the MR threshold requirements. Such projects can save considerable time and money when compared to individual lock component replacements at different times.

6.1.4 Ecosystem Considerations

1. Insufficient lock capacity and unreliable lock performance impose delays to traffic. These delays not only increase economic costs to shippers and the towing industry, but the additional time spent by tows in queue on the river, particularly around the locks, creates negative impacts on the ecosystem as well. This report considers different measures to more efficiently accommodate future traffic demand in an environmentally sustainable manner, both in the vicinity of the locks and along the entire length of the pools. To aid in this effort, cumulative environmental effects are considered in assessing modernization needs in accordance with the Corps' Environmental Operating Principles (EOPs). Key concepts of the EOP Doctrine include:

- Illuminate the ways in which the U.S. Army Corps of Engineers missions must be integrated with natural resource laws, values, and sound environmental practices.
- People everywhere will recognize the Corps roles in, and responsibilities for, sustainable use, stewardship, and restoration of our Nation's natural resources.
- Make evident the connection among water resources, protection of environmental health, and the security of our Nation.
- We can chose to design and act either in conflict with nature or in ways that take inspiration from nature and are modeled after it.

2. While the EOPs were released after the ORMSS was well underway, the Product Delivery Team conducted a review of ORMSS in light of these principles to determine if adjustments were needed to more fully align the study with the principles. This review found that the specific connections between the EOPs and ORMSS are as follows:

<u>Principle 1</u> - Strive to achieve environmental sustainability. An environment maintained in a healthy, diverse and sustainable condition is necessary to support life.

ORMSS – Achieving environmental sustainability is an overarching component of the ORMSS. This study assessed impacts in terms of how each operation, maintenance, or construction measure evaluated in this study affected long-term self-sustainability of the resource base. Any alternative (comprised of a set of measures) that would move a resource toward an unsustainable condition would result in a determination of significant adverse impact. This would require development of a mitigation program that would avoid, minimize, and compensate impacts to restore a desirable level of sustainability. Following release of the EOPs and consideration of their implications for the ORMSS, the study team developed alternatives that incorporated measures needed to improve long-term sustainability of aquatic and terrestrial ecological resources. Implementation of these would constitute a significant beneficial impact and would help to establish and maintain a balance of economic and environmental sustainability.

Principle 2 - Recognize the interdependence of life and the physical environment. Proactively consider environmental consequences of Corps programs and act accordingly in all appropriate circumstances.

ORMSS - Interdependence of life and physical environment was engrained in the assessment of environmental impacts of the ORMSS. The resource categories termed Valued Environmental Components (VECs) considered in the Cumulative Effects Assessment (CEA) for the ORMSS included human resources and conditions as well as ecological resources and habitats. Also, NEPA requires consideration of impacts to the human environment which includes human dimensions as well as natural resources. For all VECs the assessment examined how possible changes to characteristics of the physical environment affected the living resources dependent upon those environments. Further, the development of ecosystem sustainability improvement measures reflects the linkage between promoting a quality environment and the quality of life.

Principle 3 - Seek balance and synergy among human development activities and natural systems by designing economic and environmental solutions that support and reinforce one another.

ORMSS - Balance and synergy among human development activities and natural systems was a cornerstone of the ORMSS through pursuit of both an efficient navigation system and a more sustainable environment. The study sought to incorporate environmental design measures into alternatives to first avoid or minimize adverse impacts while providing for an efficient navigation system into the future. The ORMSS also resulted in establishment of an authorized program in 2000 to restore ecosystems degraded by previous human activities. Unfortunately, the program has not received Congressional appropriations for implementation to date and is now a candidate for de-authorization. The ORMSS developed alternatives to further improve the long-term sustainability of aquatic and terrestrial ecosystems in order to achieve both economic and environmental benefits. To enable follow through on both economic and environmental objectives, a “monitoring and adaptive management” strategy (stewardship program) is recommended as an on-going activity following completion of the current study. This approach would allow the Corps to monitor selected indicators of navigation system performance and environmental sustainability (i.e., keep a finger on the pulse) and to determine and implement adjustments or corrective actions in order to continue on a path toward improved and balanced sustainability.

Principle 4 - Continue to accept corporate responsibility and accountability under the law for activities and decisions under our control that impact human health and welfare and the continued viability of natural systems.

ORMSS - ORMSS not only took a very conscientious approach to compliance with environmental laws and regulations, but went beyond those requirements. For example, though not required by regulation, the study team decided to integrate the SIP/PEIS as a single report. The Corps’ commitment to preparing a comprehensive CEA of all past, present, and reasonably foreseeable actions affecting each resource is further evidence of the commitment to comply with both the spirit and intent of environmental laws. Throughout the study process, environmental considerations were on equal footing with

engineering and economics. The extensive communications, outreach, and public/agency inclusion through the Interagency Working Group (IWG) helped ensure accountability, full disclosure, acceptability, and credibility of environmental considerations prior to recommending or making decisions.

Principle 5 - Seeks ways and means to assess and mitigate cumulative impacts to the environment; bring systems approaches to the full life cycle of our processes and work.

ORMSS – The CEA is the center piece of fully integrating the National Environmental Policy Act into the ORMSS. The study considers the full life cycle of navigation improvements as well as environmental life cycles. Identification of needs for both navigation and ecosystem sustainability ensures long-term economic and environmental sustainability. In performing the CEA, stressors affecting various resources were examined to determine resiliency of each resource and its capacity to withstand further stresses before new activities are implemented. In addition, high priority needs of ecological resources were determined to identify actions that could be taken by the Corps and by others to improve conditions of those resources.

Principle 6 - Build and share an integrated scientific, economic, and social knowledge base that supports a greater understanding of the environment and impacts of our work.

ORMSS - A substantial knowledge base was established during the ORMSS. Examples include mapping of substrate conditions, depths, structure, vegetation, and hydrologic conditions for the entire 981 mile length of the Ohio River for use in a predictive model that evaluates effects of tow movements on aquatic habitats. These and several other types of information that have been developed through the study will prove extremely valuable to many researchers, natural resource managers, students, and decision-makers well into the future. The fish movement studies that have been conducted help answer many questions about how and when fish move from pool to pool on the river and how to manage fish movements to improve connectivity among pools. Compilation of information on past, present and future resource conditions provides a context for researchers and managers to design studies and formulate management actions. Another example of this principle includes compilation of a pool by pool mussel database.

Principle 7 - Respect the views of individuals and groups interested in Corps activities, listen to them actively, and learn from their perspective in the search to find innovative win-win solutions to the nation's problems that also protect and enhance the environment.

ORMSS - Since the beginning of the ORMSS, the IWG has existed to identify issues and concerns that needed to be addressed in the study process and to provide input to the overall scope of the effort. In addition, this group was used to identify data sources and data needs, as well as to design studies and actively participate in assessment of impacts. The group initially was comprised of state and federal agency personnel, but later expanded to include NGOs. In addition to the interagency group, there have two series of scoping meetings along the length of the river, numerous mailings, newspaper articles and press releases, brochures, and other proactive efforts to seek input to the study process. Further, another series of public meetings was held during the public review period on the draft report to solicit the views of the public at large on the findings and recommendations

in the report. Also, an extensive Communications Plan was developed for the study and the SIP/PEIS has a Communications Appendix to accompany the Engineering, Economics, and Environmental appendices. To communicate ORMSS activities, processes, and findings in a broad context, study participants have delivered presentations to numerous audiences and have written articles for publication in peer reviewed journals (see Communications Appendix).

6.2 PLANNING OBJECTIVES

1. Now that the problems and needs to be addressed in this report have been introduced, and several alternative solutions have been discussed, a word is in order about planning objectives. Objectives are defined as those criteria by which one alternative plan is weighed against another. The alternative or alternatives which best meet those objectives, after careful economic, environmental, institutional, and social-impact analyses would be the preferred plan(s).

2. Based on the concerns identified above, three planning objectives are specified for Ohio River Mainstem System Study:

Ensuring Future Navigability – providing appropriate maintenance to existing navigation facilities (lock, dams, and channel improvements) and providing new, improved, or replacement facilities (as justified) to ensure continued and reliable navigation for nine-foot draft vessels throughout the length of the Ohio River.

Improving Navigation Efficiency – exploring various options to schedule and execute maintenance as well as structural options so as to maximize National Economic Development (NED) net benefits – for example, by identifying cost-efficient measures to reduce transportation shipment costs.

Enhancing Environmental Sustainability - identifying means within the authorities of the Corps of Engineers (or other agencies) to minimize degradation of environmental resources which might be caused by transportation or other development, and to improve sustainability of resources in and along the Ohio River. The Corps of Engineers Environmental Operating Principles define environmental sustainability as “a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations.”

6.3 OHIO RIVER PROBLEMS AND OPPORTUNITIES RELATED TO NAVIGABILITY AND NAVIGATIONAL EFFICIENCY

1. There are two general areas of concern and one opportunity area addressed in this SIP Report for Ohio River Navigation Projects:

(1) Insufficient capacity of small chambers (less than 1200' long),
(2) Lock and dam condition and reliability, and
(3) Opportunity for operational efficiencies

2. The primary concerns for the future navigation on the Ohio River mainstem are times when all traffic is forced through the smaller auxiliary lock at any project with a small auxiliary chamber. Deteriorating lock conditions through time will increase the need to close the larger locks and magnify the importance of auxiliary chambers to the overall efficiency of the ORS. Operational measures to reduce congestion could help alleviate these conditions. These problems and opportunities are described in detail below.

6.3.1 Small Chambers

6.3.1.1 Small Auxiliary Chambers

1. Only three Ohio River projects have two 1200' chambers, large enough to accommodate the maximum size tow, Smithland, McAlpine, and Olmsted. The other 14 Ohio River locks and dams below Montgomery, including the R.C.Byrd L&D that was modernized in 1993, have a 1200' long main chamber but a shorter (600' long) auxiliary chamber. At those sites during main chamber closures, the large majority of tows (which are longer than 600'[15]) must break apart and process in two pieces – a double-cut lockage. Double cutting of tows reduces vessel throughput by as much as 50-75 percent, and long vessel waiting-lines (queues) upstream and downstream of the locks develop. Delay costs incurred by commercial shippers can reach into the millions of dollars, depending upon the site, closure duration, time of year, etc. As a consequence of the need for double-cuts through the auxiliary chambers, the capacities of those chambers are considerably lower than the main chambers at the 14 projects (see **Table 6-1**).

2. The three uppermost locks near Pittsburgh - Emsworth, Dashields, and Montgomery (EDM), each have a main chamber measuring only 110' x 600' and an auxiliary lock measuring 56' x 360'. They are the lowest capacity locks on the Ohio River (see **Table 6-1**). The impacts due to main chamber closures at these projects are magnified as all traffic must use the very small 56'x360' chambers. These small chambers can only process one barge at a time. Further, there is a five-cut limit at these three projects during closures of the main chamber. Therefore, larger tows that would require a double lockage through the main chamber require processing in several tows through the auxiliary. A double lockage through the main chamber at these projects normally takes 3 hours, which processes 15 barges. A five cut lockage through the auxiliary chamber takes 4 to 5 hours and can only process up to 5 barges.

3. The impacts of main chamber closures can be seen by considering the data in **Tables 6-2 and 6-3**. The average annual delays in **Table 6-2** are below 40-50 minutes at all new projects for most years. Years of high delays from **Table 6-2** correspond in most

[10]Between 71% - 93% of all traffic locking through any of these 17 sites during 1998-2002 were longer than 600'.

cases to years of main chambers closures noted in **Table 6-3**. For example, in 1994, the Emsworth main chamber was closed during the entire month of November for maintenance. The average delay during that closure for all tows processed was over 26 hours per tow, and individual delays reached as high as 3 days. The average delay during that closure event was roughly about 25 times the typical average delay at Emsworth of 45 minutes or so in years without a main chamber closure. This average delay translated into the increased average delay for the entire year when compared to other years with no main chamber closure. The dramatic reduction of delays at Byrd (formerly Gallipolis) reflects the replacement of the old 110'x600' and 110'x360' chambers with 110'x1200' and 110'x600' locks in 1993.

TABLE 6-1
Ohio River Mainstem Locks
Age, Chamber Dimension and Capacity, 2004 Tonnage
(Million Tons)

Lock		Chamber Dimension		Chamber Capacity			2004
Project	Age	Main	Auxiliary	Main	Auxiliary	Both	Tonnage
Emsworth	84	600x110	360x56	39.4	12.6	45.8	18.8
Dashields	76	600x110	360x56	46.5	12.9	51.7	19.7
Montgomery	69	600x110	360x56	43.9	12.9	47.6	20.3
New Cumberland	46	1200x110	600x110	78.5	44.5	132.9	31.5
Pike Island	40	1200x110	600x110	99.5	47.9	151.2	38.9
Hannibal	33	1200x110	600x110	103.1	52.4	152.1	50.1
Willow Island	33	1200x110	600x110	107.5	54.2	155.1	48.1
Belleville	37	1200x110	600x110	114.6	56.3	167.2	51.4
Racine	38	1200x110	600x110	110.5	54.0	151.1	52.3
R.C. Byrd	12	1200x110	600x110	116.3	55.5	151.0	57.8
Greenup	46	1200x110	600x110	113.3	54.3	144.2	64.5
Meldahl	43	1200x110	600x110	116.3	55.5	151.0	55.3
Markland	46	1200x110	600x110	119.0	57.1	160.5	50.1
McAlpine	44	1200x110	1200x110	120.0	123.0	225.5	52.8
Cannelton	34	1200x110	600x110	124.0	59.0	162.1	56.9
Newburgh	30	1200x110	600x110	135.6	61.7	169.8	67.2
J.T. Myers	30	1200x110	600x110	137.3	63.6	170.6	67.9
Smithland	26	1200x110	1200x110	143.4	132.9	264.4	77.0
Olmsted[1/]	0	1200x110	1200x110	na	na	na	95.0

1/ Currently under construction, 2004 tonnage is for L/D 52.

Table 6-2
Historic Average Lock Delays at Ohio River Projects
(Minutes/Tow)

Project	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Emsworth	33	45	40	180	56	48	63	57	51	40	86	39	52
Dashields	30	32	32	38	30	44	140	37	35	32	53	38	37
Montgomery	40	62	73	73	42	61	50	55	57	57	46	178	33
New Cumber	11	11	13	19	16	15	14	20	15	15	17	74	19
Pike Isl	11	11	14	18	14	15	51	15	15	66	18	23	22
Hannibal	12	13	14	18	14	15	51	15	16	15	21	19	24
Willow Isl	11	12	14	21	17	20	17	21	43	25	25	62	25
Belleville	10	12	13	14	67	30	24	19	21	21	20	21	22
Racine	15	15	68	32	25	24	23	29	24	27	32	30	30
Gallipolis	254	197	---	---	---	---	---	---	---	---	---	---	---
R.C.Byrd (1)	---	---	55	59	35	40	34	38	37	40	35	25	34
Greenup	299	36	41	97	45	45	53	142	140	56	55	46	342
Meldahl	48	43	44	45	38	36	48	50	56	59	95	199	58
Markland	29	31	37	174	46	49	33	35	59	36	58	52	73
McAlpine	62	55	179	68	56	53	437	59	150	87	84	62	51
Cannelton	53	47	53	76	38	40	38	36	86	40	45	40	35
Newburgh	60	26	30	28	23	45	23	24	27	28	47	40	35
J.T. Myers (2)	45	44	45	63	64	44	40	43	40	66	184	32	39
Smithland	9	19	19	18	17	8	9	14	4	2	4	43	68
L/D 52 (3)	186	90	9	152	126	74	134	146	242	183	170	184	29

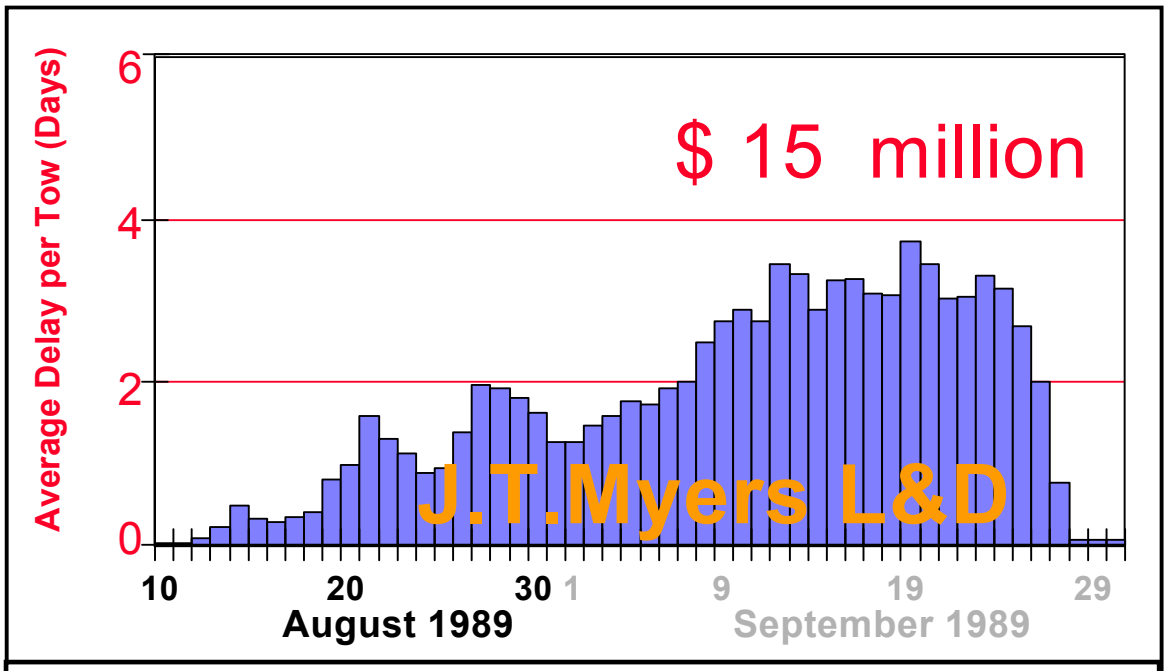
Source: Corps of Engineers Lock Performance Monitoring System Data
(1) In 1993, R.C. Byrd Locks replaced the smaller Gallipolis Locks.
(2) Uniontown L/D was renamed J.T. Myers L/D in 1997
(3) Averaged over all tows using the facility, including those using the navigable pass.

TABLE 6-3
Delays to Commercial Tows During
Recent Extended Ohio River Main Chamber Closures
(1991-2003)

Project	Days of Closure	Number of tows locked	Beginning Date of Closure	End Dates of Closure	Average Delay per Tow (hours)
Greenup	52		9/8/03	10/31/03	
Willow Island	31	367	10/15/02	11/15/02	7.3
Meldahl	42	555	6/17/02	7/28/02	23.3
Montgomery	26	231	6/18/02 & 7/14/02	6/25/02 & 7/31/02	31.4
New Cumberland	54	630	10/17/02	12/9/02	6.7
Myers	24	367	10/9/01	11/1/01	35.6
Emsworth	17	179	11/1/01&11/13/01	11/9/01&11/21/01	17.3
Pike Island	31	429	4/24/00	5/24/00	5.7
Greenup	29	390	11/2/99	11/30/99	21.8
Willow Island	38	420	6/21/99	7/28/99	4.0
Markland	10	119	6/19/99	6/28/99	10.9
McAlpine	16	155	9/13/99	9/28/99	36.5
Greenup	19	285	6/1/98	6/29/98	30.8
McAlpine	29	235	8/1/97	8/29/97	100.0
Markland	40	535	7/18/94	8/27/94	20.3
McAlpine	12	138	11/14/93	11/26/93	55.7
Greenup	32	470	6/10/91	7/12/91	30.9

4. An example of the economic impact of main chamber closure is shown for the 1989 event at Uniontown L/D (now J.T. Myers) in **Figure 6-1**. The average delay per tow waiting in queue reached 70 hours and the total economic impact surpassed $15 million (1999 dollars) of additional costs to commercial tows. These costs only reflect increased wait times spent in queue, and do not include other types of costs that shippers incur, such as diverting shipments to more expensive land based modes to avoid the increased travel time. **Table 6-2** shows that the average delay for Uniontown L/D (now J.T. Myers) that year were increased to over six hours per tow in 1989, eight to nine times greater than the typical delays for this facility. The Corps and industry take steps during main chamber closures to minimize the impacts (see Section 6.3.3); however the effectiveness of these measures is limited as reflected in the large delays that still develop.

FIGURE 6-1
Waiting Time at Myers During 45-Day Closure
Of Main Chamber in 1989



Plot of average waiting time (delay) per locked tow, during a 45-day maintenance event at the Main chamber of Myers L&D, 10 Aug.1989 -25 Sept.1989. All vessels were required to use the smaller Auxiliary chamber. Total cost of delays to commercial vessels was estimated at $15 million (1999$).

5. It is very important to note that the events shown in **Table 6-3** reflect scheduled closures (except McAlpine in 1993) in which industry was provided ample notice ahead of time and adjust operations to minimize the delays associated with those closures[3]. As infrastructure ages, unexpected and unscheduled closures become more frequent. The delays to navigation and the associated delay costs would be significantly increased if the closures were due to unexpected major failures and industry had no advance warning to make alternate plans. The 2003 Greenup Lock closure also involved unexpected emergency repairs. Originally, the lock was scheduled to be closed for an 18-day period for cyclic maintenance. However, during the course of an inspection process, some serious cracking in the lock gates was discovered, and the closure was extended to make the necessary repairs. This closure stretched to over 52 days. Costs to the navigation industry (shippers and carriers) were extensive based on a post-closure survey, estimated over $40 million even with partial information. In 2004 and 2005, damaged lock gates at McAlpine and Hannibal locks, respectively, required unscheduled repairs. Each of these events resulted in total river closure due to on-going construction of the auxiliary chamber at McAlpine and concurrent maintenance of the auxiliary chamber at Hannibal. The Corps took extraordinary steps in each of these events to minimize the duration of river closure. The McAlpine closure was completed and repairs completed in 10 ½ days rather than the

[3] Examples of the ways industry adjusts operations during main chamber closures include pre- and post-closure shipping to build and/or replenish stockpiles, shipping via other routings for all or part of the trip, making deliveries from alternative sources, and rearranging their shipping plans to minimize trips through the projects.

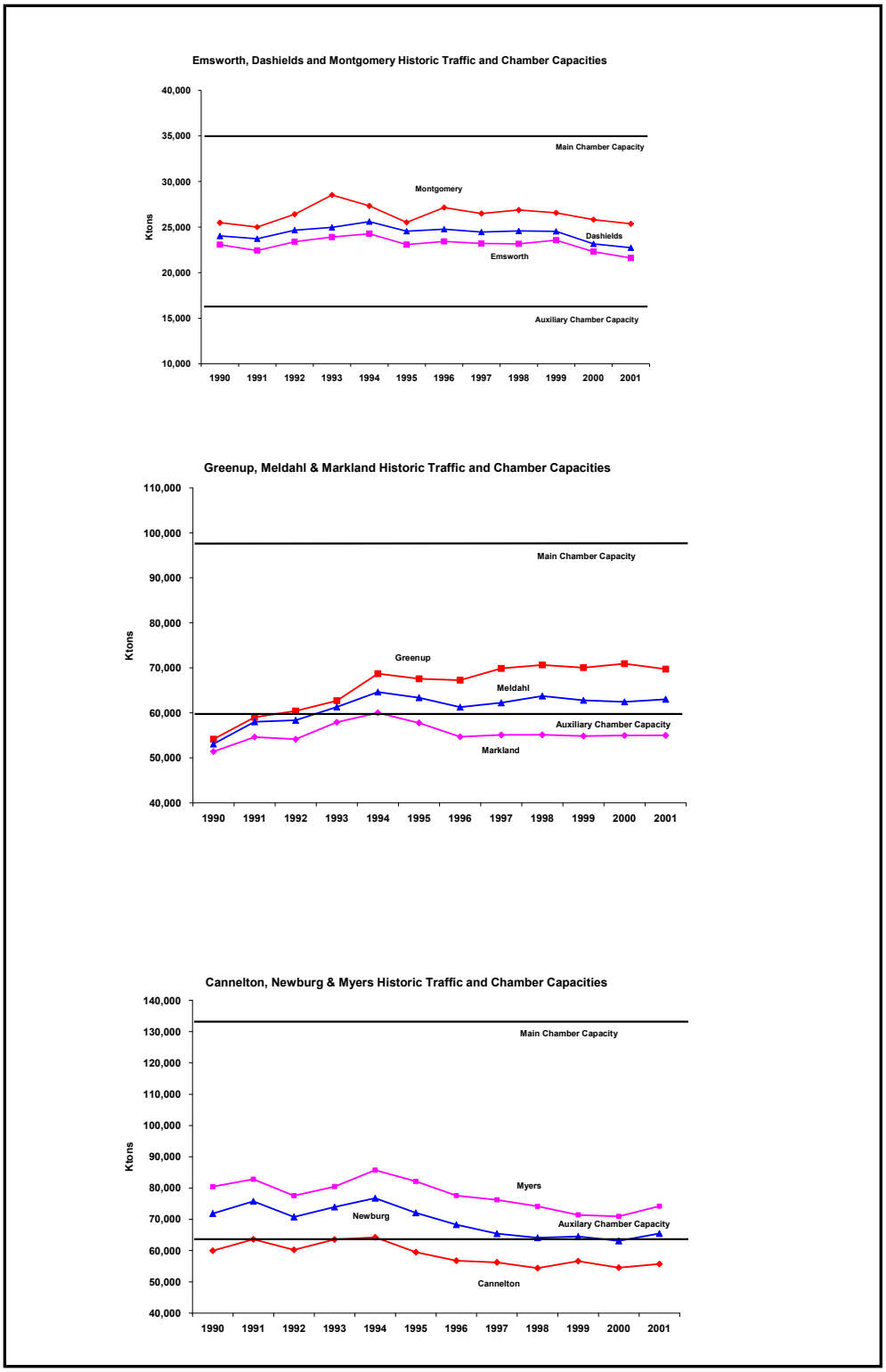
14 days estimated beforehand. However, each still resulted in added costs to industry over and above costs due only to scheduled maintenance.

6. The highest average delays per tow during main chamber closures are experienced at projects where the auxiliary capacities are less than the current traffic levels. This is generally the case since traffic arrivals during main chamber closures approximately equal the rate during typical normal operations, when both chambers are operating, and only lessen when delays become excessive (documented in the Traffic Management Report). Referring to **Figure 6-2**, the three upper Ohio River Locks and Dams are very susceptible to high average delays per tow due to the very small capacity of the auxiliary chamber at those projects. Similarly, the traffic levels at Myers and Greenup are in excess over the respective auxiliary chambers and that excess is greater than at the lower river projects. This explains in part why extensions of the auxiliary chambers to 1200' at Greenup and Myers locks and dams were advanced for project authorization in 2000. These extensions would allow traffic to be processed through a 1200' chamber at all times (unless both chambers are closed) and thereby greatly reduce delays. This study considers the need for larger auxiliary chambers at all facilities that do not have or are not authorized to have twin 1200'x110' lock chambers, or all facilities except Smithland, McAlpine, Olmsted, Greenup, and Myers Locks and Dams.

7. Environmental impacts of barge traffic also increase due to long queues of traffic. Waiting towboats scour the substrate and create suspension of sedim ents, thus negatively affecting water quality. As these towboats idle, there are increased emissions, degraded air quality, and wasted fuel. In the lower Ohio River, tows that "nose-in" to the shore for mooring damage shoreline vegetation, destroy shallow water habitat, degrade mussel beds, erode banks and debase aesthetic values. Increased noise levels can also be experienced.

8. Another aspect of these extended main chamber lock closures is the added number of operations required of tow personnel to accommodate the additional lockage requirements. Tows must be disassembled and reassembled during multiple lockages, which increases the risk of injuries to deck hands. There is increased risk to recreational boaters who must maneuver around tows in queue and possibly simultaneously lock with those tows.

FIGURE 6-2
Recent Ohio River Traffic Compared to Chamber Capacities at Several Ohio River Projects



6.3.1.2 Small Main Chambers at Emsworth, Dashields and Montgomery

Although not a problem at present, the small main chambers at EDM require that all tows greater than 600 feet double cut through those projects at all times. Significant numbers of tows greater than 600 feet long travel through these projects, resulting in additional delays to commercial traffic. From 1991 – 1999, over one-half of all tows processed through Montgomery in each year required two cuts. At Emsworth and Dashields, one-third to one-half of all traffic through the main chambers required two cuts. These chambers also present a bottleneck between the remainder of the Ohio River where the main chambers are 1200 foot-long and the Monongahela River with 720 foot-long chambers. Alleviating this bottleneck would be expected to result in some increase in river traffic as discussed in Section 9. This study will consider the benefits and costs of larger main chambers at EDM.

6.3.2 Lock and Dam Conditions

1. Ensuring future navigability of the existing lock and dam system requires reliable performance. As noted earlier, age is not the only factor in determining lock conditions, but it is telling to note the current ages of the Ohio River Locks and Dams from **Table 6-1**. Replacement of L&Ds 52 and 53 with the new Olmsted project and the new chamber being constructed at McAlpine L&Ds will improve the age situation somewhat, but the condition and the potential need to replace expensive lock components will be a significant concern throughout the 21st century. The ages of the existing Ohio River facilities in 2002 range from nine years at R.C.Byrd to 81 years at Emsworth. Many features at EDM were rehabilitated during the 1980s, yet the condition of concrete and possibly other components remain a significant concern. Just about all of the closure events described in Section 6.3.1.1 are a result of repairing or attending to main chamber components in poor condition.

2. This study evaluates the reliability of all major components, including mechanical equipment and concrete wall sections that are critical to lock operation. The most important lock components were modeled through state-of-the-art analytical engineering reliability methods. A formal two phase screening process was used to determine which components should be modeled using reliability techniques. For more information refer to the Engineering Appendix that details the screening and overall reliability modeling effort. The Engineering Appendix outlines the selection of the components for reliability modeling, as well as the detailed part of the analysis.

3. For all facilities the potential exists for movement (or stability) of individual wall sections, consisting of entire monoliths[4] of a wall, either by sliding or rotating into the chamber. The analysis is covered in the Engineering Appendix in detail, but due to original design safety factors and the load cases examined lock wall stability was a reliability issue only at the EDM facilities.

[4] All lock walls are constructed in individual monolith sections to accommodate joints that allow for expansion and contraction of material, as opposed to one continuous section.

4. The additional concerns at Emsworth, Dashields, and Montgomery involve internal cracks throughout the concrete monoliths that could eventually propagate through entire wall sections and lead to significant movements of monolith sections. A diagram showing failure potential failure scenarios is shown in **Figure 6-3**. A major cause is concrete deterioration. The main cause of concrete deterioration at locks and dams is weathering and freeze-thaw action. Since these three locks and dams were constructed prior to 1950, before the advent of air-entrainment in concrete, the concrete has been particularly susceptible to weathering and freeze-thaw damage.

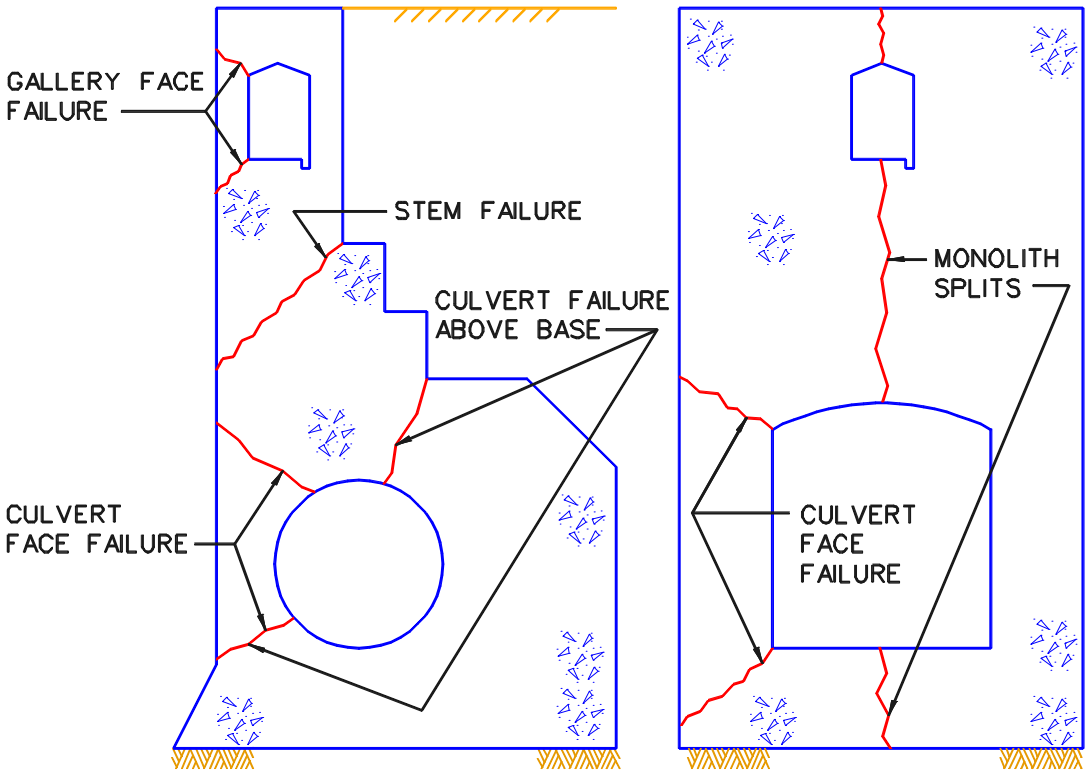
5. There are concerns about the long-term effectiveness of past major rehabilitations on the lock and approach walls at EDM. Prior to the major rehabilitation effort at EDM, horizontal and vertical surfaces of these walls were in advanced stages of deterioration and there were concerns about the stability of various wall sections. Degraded vertical and horizontal faces were removed, and a 12" overlay of new concrete was provided in an attempt to prevent water from reaching the interior concrete and thereby retard deterioration rates. However, field observations at these three projects indicate that water is reaching the deteriorated concrete, causing the concrete to become saturated and susceptible to additional deterioration. There were also stability concerns with the lock chamber walls at each of these projects that were addressed through installation of numerous "passive" anchors in the lock walls to resist movements. Passive anchors only provide resistance after movement of the monolith occurs. Further, these anchors were not designed to provide a long-term solution to wall stability, but were expected to extend reliable stability for at most 25 years. As these rehabilitations occurred during the 1980's, it is anticipated that any significant beneficial effects of the anchors can not be relied on beyond 2010 or so.

6. Following years of different attempts at estimating concrete structural reliability at EDM, including the possible development of analytical models and expert elicitation, it was decided that a condition assessment of these three projects and expert elicitation were the appropriate tools to complete this essential task. In September of 2000 a five-person panel of experts was assembled to estimate the current and future reliability of the structures on the Upper Ohio (Expert Elicitation For Concrete Monoliths at Emsworth, Dashields and Montgomery Locks and Dams, Ohio River). The expert elicitation process established probabilities of failures, the potential consequences for various failure modes and estimated the impacts to the expected service life of several repair or replacement options for concrete wall sections.[5]

[5] For a summary of the EDM Condition Assessment and Expert Elicitation, refer to the Engineering Appendix, Sections …

FIGURE 6-3

Concrete Monolith Failure Modes Considered For Walls At Emsworth, Dashields, And Montgomery Locks.



7. Other specific major reliability concerns at the existing Ohio River facilities are the lock miter gates (Markland, McAlpine, Greenup, and Meldahl) the dam gates, associated operation machinery and scour protection below the stilling basins at Emsworth, and erosion of the scour protection below J.T. Myers dam. Major Rehabilitation and Evaluation Reports (MRERs) have been approved by HQUSACE for the Markland lock gates and the dam gates and scour protection at Emsworth as noted in **Table 3.1**. These problem areas are summarized below. See the Engineering Appendix for more details.

8. The major problem at Markland is the potential loss of service of the main lock due to the condition of the miter gates and the subsequent impact to Ohio River navigation. Major girders in the lock gates at Markland have visible cracks. Serious concern regarding the integrity of the miter gates at Markland arose during a scheduled maintenance dewatering in 1994. This dewatering was scheduled to do major maintenance for the main chamber, including jacking the miter gates and replacing the pintle, seals, etc. However, once the chamber was dewatered and the gates were inspected, severe cracking at several locations was noted. The recommended plan in the Markland MRER includes replacement of the main lock miter gates at the earliest possible time and replacement of the main lock culvert valves at the same time. The lock gates at Meldahl, Greenup, Pike Island and New

Cumberland were designed using similar criteria and were constructed with similar welding methods.

9. The dam gates at Emsworth are difficult to operate and subject to failures of electrical truck mechanisms that guide the gates up and down. Beginning in 1998, operation of the dam gates has been plagued by failures of the bottom truck assemblies. Out of a total of 52 truck assemblies on 13 gates, 16 assemblies on 8 gates have required emergency repairs between 1998 and 2001. Sections of the scour protection installed during the Major Rehabilitation in the 1980's have already been damaged. Left unchecked, the dam apron and stilling basin could have been undermined which in turn would have threatened the integrity of the entire gated dam structure. The Emsworth Dam MRER recommended replacement of 13 dam gates on the main and back channel dams and reconstruction of the scour protection below each dam. The Pittsburgh District began Preconstruction Engineering and Design studies in 2004, with replacement of gates on the back channel dam scheduled to begin in 2006. All gate and stilling basin work at both dams is scheduled to be completed by 2011.

10. There is considerable erosion of the original concrete slab stilling basins, dam piers, and baffle blocks just downstream of the J.T. Myers dam. Recent hydrographic surveys and dive inspections, combined with underwater sonic camera imaging, have indicated some large holes in the stilling basin slabs at various locations. Continued erosion will not only render the dewatering system ineffective, but also threaten the overall integrity of the dam. In addition, there are other areas of concern regarding the condition of the dam including the dam tainter gate trunnion anchorages, the tainter gate cable connections, and mechanical/electrical equipment. The MRER for J.T. Myers dam was completed in July 2007 with a projected completion date of 2008.

6.3.3 Operational Efficiency Opportunities

1. The capacity of any project can be enhanced through more efficient operation, or "traffic management" measures. Traffic management is a fairly inclusive term encompassing all waterway transportation nonstructural alternatives. These relate to technical measures that increase the throughput of the system of locks and dams, as well as those measures that provide the lowest cost to users who value the system most. The first group of measures can be thought of as supply management and the later as demand management. Examples of supply management include tow sequencing lockage policies, the use of tow haulage equipment, and helper-boat operations. Each increase the throughput of the lock over processing tows on a first come first served policy. Demand management policies seek to alter shipper behavior either by making user costs more closely approximate the true economic cost of using the transportation system or by educating users on the external costs so they will act as though the external costs are reflected in the price. Examples of demand management include tow size restriction, traffic scheduling, congestion fees, and tradable lockage permits.[6] These measures do not

[6] Much of the literature on demand management of transportation systems is concerned with overland modes, most notably highways where external costs – accidents, road wear, congestion, noise, pollution, degraded living conditions in communities – are judged to be significant and not reflected in the cost of the highway system, therefore leading to over-consumption of this service. In this literature, the goal is to offer competition, choice, cost-based pricing (unless subsidy is justified) and economic neutrality. Waterways are regarded as a means of offering choice and competition in the movement of freight.

increase throughput, but do offer the potential to lower traffic delays by moving shippers away from congested shipping periods, which on the Ohio River System occur during unexpected lock chamber outages due to accidents, weather, or lock equipment malfunctions, or during planned lock chamber closures for repair or preventative maintenance. An objective of this study is to identify such measures that will ensure the most efficient operation of the ORS during all times, including those times when a main chamber is closed.

2. As previously discussed, the greatest delays to navigation occur during closures of main chambers. Both the Corps and industry take steps to minimize the adverse economic impacts of added delays during these times. The Corps attempts to reduce delays during main chamber closures in a number of ways. One is to meet with industry well in advance of any lengthy closures to discuss particular concerns involving the specific work activities and coordinate operations with navigation requirements as practical. During the closures, the Corps adopts an N-up/N-down lockage policy after queues of tows develop on both sides of the lock. N-up/N-down policy saves time over the "first-come-first served" policy used during most times when both chambers are operational for appropriate values of "N"[7]. For most Ohio River projects, N is set at 6, except at EDM where N is set at 3 since each tow is limited to 5 cuts through due to the extremely small size of the auxiliary locks. This arrangement is coordinated with industry before each extended main chamber closure. Industry also helps during these times of heavy congestion through a voluntary self-help program where towboats assist tows moving in the opposite direction by pulling out the unpowered cuts from the auxiliary chamber which in turn reduces the total lockage times. Pleasure boating is discouraged during main chamber closures but recreation lockages during these times are made when possible.

6.4 PROBLEMS AND OPPORTUNITIES RELATED TO ENVIRONMENTAL SUSTAINABILITY

1. Problems and Opportunities addressed in this SIP/PEIS report for environmental sustainability can be characterized as:

(1) Ensuring factors adversely affecting long-term sustainability of environmental resources are identified, controlled and addressed; and
(2) Identifying ways to enhance sustainability of aquatic and riparian ecological resources.

2. As stated in Section 6.2, one of the three main objectives for the ORMSS is to enhance Environmental Sustainability through identifying means within the authorities of the Corps of Engineers (or other agencies) to minimize degradation of environmental resources which might be caused by transportation or other development, and to improve

[7] Due to characteristics that may vary from lock to lock, the time required for a "turn back" lockage (or lockage in the same direction as the lockage immediately preceding it) may be less than the time required for locking succeeding tows in the opposite direction. N-up/N-down takes advantage of that time savings by locking N tows in one direction, then N tows in the other, when there are queues on either side of the lock.

sustainability of resources in and along the Ohio River. The Corps of Engineers Environmental Operating Principles define environmental sustainability as "a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations."

3. This section provides an overview of the study processes and presents areas of environmental concern. Section 6.5 includes more detailed information on opportunities and tools for addressing these concerns.

6.4.1 Identification of Environmental Sustainability Concerns and Opportunities

1. In accordance with the Council on Environmental Quality (CEQ) guidance, the CEA developed for ORMSS assessed the full direct, indirect, and contributed impacts of future modernization of the Ohio River mainstem navigation system on ten valued environmental components (VEC): water quality, fish, mussels, riparian/floodplain resources (RFR), air, health & safety, recreation, transportation & traffic, socioeconomics, and cultural resources. These assessments can be read in more detail in Section 10.2.2 of this report and in their entirety in the Environmental Appendix. The CEA holistically assessed the environmental sustainability (ES) of each VEC as an "ultimate test" for determining the significance of cumulative effects. The resulting ES findings and the actions subsequently identified form the basis for identifying problem areas and potential opportunities to address them.

2. To determine ES status, it was necessary to define ES categories. The general template used is as follows:

- Not sustainable (NS) – The composite conditions of the selected indicators do not reflect conditions that can sustain the resource over the long-term.

- Marginally sustainable (MS) – The composite conditions for the selected indicators are such that the resource can be sustained for the majority of river miles in or along the Ohio mainstem, but conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences.

- Sustainable (S) – The composite conditions of the selected indicators reflect sustainability for essentially all the river miles in or along the Ohio mainstem. Further, conditions of the indicators exceed regulatory thresholds and pertinent governmental programs are in place to support the resource.

3. ES categories of the various VECs were derived by combining the best professional judgment of the study team and from information developed by IWG members on the cumulative effects of multiple actions (i.e. Reasonably Foreseeable Future Actions, or RFFAs) as manifested through information available on indicators selected for each VEC. Although ES categories are somewhat qualitative, they are based on thorough analyses of past and present conditions as well as future conditions related to trends, plans, laws, regulatory programs and other sources of information.

6.4.1.1 Environmental Sustainability of Priority VECs

1. Of the ten VEC chapters described above, ongoing analysis and review discussions identified six that were of higher priority: Water and Sediment Quality, Fish, Mussels, Riparian/Floodplain Resources, Health and Safety, and Recreation. Reasons for assigning higher priority to these VECs included: relative importance or value of the component (e.g., water quality is essential to aquatic life, recreation and other uses), sensitivity of the VEC to ongoing factors affecting the sustainability of the component and sensitivity to changes related to commercial navigation on the Ohio River.

2. These priority VECs also displayed significant interdependencies or sensitivity to related influences. In this context, ES values of certain VECs become important "drivers" that influence ES values of other VECs in the overall system. Most notably, dramatic improvements in ES of the Water Quality VEC, have driven the other components of the aquatic ecosystem of the Ohio River toward increased ES. The ES of fish has measurably improved, while ES of riparian resources and mussels have benefited to a lesser extent. Cleaner water and improved aquatic resources in turn have enhanced recreational boating and fishing on the mainstem and stimulated growth of related support facilities such as marinas. Cleaner water nationwide also has contributed to a trend toward increased development and use of trails, greenways and other recreational facilities along rivers, including the Ohio mainstem. Such recreation facilities often stimulate riverfront development, including restaurants and entertainment districts, which add to local economic growth, but concomitantly contribute to loss of RFR and cultural resources.

3. H&S represents a VEC with improved ES in recent decades (due to improved water quality and more stringent workplace regulations), but with the potential for its ES to be driven downward by complex interactions with other VECs. Possible growth of commercial navigation, recreational activity, river-oriented industries, and other river users will require vigilance in management and regulation of H&S issues just to maintain the status quo.

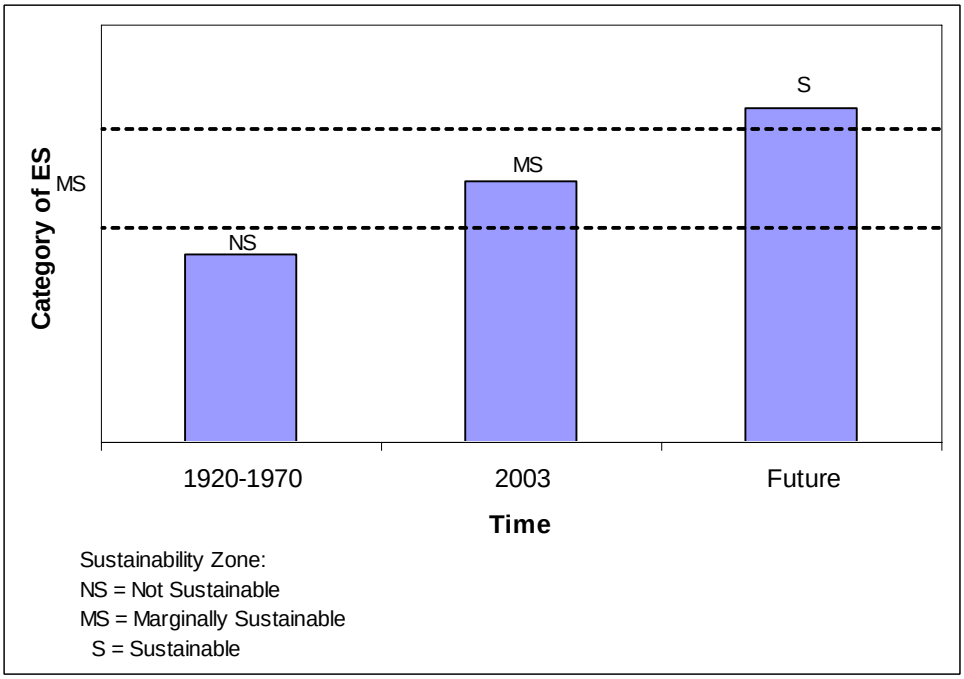
4. ES values of RFR and mussels are particularly confounding in part because of somewhat limited knowledge of these VECs. Regarding RFR, lack of knowledge until recently was correlated with the relatively low value assigned to these resources. Although interest in RFR has increased, these resources present a challenging complex of biogeochemical, hydrological and ecological processes. Similarly, Ohio River mussels are challenging to study, despite the fact that information on Ohio River mussels has been collected since the 1800s. Scientists studying mussels are hampered not only by lack of knowledge of reproductive cycles and habitats needs, but also by increased water depths due to impoundment of the river. Figures 6-4 through 6-9 below summarize the past, present and future ES conditions of the six priority VECs.

6.4.1.1.1 Water and Sediment Quality VEC

1. Due to the programs of ORSANCO, and requirements of the Federal Water Pollution Control Act (FWPCA) (and the amended Clean Water Act (CWA)), the water quality of the Ohio River has shown a steady improvement in recent decades. For example, DO concentrations are typically above the 5.0 mg/L standard, pH levels are between the 6.0 to 9.0 standard, and nitrogen concentrations meet current water quality criteria. However, continuing concerns include bacterial contamination primarily associated with non-point source (NPS) pollution downstream from major urban areas, legacy "contaminated sediments" in the upper river, and fish consumption advisories throughout the mainstem. Accordingly, although there are many positive signs, the ES of the water quality VEC is classified as having improved from an historic status of "unsustainable" to the present status of "marginally sustainable".

2. Regarding the future, it is expected that water quality of the Ohio River mainstem will further improve with continuation of source control and other pollution reduction programs. Therefore, it is anticipated that the ES of water quality will achieve a "sustainable" condition. However, vigilant efforts are still needed to continue effective water quality and aquatic ecological monitoring and management efforts. Actions expected to be beneficial to water quality in the future include implementation of nonstructural navigation improvements and technological improvements related to communications and more environmentally-advanced barge design. Activities that support commercial navigation (e.g. port development and maintenance dredging) will continue to be scrutinized by regulatory agencies and nongovernmental organizations (NGOs) and may be more strictly regulated. Much development activity, however, will involve conversion of existing floodplain lands that now afford habitat protection, open space and ecosystem values. Once converted, such lands are unlikely to revert to their former more natural states. Increasing emphasis on pollution prevention, erosion control best management practices (BMPs), and implementation of the Phase 1 and 2 National Pollutant Discharge Elimination System (NPDES) programs could counteract some adverse impacts, particularly in more urban areas. In general, several regulatory initiatives in recent years should measurably improve water and sediment quality, but it is not possible to predict the magnitude of their beneficial effects.

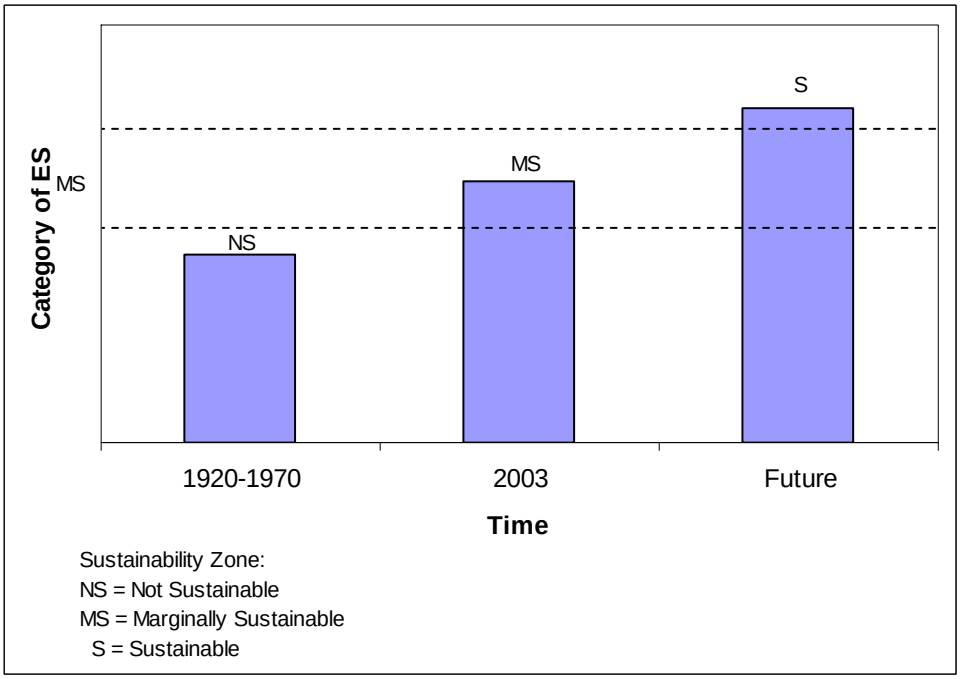
FIGURE 6-4
ES of Water Quality



6.4.1.1.2 Fish VEC

1. Prior to1920 and continuing well into the mid-20th century, fish communities became severely degraded, especially in the upper and middle reaches of the river, as reflected in the decline of many native species and the increase in pollution tolerant species. From the mid-20th century until the present time, improvements in the sustainability of the fish resource have been observed throughout the mainstem. Such improvements have resulted primarily from initiatives by ORSANCO, efforts of the six Ohio River states, and the requirements of the Federal Water Pollution Control Act (FWPCA) and the amended Clean Water Act (CWA). Concurrent with improvements in water quality, however, has been the continued inundation of fish habitat and impediments to fish passage not only from navigation structures constructed before 1950, but also from continuing construction and operation of additional high-lift dams. The modern navigation system, combined with land use and flood control practices in the watershed, has caused the inundation and siltation of extensive areas with gravel substrate, preferred by many migratory fishes. Also, the barriers to fish migration created by the dams may have disproportionately affected the native migratory fish that have not been documented to use the lock chambers to move between pools. This fish assemblage, referred to as the Great River Fishes, has not recovered and represents a subset of the fish resource that is currently at less than a sustainable condition. Two major uncertainties emerged during the last decade that may affect the fish resource into the future: 1) the invasion of four Asian carp species and 2) the invasion and unknown population dynamics of zebra mussels, which seriously impact native mussels, an important food resource for many fish species. Accordingly, the ES of the fish resource as a whole at present is classified as having improved from “unsustainable” to “marginally sustainable.”

FIGURE 6-5
ES of Fish Communities

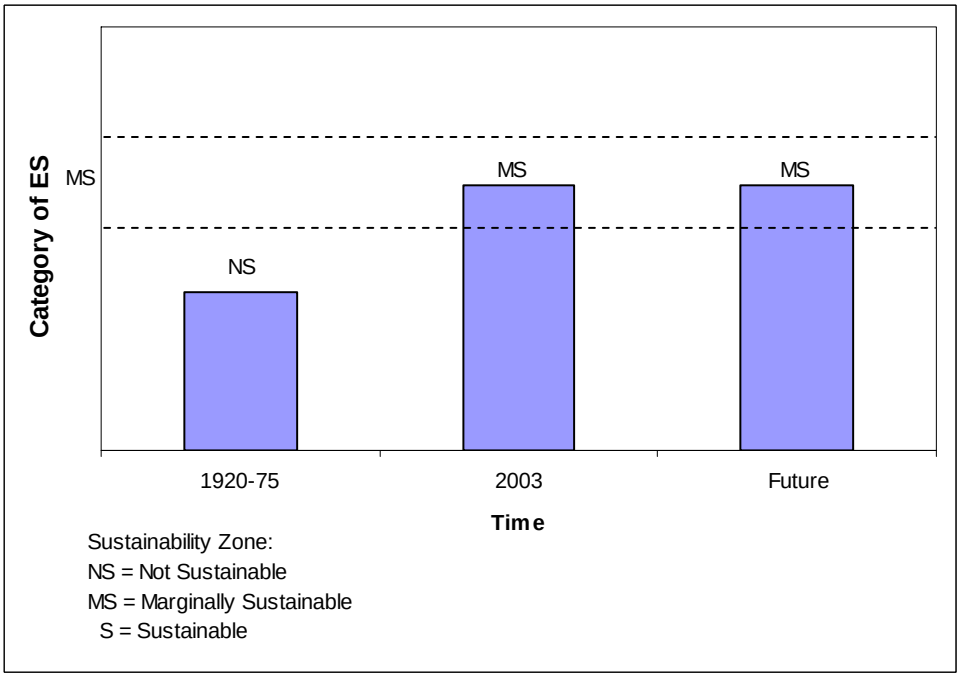


2. Regarding the long-term future, regulatory requirements and pollution control programs have been implemented that will benefit the fish resource, if continued into the future. Given recent improvements in the resource, the development of new assessment tools, and the level of stakeholder interest, it is expected that fish communities of the Ohio River mainstem will attain a "sustainable" condition and may further improve with long-term elimination of combined sewer overflows and better nonpoint pollution control. The habitat effects of impoundment of the river are expected to persist into the future, but ecosystem improvement measures may counteract such effects and to produce habitat benefits and enhance interpool connectivity. Concerning the Great River Fishes, for which the future sustainability is uncertain, removal of migratory barriers through operational or structural measures would be an important contribution toward improving their status. Fish passage strategies will be studied at site specific projects recommended in this study to address the sustainability goal for this assemblage.

6.4.1.1.3 Mussels

1. In the time period from 1920, and continuing up to the mid-point of the last half of the 20th century, the ES of freshwater mussels in the mainstem was in a continuing decline and thus classified as "not sustainable". Numerous actions contributed to the decline, including, but not limited to, acid mine drainage in the upper river, high-lift locks and dams disrupting mussel and fish-host migration, numerous discharges of untreated to partially treated municipal and industrial wastewaters, in-stream sand and gravel mining, dredging for new ports and terminals, periodic maintenance dredging for the navigation system, mussel harvesting for button manufacturing and the cultured pearl industry, and multiple land use changes resulting in increased nonpoint source pollution.

FIGURE 6-6
ES of Mussel Resources



2. In the time period from 1975 up to 2003, some improvements in sustainability of the mussel resource in the mainstem were noted, although improvements were typically localized and exhibit frequent fluctuations. Conversely, there has also been a general reduction in number of mussel beds since about 1975. Improvements that have occurred resulted from 1) reduced acid mine drainage in the upper river, 2) enhanced treatment requirements for municipal and industrial wastewater treatment plant discharges, 3) consideration of mussel bed locations in river-related permitting programs (e.g., Section 404 and Section 10 permits) and navigation system operational features (location of queuing and barge fleeting/storage areas, and placement of dredged material), and 4) protection provided through designation of several mussel species as threatened or endangered under the Endangered Species Act (ESA) and similar state protective mechanisms. The current designation of "marginally sustainable" is appropriate considering that composite conditions for the selected Ecological Sustainability indicators are such that diverse mussel populations are occurring only along some segments and in some pools of the river and that conditions of the indicators are somewhat tenuous both in location and likelihood of occurrence. The conditions also reflect a continuing level of uncertainty regarding appropriate quantitative measures of the Ecological Sustainability of freshwater mussels.

3. Regarding the future, as additional regulatory requirements and pollution control programs are implemented, mussel habitat conditions should be more conducive to reproductive success and community connectivity than at present. Of particular importance is the need to integrate considerations of mussel beds and the life cycle features of mussels into permitting and other locational decisions within or along the mainstem. As further mussel monitoring and research is conducted, these data should be added to

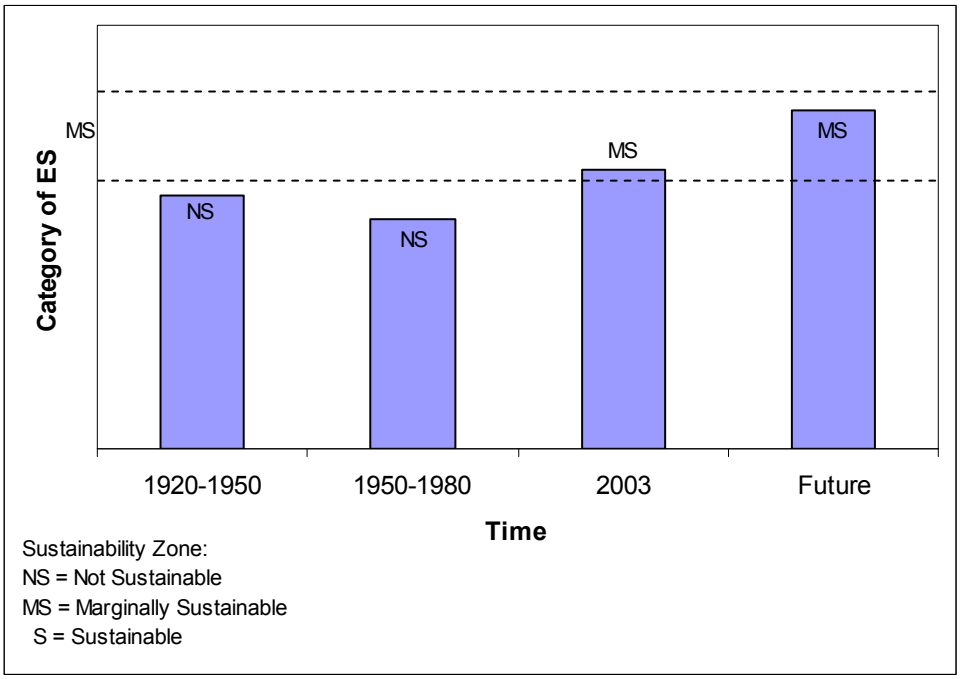
existing databases to provide further information for both protecting and promoting mussels. Equally as important is developing operational and structural strategies for fish passage through the navigational structures to allow fish hosts to freely move between pools for the purpose of recolonizing mussel beds and increasing numeric abundance. Further, consideration should be given to implementation of an integrated adaptive management program for the Ohio River freshwater mussels. This assessment of future marginal sustainability acknowledges that many unknowns remain and that recovery of the Ohio River mainstem native mussel populations will be a long-term process involving many years of collaborative efforts and monitoring. One of the major unknowns is the effect zebra mussels will exert on native mussels in the future. Evidence of recruitment and population stability is necessary to validate viability.

6.4.1.1.4 Riparian/Floodplain Resources

1. In the time period prior to 1920, and continuing up to about 1950, the riparian/floodplain resource (RFR) can be classified as "not sustainable" due to relatively rapid losses of riparian habitats and their functions, the lack of knowledge of the importance of these resources to both terrestrial and aquatic ecosystems, and the essential absence of any institutional programs to manage or control riparian areas. In the time period from 1950 to 2000, worsened "not sustainable" conditions occurred in the first several decades as a result of still more disruptions and losses of riparian areas. However, recent decades have included an increasing awareness of riparian services, including regulation of wetlands, a highly productive riparian component. The establishment of the Ohio River Islands National Wildlife Refuge has focused attention on the disappearance of another riparian habitat type, islands, and has heightened visibility of the riparian resources of the Ohio mainstem embayments. These initiatives suggest the current status of RFR may be moving toward "marginally sustainable." Accompanying these initiatives is an increasing recognition that institutional programs must be established to protect RFR.

2. Regarding the future, the growing awareness of environmental services performed by RFR such as flood risk reduction downstream and reduction of stream bed scouring for mussels, as well as increasing demand for river corridor enhancement and protection for passive recreation may help move RFR toward a more sustainable future. However, it is less certain if environmental regulations and institutional programs will be in place to support RFR sustainability and stem fragmentation and loss of RFR from development along the Ohio River mainstem. Accordingly, the future ES of RFR is classified as "marginally sustainable."

FIGURE 6-7
ES of Riparian/Floodplain Resources



6.4.1.1.5 Health and Safety

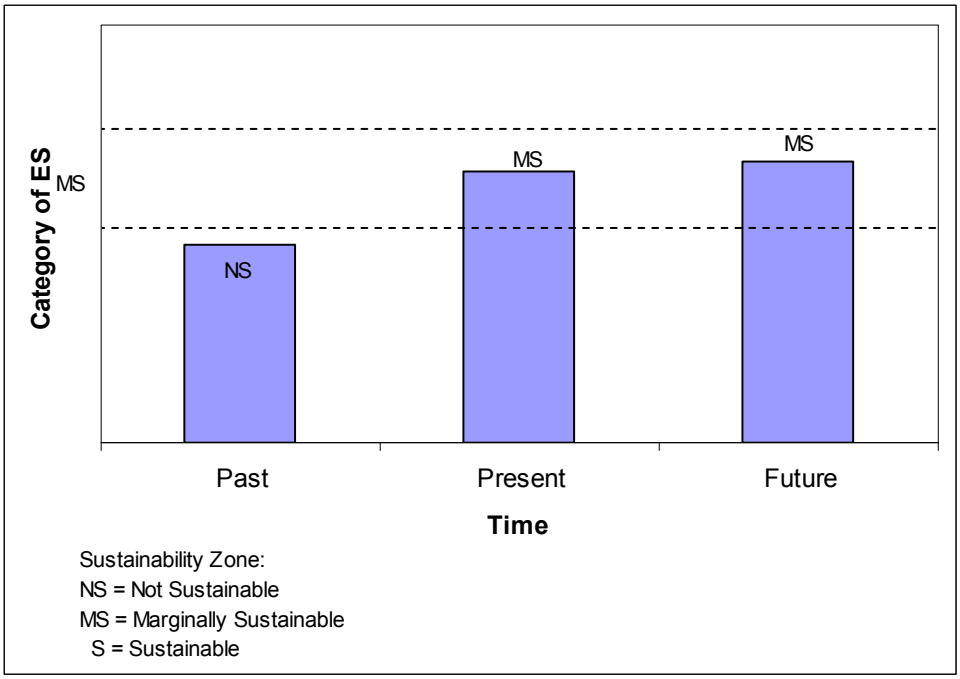
1. In the time period prior to 1920 and continuing into the 1960-70s, health and safety (H&S) issues on the Ohio River represented a broad spectrum of risk factors. Construction and workplace conditions were generally more dangerous than at present; spills and discharges from commercial navigation, river oriented industries, and untreated municipal effluents contributed to a variety of public health risks; and little or no information was available to advise the public of ambient risk levels associated with river oriented activity.

2. While individual risk factors no doubt varied significantly from time to time, most H&S related issues for the period are categorized as 'marginally sustainable.' However, activities that involved more direct exposure to water quality risk factors are categorized as 'not sustainable' in **Figure 6-8**.

3. Improvements to water quality, reduced risks of spills and faster response, improved workplace safety standards, and effective safety standards for recreational boating have all combined to make the Ohio River a safer place to work, live, and play. These improved present day conditions result in a 'sustainable' classification for some H&S related issues**.** Improved conditions have also contributed to reduce risk factors associated with contact recreation and fish consumption. However, problems associated with continued exceedances of biological standards, the persistence of some contaminants associated with fish consumption, and mixed signals regarding fish consumption standards result in a present time classification of 'marginally sustainable' for these activities.

4. With respect to the future, some H&S issues are expected to remain in the 'sustainable' rankings. It is important to note, however, that continued growth of commercial navigation, recreational activity, river oriented industries, and other uses of the river will require continued improvements in management and regulation of H&S issues just to maintain the status quo.

FIGURE 6-8
ES of Health & Safety for Contact Recreation and Fish Consumption



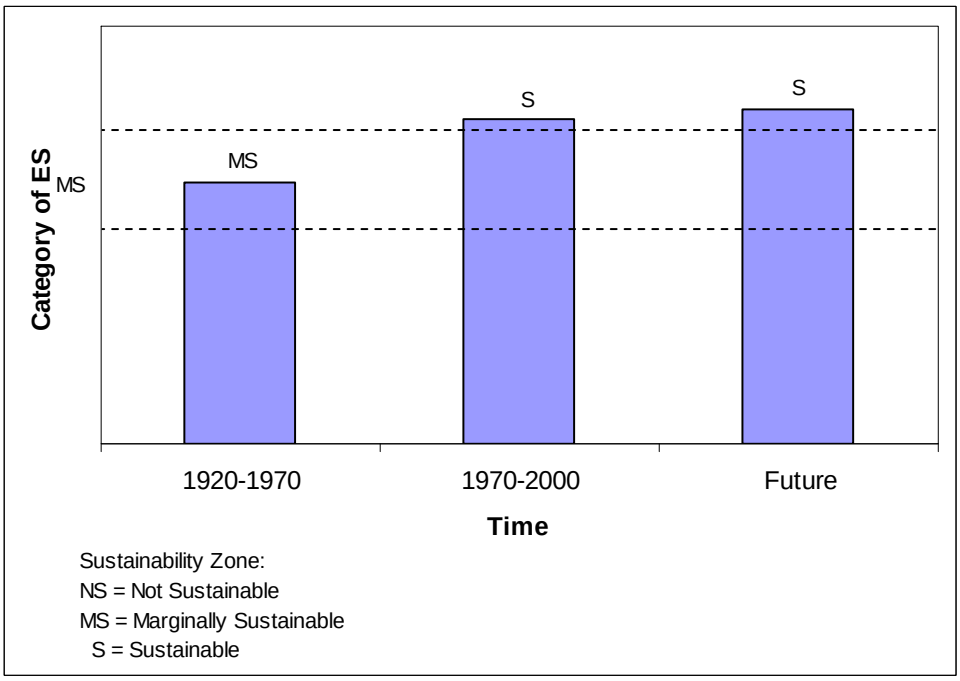
5. While improvement of risk factors associated with contact recreation and fish consumption is expected to continue, these factors are kept in the 'marginally sustainable' category as a conservative estimate of potential trends. Some efforts required for continued improvement, such as rehabilitation of sanitary sewer systems to eliminate combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) or reduction of mercury emissions from coal combustion, will require significant investments and long periods of time to achieve results.

6.4.1.1.6 Recreation

1. In the time period prior to 1920, and continuing up to about 1950, recreation on the Ohio River occurred in a degraded environment due to largely untreated and uncontrolled pollution discharges from growing municipalities, mining activity, and various types of industries and land uses along the river. Although the river continued to be used for recreation during this period, the overall ES was "marginally sustainable" and may have been "not sustainable" for the worst years of pollution. However, recreation information from the worst decades of pollution is limited as that time period coincided with the Great Depression, World War II, and the post-war period shortly thereafter, when leisure time and financial resources were limited.

2. At the present time, recreation on the Ohio River is currently in a "sustainable" condition due in large measure to water quality improvements related to ORSANCO programs and requirements of the FWPCA (and the amended CWA). Water quality improvements, combined with increased economic prosperity, have increased the demand for and stimulated the development of marinas, ramps and other recreation facilities along the river. The recent era of more integrated riverfront planning also has addressed recreation needs and has increased opportunities for an expanded spectrum of recreational choices.

FIGURE 6-9
ES of Recreational Resources



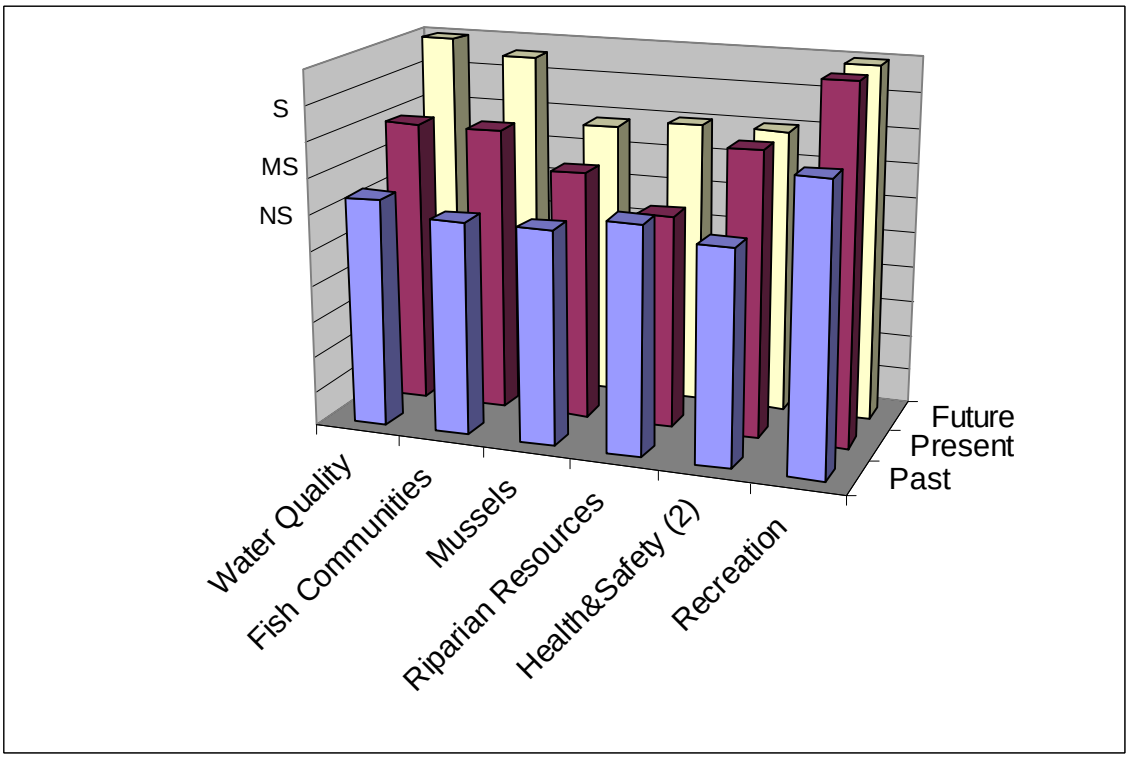
3. Regarding the future, it is expected that community planning and development of recreation facilities, further water quality improvements, especially in stormwater and CSO management, and habitat protection and restoration efforts will continue to enhance recreation experiences. Socioeconomic projections for a stable or slowly growing population and continued improving standard of living would be expected to result in continued growth of demand for recreational opportunity. Consequently, the future ES is classified as "sustainable." Although the perception exists that increased participation could lead to overcrowding and competition for limited resources, it does not currently seem to be an overriding influence affecting people's decisions to participate in river-related activities.

6.4.1.2 VEC Interdependencies

1. As suggested in Section 6.4.1.1, analysis of sustainability needs suggested a high degree of linkages and interdependencies. For example, barriers to fish passage have significant impacts on recolonization of mussel beds which are further subjected to

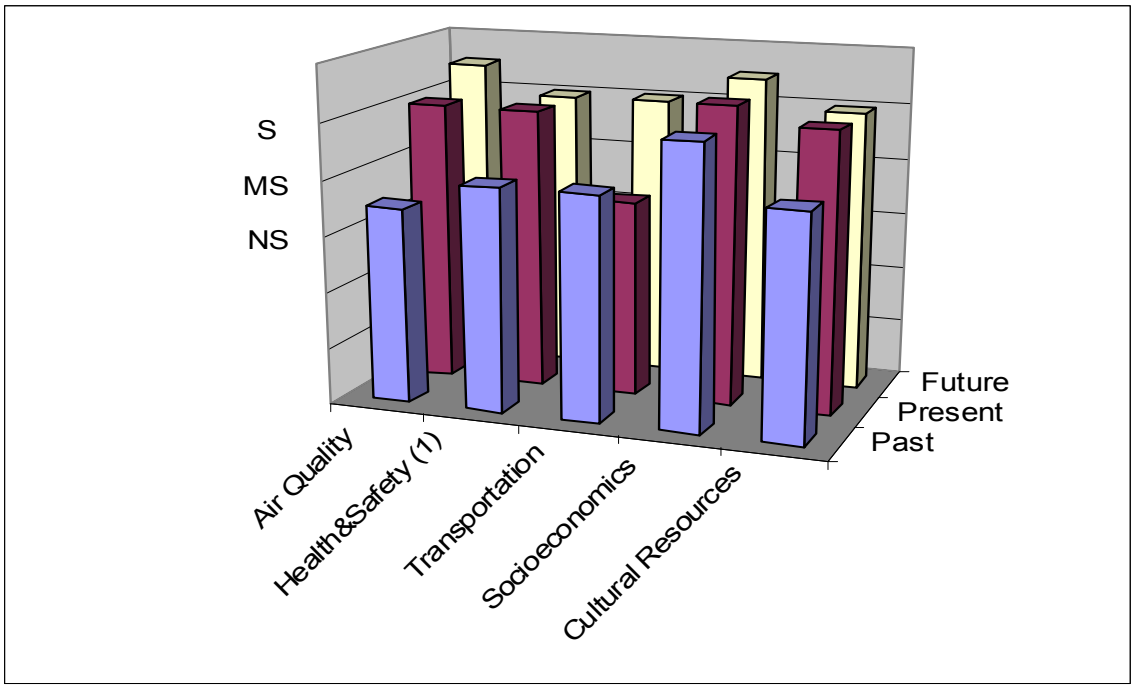
increased scouring resulting from disturbed riparian areas. Figures 6-10 and 6-11 below summarize the past, present and future ES conditions of the ten VECs and are discussed in detail in the CEA report in Appendix A. The VECs are divided into two groups to improve viewability of the graphs. Group 1 includes those resources that are potentially more sensitive to changes related to commercial navigation on the Ohio River. Analysis of the Health and Safety VEC resulted in the reporting of two ES trends. Health and Safety (2) refers to fish consumption advisories and direct contact with river water (e.g. swimming or boating). All other issues addressed by this VEC are included in Health and Safety (1).

FIGURE 6-10
ES Trends for VEC Group 1



Sustainability Scale: Taller columns represent greater sustainability. NS, values in the "not sustainable" range; MS, values in the "marginally sustainable" range; S, values in the "sustainable" range.

FIGURE 6-11
ES Trends for VEC Group 2



Sustainability Scale: Taller columns represent greater sustainability. NS, values in the "not sustainable" range; MS, values in the "marginally sustainable" range; S, values in the "sustainable" range.

2. Sustainability concerns identified in the CEA Report are presented in **Table 6-4**. It should be noted that some concerns apply to more than one VEC. CSOs, for example, affect Water Quality, Health & Safety and Recreation and also have effects on Fish, Mussels and Riparian Resources. Addressing such complex issues will require long-term collaboration, but can lead to major gains in the river's long-term sustainability.

3. Opportunities to enhance Environmental Sustainability of VECs through existing regulatory efforts, educational programs and various existing authorized programs were identified and offer positive signs for sustainability of several VECs. The continuation or success of such efforts and trends, however, needs to be monitored and must be reinforced through continued support of the public.

TABLE 6-4
Sustainability Concerns

Water Quality & Sediment Quality
1) Legacy contaminated sediments
2) Bacterial contamination from CSOs
3) Continued development in riparian areas

Fish
Asian carp species moving upriver

Mussels
1) Incomplete knowledge of life histories for species of concern, including life histories of host fishes.
2) Protection of mussel habitat
3) Habitat degradation
4) Species of concern extirpation or population reduction
5) Lack of resources to enforce all laws and regulations pertaining to collection of specimens and protection of habitat.
6) Zebra mussel and Asian carp invasions.
7) Lack of public and agency awareness of existing laws that protect mussels.

Riparian/Floodplain Resources
1) Continued fragmentation and loss of riparian resources
2) Need for institutional coordination for riparian area management, including:
    a. Requiring impact identification and mitigation through NEPA
    b. Designation of special management areas on public lands
    c. Regulation of activities on privately-owned riparian areas
    d. Utilization of incentives to encourage use of BMPs, and
    e. Purchase of privately owned lands for public management

Air
Establishment of more effective limits for mercury emissions

Health & Safety
1) Growing potential conflicts among recreation, commercial and navigation river users
2) Need to eliminate CSOs and SSOs
3) Reduction of mercury emissions from coal-fired power plants
4) Clarification of fish consumption advisories

Recreation
1) Need to eliminate CSOs and SSOs
2) Perception that increased participation could result in overcrowding and competition for limited resources

Transportation &Traffic
1) Competition over time between navigation and recreation vessels for use of locks
2) Amounts and types of fuels used by tows

Socioeconomics
Need to balance long-term growth of navigation with infrastructure that supports it.

6.4.2 Environmental Sustainability Concerns and Opportunities For Ohio River Aquatic and Riparian Resources

1. During the course of this study, the Corps assembled a team of national and regional experts on the topic of aquatic and riparian resources of the Ohio River. Through a series of workshops, the group identified the ecological functions that have been compromised along the river and possible causes of such compromises. Many of the specific problems were listed in **Table 6-4**. Those subject matter experts were then asked to describe attributes of a desirable state for ecological resources. Next, the groups were asked what actions were needed to move the resources toward the desirable state. The group was not constrained by how the actions might come about or who would implement those actions; however the resulting list provides a means or concept plan for meeting sustainability needs. The measures identified are listed in **Table 6-5** below. It is important to note that the actions identified were focused solely on needs of aquatic and riparian resources, and that no single agency or organization has the authority or responsibility for implementing all of these actions. Rather, all interested parties could work cooperatively to undertake specific actions that would contribute to improving resource sustainability.

TABLE 6-5 **Opportunities for Enhancing Ecosystem Sustainability**
Enhance fish passage around or through dams
Dismantle unneeded federal tributary dams
Dismantle unneeded non-federal tributary dams
Increase seasonal flooding in grasslands, bottomland hardwood forests, and other habitats
Allow flows to mimic natural regimes including seasonal and extreme floods and droughts
Restore unique mainstem habitats such as canebrakes, river bluffs and mussel beds
Protect tailwaters and provide structures to serve as refugia for fish
Create spawning shoals and other in-stream features to enhance habitat diversity in navigation pools
Identify and expand areas of submerged and emergent aquatic vegetation
Protect and manage mussel populations and their habitat on a site-specific basis
Mark critical locations to prevent mooring near mussel beds or special shoreline areas
Mark shallow mussel beds to reduce direct impacts of tow traffic
Provide the navigation industry with charts showing locations of sensitive resources and include rationale for avoiding such resources
Protect existing aquatic habitats, restore lost habitats and diminished resources
Reintroduce native fauna and expand the range and populations of native fauna from reduced levels
Control exotics, including minimization of existing populations and prevention of new introductions
Reduce bacterial contamination from combined sewer overflows
Address point and non-point sources affecting aquatic nutrient balance
Minimize catastrophic contamination events through reduction of spills, accidents, and improvement of spill response procedures
Continue remediation of CERCLA, brownfields, and other contaminated sites
Reconnect and restore streams with floodplains on the mainstem and tributaries
Protect or restore riparian habitat diversity, including islands, on the mainstem and tributaries

2. The above list of needed actions primarily includes approaches that address restoration of habitat variety, recovery of 'missing' habitat components, reestablishing functions and connectivity, removing outdated infrastructure, and generally finding ways of compensating for the effects of infrastructure that must remain. The expertise of the Corps of Engineers stemming from development and long term operation and maintenance of the Ohio River Basin's navigation and flood control infrastructure would provide a valuable source of expertise to the planning, design and implementation of these holistic approaches to ecosystem restoration.

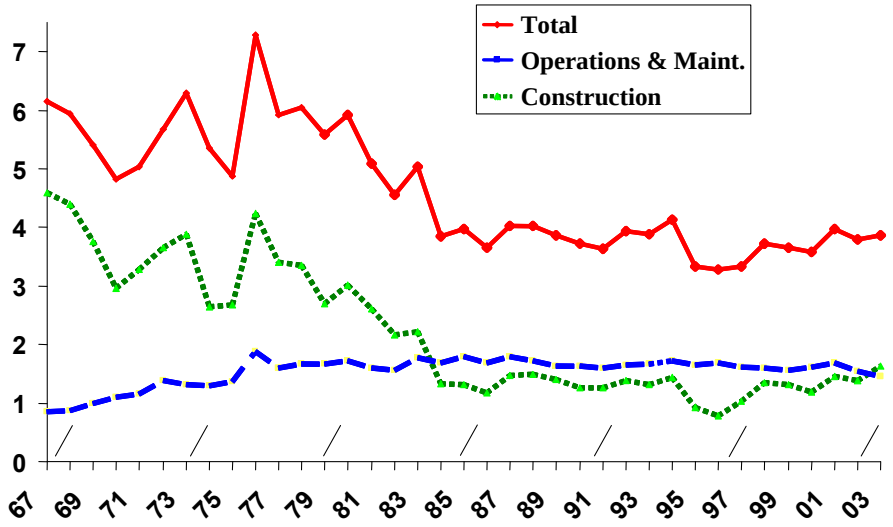
6.5 INVESTMENT OPTIONS

This section provides an introduction to possible solutions to the above problems and ways to realize opportunities. Investment options, or measures, addressing future navigability and navigation efficiency objectives are grouped into three categories, from least to more expensive: (1) maintenance, (2) low-cost structural and operational, and (3) major structural improvements. Additional investment options that address the environmental sustainability objective are described in Section 6.5.5.

6.5.1 Continued Navigation Planning

1. As stewards of the nation's inland navigation assets, the Corps of Engineers, in partnership with navigation and resource agency stakeholders, strives to maintain an inland waterway system capable of handling transportation demands in an efficient, reliable and environmentally sustainable manner. This role as stewards is even more critical on the Ohio River as over half of the navigation projects have or will soon exceed their 50-year design life. The Corps is striving to strengthen its role as navigation stewards through the establishment of the National Center of Expertise for Inland Navigation located in Huntington, WV. The Center's goal is to ensure that navigation projects receive the appropriate level of maintenance and modernization upgrades to effectively and efficiently meet system traffic demands on the waterways without compromising the environmental integrity of the river. Efforts to meet the high goals of this program are complicated by Federal funding levels that have declined dramatically in the 1980's and 1990s (**Figure 6-6**) and remain relatively low today compared with system infrastructure needs, thus hampering Corps efforts to maintain its existing infrastructure and to modernize with major structural improvements (such as larger locks). Constant or declining budgets make the heightened attention to the navigation system all the more necessary.

FIGURE 6-12
Civil Works Appropriations (1967-2003)
in Constant FY95 $Billions



2. The Center of Expertise for Inland Navigation will eventually apply the ORNIM methodology to all Ohio River mainstem dams, navigation structures on Ohio River navigable tributaries, and will continue to develop the metrics and gather the data to assess future traffic forecast scenarios. By tracking and updating the scenarios, the Corps will be able to apply the proper investment package (maintenance and upgrades) to the navigation system in order to maximize navigation benefits. Also included is consideration of potential impacts to environmental sustainability of the entire Ohio River system. Environmental Impacts will be assessed to help predict if any valued environmental components (VECs) are threatened by navigation-related activities in combination with actions by others that also affect the river environment. The Corps will continue to refine several aspects of the environmental models used in this study and will collect data to develop the input files for the navigable tributaries within the basin. For a more complete list of environmental efforts, see **Table 6-6**. On an ongoing basis, the Corps will consult with resource partners and will monitor the environmental metrics to ensure predicted sustainability trends are occurring.

3. Federal decisions regarding navigation based on this study should focus on "near term" actions requiring immediate action in order to implement the SIP. Follow-on studies will be recommended for major rehabilitations, lock improvements and managerial actions not currently covered by Corps authorities (i.e. congestion fees), or new authorities. Certain actions covered by Corps authority, such as improved operational procedures, maintenance items, low cost structural measures, or previously approved major rehabilitations could be implemented as soon as needed without further study, assuming that funds are made available. However, decisions for actions required in the longer term (i.e., not requiring immediate action) will be deferred and confirmed during future updates. At some point in the future, these long term actions could well become near term and follow-on studies recommended at a later date. Alternatively, actions not currently envisioned during the analysis period may surface during these updates.

4. Federal decisions regarding the environment should focus on two areas: 1) ensuring navigation improvements in combination with other reasonably foreseeable actions do not significantly degrade long-term resource sustainability and 2) taking all practical steps available to enhance sustainability. The first of these two can be accomplished through implementation of environmental components in **Table 6-6**. Means of enhancing environmental sustainability are discussed later in Section 6.6.

TABLE 6-6
Environmental Sustainability Strategies
Under the Navigation Stewardship Program

Strategy	Time Frame
Refine the NAVPAT model, especially the species curves, to reflect findings from traffic effects studies conducted by ERDC-WES since initial species curves were developed in the 1980s and develop capability to assess traffic effects on backchannels and embayments.	MONTHS 1-60
Develop NAVPAT module in ORNIM to perform equivalent to other modules, specifically to allow ORNIM to optimize environmental considerations along with economic and engineering.	MONTHS 1-60
Complete development of QUEPAT to evaluate near field traffic effects of tow queuing in proximity of Locks and Dams.	MONTHS 1-24
Pursue development of a model to assess traffic impacts to mussels	MONTHS 1-36
Periodically conduct substrate condition assessments	PERIODICALLY
Continue to update environmental data on freshwater mussel resources	ONGOING
Conduct periodic resurveys of water based recreational use of the river	MONTHS 108-120
Monitor riparian habitat condition	ONGOING
Maintain GIS databases and supplement with new data as available	ONGOING
Continue periodic interagency team meetings with resource agencies and others to communicate findings and evaluate sustainability conditions	ONGOING
Prepare additional cumulative effects assessments and NEPA supplements as needed	MONTHS 60-78

5. Refinement of the NAVPAT model, emphasizing fish guilds, rather than individual species curves, would reflect findings from traffic effects studies conducted by

the Engineering Research and Development Center-Waterways Experiment Station (ERDC-WES) since initial species curves were developed in the 1980s and would develop capability to assess traffic effects on backchannels and embayments. A NAVPAT module in ORNIM would perform equivalent to other modules, specifically to allow ORNIM to optimize environmental considerations along with economic and engineering. The QUEPAT model would evaluate near field traffic effects of tow queuing in proximity of Locks and Dams. No recreation studies, CEA, or NEPA supplements would be anticipated in the near term but these documents would be reviewed periodically in later years to determine if supplements are needed.

6. Environmental activities similar to those practiced on the Ohio River mainstem would be adapted for application on navigable tributaries as shown in **Table 6-7**. Additional species curves would be developed for select tributaries based on species occurrence. Characteristics of various resources would be defined and ecosystem sustainability needs for each tributary would be determined. Periodic tasks would include CEA and NEPA analyses and preparation of documents for investment plans

TABLE 6-7
Environmental Sustainability Strategies
Navigable Tributaries to the Ohio River

Collect NAVPAT/QUEPAT base data for tributaries
Develop additional species curves for selected tributaries based on species occurrence
Define characteristics of various resources of each tributary
Obtain or develop GIS databases
Determine ecosystem sustainability needs for each tributary
Conduct cumulative effects assessments and NEPA analyses and prepare documents for investment plans
Establish or supplement interagency team

6.5.2 Maintenance Measures for Navigation

These are maintenance policies designed to reduce closures times and/or to reduce the impacts of maintenance of the navigation system on waterway shipping. A list of maintenance measures considered includes:

- Routine and Cyclic Maintenance. One possible enhancement includes full implementation of the miter gate quick change-out system. This system is partially implemented, but full implementation would realize the maximum potential of reduction in closure durations due to miter gate maintenance. This scenario is still in development and will continue to be investigated since each project is in different stages and each district is still assessing this methodology.

- Replacement of major components, including the need for Major Rehabilitation.

6.5.3 Operational Efficiency and Low-Cost Structural Measures for Navigation

1. These are methods that involve largely operational and relatively low-cost structural measures generally costing less than $15 million, considerably less than lock expansion or new lock options. Examples of low cost and operational measures considered includes:

- Continuing an N-tow-up / N-tow-down lockage policy (queue discipline) whenever a Main chamber is closed. This procedure is already used whenever major maintenance occurs at any of these locks, where N is 3 at Emsworth, Dashields and Montgomery Ls/Ds on the upper river, and N is 6 at all other Ohio River Ls/Ds.

- Use of helper-tow boats to provide tow assists during Main-chamber shutdowns. This is generally accomplished through "industry self-help," whereby commercial motor vessels volunteer to aid other tows in making approaches or in pulling unpowered barge-cuts from the Auxiliary chamber. Industry provides this service during any extended (30 days or more) main chamber closure.

- Congestion fees. This procedure is not currently in use at any Corps project. Implementation would require additional authority.

- Traffic Management, including the scheduling, and/or rescheduling, of tows during chamber shutdowns. Industry currently adjusts their schedules voluntarily during main

chamber closures. This study considers the potential benefit of Corps mandated lockage times, particularly during closures of the main chamber when delays are most severe. Implementation beyond voluntary efforts by the towing industry would require additional authority.

- Providing mooring cells and /or buoys upstream or downstream of locks to reduce some approach and exit times. Facilities currently without mooring cells either downstream (DS), or both upstream and downstream from the locks (B) include: Willow Island (DS), Belleville (DS), Racine (DS), Greenup (DS), Meldahl (DS), McAlpine (B), and Smithland (B).

2. These same measures for decreasing delays at the locks by decreasing lockage times and reducing waiting times incurred by tows waiting to lock through will also lead to environmental sustainability improvements. Many of these practices are already in place to reduce traffic delays and tow queuing that can damage habitat and interfere with fish and mussel communities and other aquatic life, especially during prolonged lock closures. Others, such as new mooring cells, are considered further in this study as a feature of the without project condition. A mooring cell downstream of Greenup is included in the Auxiliary lock chamber extension authorized in WRDA 2000.

6.5.4 Lock Modernization Measures

1. Substantial delay reduction at any Ohio River lock (where that reduction cannot be provided through the use of non-structural and/or low-cost measures) is available only through major construction that increases lock capacity. Innovative construction techniques would be employed to allow much of the construction to take place "in-the-wet" (without cofferdams) and utilizing pre-fabricated float-in or "lift-in" lock segments. This would lessen the impact on on-going navigation at the existing site during construction by moving much of the construction off-site, as well as provide anticipated cost and time savings versus "traditional" methods. Based on previous study, two general types of major structural improvements were considered for Ohio River projects:

- At Emsworth, Dashields, and Montgomery, replacement of the existing auxiliary with either a 600'x110' or 1200'x110' chamber and possible reconstruction or enlargement of the existing 600'x110' chamber.

- At the remaining projects with 1200'x110' and 600'x110' chambers, the existing 600' chambers would be extended up to a maximum length of 1200'.

2. Detailed consideration of alternatives at any project and recommendations for lock modernizations will be deferred until site-specific Feasibility Studies. The measures cited above are specifically related to this SIP report.

6.5.5 Additional Environmental Sustainability Improvement Options

1. Section 6.2 (Planning Objectives) explained that the ORMSS study objective of enhancing environmental sustainability focuses on identifying and implementing measures within the authorities of the Corps of Engineers and other agencies to minimize degradation of environmental resources caused by transportation or other development, and to improve sustainability of resources along and in the Ohio River. Environmental sustainability seeks a balance between environmental and economic considerations to improve the quality of life for present and future generations. The integration of the economic and environmental aspects of the navigation system is an important focus in future navigation investment decisions.

2. Several opportunities for enhancing environmental sustainability already exist within the Corps of Engineers, the navigation industry, federal and state natural resources agencies, and non-governmental organizations. In addition, a new, more comprehensive approach, the Ohio River Ecosystem Restoration Program was authorized in 2001 and addresses environmental improvements specific to this river.

3. Studies and workshops conducted for the CEA resulted in a number of ecosystem restoration recommendations that could contribute to improved sustainability of aquatic and riparian resources of the Ohio River. These recommendations were previously listed in **Tables 6.4 and 6.5**. These activities included some additional components for enhancing environmental sustainability, such as agency coordination, monitoring, adaptive management, good environmental design and public education which are discussed in further detail in Chapter 13 of the CEA Report. Continuing dialogue concerning adaptive management and environmental sustainability issues at various forums should lead to new collaborative and creative ideas and projects.

4. Finally, there is potential for additional approaches to environmental sustainability on the Ohio River. As the opportunities are identified and assessed, if existing authorities do not exist, they can be requested. This applies not only to the Corps or Engineers but to all agencies with jurisdiction for resources along the river. Agencies can also adopt a new approach to mitigation for impacts associated with their actions to address sustainability concerns (i.e., sustainability-focused mitigation) as discussed later in section 10.4.1..

6.6 PLANNING CONSTRAINTS AND ASSUMPTIONS

Presented below are four constraints and three assumptions that have, in a sense, defined the range of options explored in this study. The first of these were implicit from the earliest stages of the Mainstem study.

Constraint 1: There Will Be No Change to Authorized Nine-Foot Draft Ohio River Channel

Deepening the Ohio River channel might be one way to increase the freight-handling capacity of the system (more tons per tow-surface-area). Since completion of the

Ohio River canalization project in 1929, the U.S. Government has maintained a 9-foot deep x 300-foot wide navigation channel between the lock and dam projects.

Deepening the channel would require combinations of the following:

- extensive and on-going dredging of long segments of the river, including areas currently not requiring maintenance dredging;
- raising the minimum "Normal Pool" levels – which would require modifications to many or all the lock and dam structures as well as other infrastructure (e.g., water intakes, bridges, etc.).

Thus, deepening of the channel was not considered for a number of reasons, particularly:

- No precedence for channel deepening has ever been established in recent Ohio River infrastructure feasibility reports (the Gallipolis, Olmsted and McAlpine authorization reports). All current structures and those under construction are designed expressly for an authorized 9-foot channel depth. The depth over the lock gate sill is designed for tows that accommodate this channel depth.
- There is no reason to believe such a deepening would be cost-effective, due to the associated expense of modifying 19 locks and dam structures to safely allow deeper drafted vessels to lock through.
- The environmental consequences of deepening, requiring dredging to levels well below current river strata, are assumed to result in a serious negative impact to river fish, wildlife, and plant-life. Also, the environmental impacts associated with disposal of large amounts of dredged materials would be a significant problem.

Constraint 2: Maximum Lock Size Considered is 1200' L. x 110' W. (nominal dimensions)

Constraint 2 is in some ways similar to constraint 1 in that it is governed by the natural geometry of the river itself. Locks larger than the nominal size of 110' wide x 1200' long were not considered, based on previous input from commercial navigation interests, as well as being consistent with the existing maximum lock chamber sizes currently in use.

Natural river geometry tends to limit tow sizes to about 108' wide x 1200' long along most of the river, particularly in bend-way areas. Occasionally, a few companies run double-wide (30-barge) tows along portions of the lower Ohio and Tennessee Rivers, particularly during higher water periods. However, these tows arrange in advance to pass through the locks in 108'x1200' (or smaller) configurations.

Constraint #3: The Ohio River Mainstem will remain canalized.

The study recognizes the Ohio River mainstem ecosystem is highly modified and likely to remain for the foreseeable future, due to mainstem impoundment by the Corps that began in the late 19th century and is continuing into the 21st century. Floodplain development, which encompasses extensive industrial, commercial, and residential use and infrastructure essential to transportation and community services, is based on existing pool

levels created by the system of high-lift dams begun in the mid-20th century. Returning the river to its pre-impoundment state would have profound environmental, economic and engineering implications. It is therefore unrealistic, if not impossible, to return the floodplain to predevelopment conditions.

Constraint #4: Impacts to Ohio River Floodways will be minimized.

The Federal Emergency Management Administration (FEMA) and individual states along the Ohio River have attempted to curtail construction in flood prone areas. Care will be taken in final plan design (during Prelim inary Engineering and Design stage) to assure compliance with appropriate Federal and states' floodplain and floodway regulations.

Assumption #1: There will be no constraints on assessing the Ohio River Mainstem's resource needs.

This study examined and assessed the resources, ecosystems and human communities of the Ohio mainstem by assuming the perspective of each resource itself. In keeping with this unique approach, no institutional, fiscal, or temporal constraints were imposed while developing recommendations beneficial to the resources. Lack of such constraints stimulated open-ended thinking and flexibility in considering conditions over such a protracted time frame. Extending this approach as an example, the study not only examined conformance to existing programs and legislation relevant to the resources but also explored trends that may lead to new opportunities and solutions to present resource problems.

Assumption #2: Determination of Dam Maintenance is based on Results of Other Studies and Engineering Judgment.

1. Dam components were not specifically modeled using reliability analysis as a part of the ORMSS. Gates, electrical and mechanical components, and concrete components of all dams were initially considered for reliability analyses; however, as the state-of-the-art methodology for implement reliability analysis was developed under ORMSS, funding and budget issues led the team to focus on lock components. Recent dam rehabilitation studies (Emsworth, J.T. Myers) that either have been completed or are currently in process have been taken into consideration for these projects and those with similar problems. As previously described, the only Ohio River dams currently being rehabilitated are the main and back channel dams at Emsworth; however, the J.T. Myers Dam Rehab Study was completed in FY07. The investment strategy resulting from specific engineering and economic studies related to the on-going major rehabilitation at Emsworth was incorporated into analyses for the SIP, as was the projected needs at J.T. Myers based upon the latest analysis of that MR study.

2. Currently, there are no known stability issues associated with any dam piers or the fixed weirs for Ohio River dams. The original safety factors included in the design of these structures and the fact that overall condition of these structures does not change significantly with time led to the conclusion that they would remain reliable throughout the study period.

<u>Assumption #3:</u> No Assessments of Alternatives Involving the Removal Of Any Locks and Dam Will Be Included In This Study.

Plans to reduce the number of locks and dams below nineteen are not included in any analyses for this study. The economic, environmental, and social impacts of this type of plan would be fully considered in future site-specific studies if deemed appropriate. Deferral of consideration of this type of plan is not expected to impact the schedule of future studies developed through use of this SIP. Furthermore, addressing the potential elimination of a facility in this SIP would require case specific modification of the CEA and PEIS, which is beyond the scope and budget for this study.

<u>Assumption #4:</u> All Locks and Dams on Ohio River Tributaries Are Modeled as Operating at Full Capacity.

No reliability analyses were conducted at locks and dams on any of the Ohio River tributaries. These projects are modeled as operating at full capacity with no unscheduled closures due to failures of major lock components.

SECTION 7
PUBLIC INVOLVEMENT AND INTER-AGENCY COORDINATION

This section provides presents a summary of communications with various groups and public agencies throughout the Ohio River Mainstem System Study, emphasizing activities during the preparation of this System Investment Plan and Programmatic Environmental Impact Statement. These activities build upon the extensive coordination conducted during preparation of the J.T. Myers and Greenup Locks Improvements Feasibility Report (April 2000) and the Ecosystem Restoration Report (October 2000).

7.1. ENVIRONMENTAL OUTREACH

7.1.1 Summary Of Scoping Process

1. Scoping for the current phase of this study was initiated by six public meetings held in 2001. They were announced by notice in the Federal Register on June 26, 2001, with additional notification made through mailing to over 3,000 addressees on the mailing list developed during preparation of the two prior interim reports. The meeting dates and locations were: July 10, 2001, Metropolis, IL, and July 12, 2001, Evansville, IN (Louisville District); July 31, 2001, Parkersburg, WV, August 7, 2001, Portsmouth, OH, and August 6, 2001, Covington, KY (Huntington District); and August 1, 2001, Monaca, PA (Pittsburgh District). **Figure 7-1** illustrates that the six locations were distributed along the bordering states along the Ohio River. There were two primary purposes for these meetings. One was to allow input from interested agencies and individuals concerning issues that should be factored into this study. The second purpose was to satisfy part of the requirements for public scoping and coordination under NEPA for preparation of a programmatic environmental impact statement. Presentations at these meetings focused on the three key study elements – the System Investment Plan, the Cumulative Effects Assessment, and the Programmatic Environmental Impact Statement. The presentations were followed by a moderated question and answer session that typically lasted for about one hour.

2. Two sessions were held for each meeting, a daytime session with governmental agencies and an evening meeting open to the public. Forty-four people attended the six meetings with agency representatives. More than half of the participants represented federal and state resource or regulatory agencies. The remaining participants represented various public agencies or business interests. One hundred forty one people attended the six public meetings. Nearly 50 percent of the participants were interested citizens. Approximately 25 percent represented business or development interests, with

the largest representation from the shipping industry. The remaining participants included anglers, elected officials, representatives of environmental non-governmental organizations (NGOs), the media and government agencies. **Table 7-1** lists the key issues that were raised either at the public workshops or through written letters. These issues were published in the ORMSS folder on the public-accessible web page in the Louisville District -http://www.lrl.usace.army.mil/ORMSS.

FIGURE 7-1
Scoping Meeting Locations

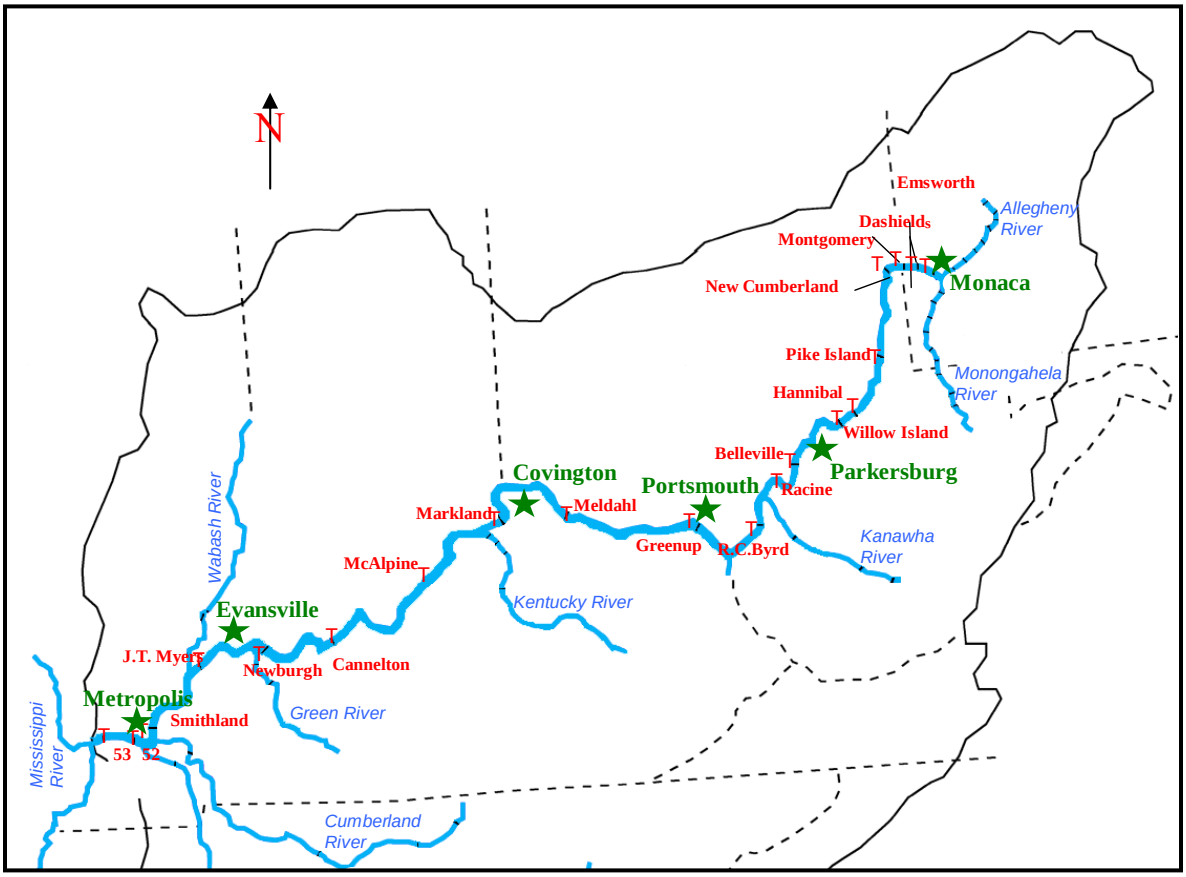


TABLE 7-1
Key Issues Raised at Scoping Meetings

Topic	Comments/Concerns
BARGE TRAFFIC	1) Loss of shoreline trees and river property caused by barge activities
	2) Reliability of barge traffic forecasts in relation to globalization and comparative costs of other modes of transportation
	3) Increased spills and accidents potentially damaging aquatic life and impairing water quality as barge traffic increases
	4) Failure of barges to stay in designated shipping lanes
	5) Changes in shipping demand as low sulfur coal reserves in the region near depletion within the next 25 years
	6) Lights from barges shining into residences and other buildings on shore
	7) Possible trash hauling by barges in the future
NAVIGATION INFRASTRUCTURE	1) Navigation improvements presently not keeping pace with traffic demands
	2) ORMSS schedule possibly lagging behind future navigation needs
	3) Scheduling and frequency of lock closures
	4) Locks' eligibility for classification as historical structures
	5) Issuance of bonds to fund navigation improvements
	6) Improvements viewed as lacking benefits except to shipping industry
INTERMODAL FACILITIES	1) Enhancement of river transportation capabilities through corresponding development/improvements of intermodal transportation facilities
	2) Need for long-range coordination with FHWA and state transportation departments
	3) Potential lack of integration of navigation with other transportation modes
LAND USE	1) Loss of significant farmland to urban development along river corridor
	2) Loss of green space and wildlife habitat with development of commercial and recreational docking/loading facilities
	3) Development of floodplains and wetlands causing increased runoff
WATER QUALITY	1) Cumulative effects of discharges to river offsetting water quality improvements
	2) Challenge to water quality presented by combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs)
	3) High levels of mercury, arsenic, chloroform and agricultural chemicals in surface water
	4) Need for more stringent discharge permitting processes or moratorium by regulatory agencies
	5) Prolonged bureaucratic procedures in obtaining discharge permits

	6) Importance of coordination between USACE and public water suppliers withdrawing from Ohio River
GROUNDWATER	1) Overall effects of navigation structures and activities on groundwater levels
	2) Protection of public groundwater supplies
SEDIMENTATION	1) Mouths of tributaries silted in, impairing fish habitat and limiting access
	2) In-stream sedimentation forming bars and causing grounding of vessels
	3) Impaired water quality and bioaccumulation of harmful substances in fish tissue from pollutants stirred up in sediments
DREDGING	1) Damage/destruction of mussel beds and fish spawning areas
	2) Use of dredge spoils to improve riparian or island habitat or for upland filling
BANK/SHORELINE INSTABILITY	1) Bank undercutting and failure caused by increased barge traffic/queuing and attendant wave action
	2) Bank erosion caused by USACE-controlled pool fluctuations
	3) Shoreline instability threatening costly restoration projects in wildlife management areas
POOL ELEVATIONS	1) Adverse effects on bridges and property from higher pool elevations
	2) Pools maintained at a higher elevation than agreed on in flowage easement contracts with riparian property owners
RECREATION/ FISHING	1) Need for more public access ramps in each pool to reduce recreational crafts' usage of locks
	2) Interest by State of Ohio in increasing river access to promote Ohio River as a vacation destination
	3) Degradation of recreational value of river caused by increasing industrialization
	4) Health and safety concerns related to increased traffic and discharges
	5) Impaired fishing caused by water level fluctuations
	6) Fishermen underrepresented in ORMSS scoping process
FISH & WILDLIFE	1) Need for fish habitat improvements, including fish passages around locks/dams
	2) USASCE role when fish kills occur
	3) Loss of wildlife corridors as shoreline develops
	4) Stress and disruption of waterfowl migratory patterns caused by barge traffic
THREATENED & ENDANGERED SPECIES	1) Need for USACE to coordinate with US Fish & Wildlife Service on these issues
	2) Potential displacement of interior least tern from Cottonwood Island
	3) Development constraints related to endangered and threatened species
EXOTIC SPECIES	Preventing distribution of exotic plants and animals as a result of

	USACE actions
CULTURAL RESOURCES	Need to adequately address the Native American Grave Protection and Repatriation Act (NAGPRA)
ENERGY	Need for possible development of hydroelectric power at dams by private concerns
TRASH	1) Increasingly becoming a problem for property owners and river users
	2) Need for stricter litter laws
AESTHETICS	Impairment of scenic value of river corridor for millions of people living in the Ohio Valley
PRIVATE PROPERTY	1) Procurement and control of land by the federal government (e.g. land acquired for OR Islands National Wildlife Refuge)
	2) Restrictions placed on property owners participating in federal programs (e.g. Conservation Reserve Program)
ORMSS	1) Possible overemphasis on transportation and river commerce
	2) Sufficiency of input from other federal agencies, including U.S. Coast Guard
	3) Sufficiency of scoping meetings notification process
	4) Procedures for getting on mailing list and receiving follow-up materials
	5) Issuance of official Record of Decision (ROD) for ORMSS
	6) Application of Ohio River Navigation Investment Model (ORNIM) to ORMSS
	7) Relationship between ORMSS and completion of Olmsted L/D
CEAs	1) Tendency for Cumulative Effects Assessments (CEAs) to emphasize negative impacts
	2) Need for ORMSS CEA to go beyond navigation structures when addressing the system's "carrying capacity"
	3) Need to learn from other CEAs
	4) Interest in including a vision for the future of the Ohio River in 2060
	5) Methods for assessing water quality in the CEA
	6) Relationship between CEA and site-specific impacts
	7) Accuracy of models used for predicting population growth, riverfront development and industrial expansion
BASELINE CONDITIONS	1) Need to define, limit and establish parameters of baseline conditions
	2) Importance of coordination with resource agencies in determining baseline conditions
	3) Need to define parameters for Reasonably Foreseeable Future Actions (RFFAs)
	4) Importance of understanding baselines for different environmental components

ECOSYSTEM RESTORATION PROGRAM	1) How, when and where the Ecosystem Restoration Program (ERP) will be funded and implemented
	2) Ability to raise 35percent local match for environmental restoration projects
	3) Potential difficulty in identifying non-federal partners
	4) Clarification of relationship between ORMSS and ERP
	5) Understanding of what constitutes ecosystem restoration

3. A summary of the meetings was issued to all attendees about three months after the meetings were concluded. Further, a composite "Scoping Comments Matrix" was compiled to summarize all of the received comments and issues identified from the meetings. The comments were grouped into categories as illustrated in **Table 7-1** (in many cases the same comment was made multiple times, and this was so noted in the matrix). The Scoping Comments Matrix is in the Environmental Appendix, CEA Report, Exhibit A. Its structure consisted of the left column comprised of the categories in **Table 7-1**, with as many rows as needed for the individual comments and issues associated with each category. Twelve columns in the matrix related to the 12 VECs, with three additional columns associated with an authorized but unfunded Ecosystem Restoration Program (ERP), the overall ORMSS, and general concerns. Each comment row was connected, as appropriate, to the relevant columns. The final column in the matrix was entitled "Action", and a brief statement was included as to the disposition of each comment relative to the CEA study. The following "actions" were typically noted:

- Comment noted (no further action needed at this time)
- Currently being addressed
- Will be addressed (later in the CEA study)
- Will be addressed for a specific VEC (later in the CEA study)
- Addressed in the (scoping) meeting
- Comment will be forwarded to the ERP team

4. An early section in each of the VEC chapters in the Environmental Appendix included a tabulation of the pertinent direct and related comments. These comments were addressed, as appropriate, in the respective chapters. Further, they were used, along with other information, in the prioritization of the VEC chapters into higher and lower importance groups. The higher importance group includes aquatic ecological resources (water quality/sediment quality, mussels, and fish), riparian/floodplain ecological resources, human health and safety, recreation, and transportation. The lower importance group included chapters on air quality, socioeconomics, land use, and cultural resources.

7.1.2 Interagency Coordination

1. Throughout the ORMSS study, including preparation of the earlier interim feasibility studies, the environmental team maintained regular communication with resource agencies through regularly scheduled meetings with an Interagency Work Group (IWG) held at various locations along the Ohio River. **Table 7-2**, lists the locations and attendees at each of the meetings starting in April 2001, at which time the preparation of the SIP, PEIS, and CEA began in earnest. **Table 7-2** also includes eight meetings (shown by asterisk) with other professional or multi-agency groups with interests in environmental management.

TABLE 7-2. Environmental Meetings

Date(s) / Meeting/Location	Audience
October 29, 1996/Interagency Team Meeting/**Wheeling, WV**	USFWS, State Resource Agencies, EPA, NGOs
October 31, 1996/ Interagency Team Meeting/**Louisville, KY**	USFWS, State Resource Agencies, EPA, NGOs
January 23, 1997/**Cincinnati**	State Historic Preservation Officers
February 6, 1997/Interagency Team Meeting/**Columbus, OH**	USFWS, State Resource Agencies, EPA, NGOs
May 21, 1997/In-Progress Review Meeting-/**Cincinnati, OH**	USFWS, State Resource Agencies, EPA, NGOs, Navigation Industry
August 27, 1997/NAVPAT Model Explanation/**Vicksburg, MS**	USFWS, State Resource Agencies, EPA, NGOs (?)
November 13, 1997/Interagency Team Meeting/**Columbus, OH**	USFWS, State Resource Agencies, EPA, NGOs
February 24, 1998, Interagency Team Meeting/**Parkersburg, WV**	USFWS, State Resource Agencies, EPA, NGOs
April 14-15, 1998, In-Progress Review Meeting/**Pittsburgh, PA**	USFWS, State Resource Agencies, EPA, NGOs, Navigation Industry
August 7, 1998/Interagency Team Meeting/**Cincinnati, OH**	USFWS (w/directors), State Resource Agencies, EPA, NGOs
May 27-28, 1998/Interagency Team Meeting/**Louisville, KY**	USFWS, State Resource Agencies, EPA, NGOs
July 21, 1998/Interagency Team Meeting/**Huntington, WV**	USFWS, State Resource Agencies, EPA, NGOs
August 12, 1998/Scoping Meeting/**Pittsburgh, PA**	Pennsylvania Resource Agencies
August 27, 1998/Scoping Meeting/**Columbus, OH**	Ohio Resource Agencies
October 20-21, 1998/Interagency Team Meeting/**Louisville, KY**	USFWS, State Resource Agencies, EPA, NGOs
January 26-27, 1999/Interagency Team Meeting/**Parkersburg, WV**	USFWS, State Resource Agencies, EPA, NGOs
March 30-31, 1999/Interagency Team Meeting/**Ashland, KY**	USFWS, State Resource Agencies, EPA, NGOs

July 21-22, 1999/Interagency Team Meeting/**Evansville, IN**	USFWS, State Resource Agencies, EPA, NGOs
October 28-29, 1999/Interagency Team Meeting/**Cincinnati**	USFWS, State Resource Agencies, EPA, NGOs
January 19, 2000/Ecosystem Restoration Presentation/**Frankfort, KY**	Ohio River Fish Management Team
January 20-21, 2000/Interagency Team Meeting/**Frankfort, KY**	USFWS, State Resource Agencies, EPA, NGOs
January 26, 2000/Ecosystem Restoration Presentation/**Crittenden, KY**	State Resource Agencies
February 9, 2000/Recommendations for Greenup & Myers/**Greenup, KY**	Environmental Agencies, Navigation Industry & General Public
February 14, 2000/Recommendations for Greenup & Myers/**Mt. Vernon, IN**	Environmental Agencies, Navigation Industry & General Public
February 15, 2000/Study Update/**Somerset, PA**	PA Fish and Boat Commission
April 3-4, 2000/Interagency Team Meeting/**Frankfort, KY**	USFWS, State Resource Agencies, EPA, NGOs
June 13-15, 2000/Ecosystem Restoration Study Update/**Marietta, OH**	USFWS, State Resource Agencies, EPA, NGOs
July 18-19, 2000/Interagency Team Meeting/**Pittsburgh, PA**	USFWS, State Resource Agencies, EPA, NGOs
August 4, 2000/Coordination Meeting/**Cincinnati, OH**	ORSANCO
September 15, 2000/Aquatic Studies Update/**Frankfort, KY**	USFWS and Ohio River Fish Management Team
October 12, 2000/Recommendations for Ecosystem Restoration Program/**Cincinnati, OH**	Environmental Agencies, Navigation Industry & General Public
October 24-25, 2000/Interagency Team Meeting/**Crittenden, KY**	USFWS, State Resource Agencies, EPA, NGOs
November 27-29,.2000/Environmental Monitoring & Assessment/**St. Louis, MO**	EPA
January 30-31, 2001/Interagency Team Meeting/**Columbus, OH**	USFWS, State Resource Agencies, EPA, NGOs
February 6-8, 2001/Ecosystem Restoration Meeting/**Columbus, OH**	USFWS
March 14-16, 2001/Ecosystem Restoration Update/Bettendorf, IA	Mississippi River Conservation Committee
March 26, 2001/Lock Design Workshop (Environmental Considerations)/**Vicksburg, MS**	Corps of Engineers
March 31, 2001/Ecosystem Restoration Update/**California, PA**	Western Pennsylvania Conservancy
April 5, 2001/ Interagency Team Meeting/**Frankfort, KY**	USFWS, State Resource Agencies, EPA, NGOs
June 5-6, 2001/Ecosystem Restoration Meeting/**Louisville, KY**	USFWS
July 10, 2001/ORMSS Scoping Meeting/**Metropolis, IL**	Resource Agencies and General Public
July 11, 2001/Interagency Team Meeting/	USFWS, State Resource Agencies, EPA,

Paducah, KY	NGOs
July 12, 2001/ORMSS Scoping Meeting/**Evansville, IN**	Resource Agencies, Navigation Industry and General Public
July 31, 2001/ORMSS Scoping Meeting/**Parkersburg, WV**	Resource Agencies, Navigation Industry and General Public
August 1, 2001/ORMSS Scoping Meeting/**Beaver, PA**	Resource Agencies, Navigation Industry and General Public
August 6, 2001/ORMSS Scoping Meeting/**Covington, KY**	Resource Agencies, Navigation Industry and General Public
August 7, 2001/ORMSS Scoping Meeting/**Portsmouth, OH**	Resource Agencies, Navigation Industry and General Public
October 2-3, 2001/Poster Session/**Rend Lake, IL**	State DNR Directors
October 11, 2001/Poster Session/**Louisville, KY**	Ohio River Basin Consortium for Research and Education
October 17, 2001/ORMSS Presentation/**Covington, KY**	Cincinnati Propeller Club
October 25, 2001/Cumulative Effects Assessment Course/**Memphis, TN**	Corps of Engineers
November 14-15, 2001, Interagency Team Meeting Cincinnati, OH	USFWS, State Resource Agencies, EPA, NGOs
November 20, 2001, Portsmouth, OH	Shawnee Nature Club, Quarterly Meeting
December 18-19, 2001/ORMSS Presentation/**Cincinnati, OH**	ORSANCO Advisory Committee
February 1, 2002, Interagency Team Meeting Frankfort, KY	USFWS, State Resource Agencies, EPA, Non-Governmental Organizations (NGOs)
February 28-29, 2002, **MV MISSISSIPPI**	Midwest Natural Resource Leaders Group
March 19-21, 2002, **Anstedt, WV**	USFWS, Ecosystem Team
June 11, 2002/Interagency Team Meeting/Paducah, KY	USFWS, State Resource Agencies, EPA, NGOs
August 26, 2002/Green River-Ohio River Confluence/**Louisville, KY**	USFWS, Kentucky DFWR, Kentucky DOT
November 7, 2002/N. Kentucky University?	Ohio River Basin Consortium for research and Education
November 13, 2002, Interagency Team Meeting Columbus, OH	USFWS, State Resource Agencies, EPA, NGOs
November 20, 2002/Columbus, OH	TNC
Feb 5, 2003/Cincinnati, OH	Ohio River Fish Management Team
Mar 1, 2003/Cincinnati, OH	Midwest Natural Resources Leaders Group
Apr 23, 2003/Interagency Team Meeting/Cincinnati, OH	USFWS, State Resource Agencies
Jul 9, 2003/Pittsburgh, PA	PA Environmental Council
Sep 9, 2003/Interagency Team Meeting/Marietta, OH	USFWS, State Resource Agencies, EPA, NGOs
Feb. 10-11, 2004/Interagency Team	USFWS, State Resource Agencies

May 11, 2004/Interagency Team Meeting/Pittsburgh, PA	USFWS, State Resource Agencies
Aug. 18-20, 2004/Athens, Ohio	Ohio River Basin Consortium for Research & Education
Oct 19. 2004/Frankfort, KY	Interagency Team Meeting
Dec 12-15, 2004/Indianapolis, IN	Midwest Fish and Wildlife Assoc.
Oct 26-28, 2004/Huntington, WV	Ohio River Basin Consortium for Research & Education
May 16-17, 2006/Frankfort, KY	Interagency Team Meeting

2. The IWG consists of approximately 40 members representing federal and state agencies with responsibilities for environmental management, as well as several NGOs. Six members were from the U.S. Fish and Wildlife Service, with one serving as the coordinator for the USFWS group; two were from the U.S. Geological Survey; and one was from the U.S. Environmental Protection Agency. Members from NGOs include one person from the Sierra Club, one from the Ohio River Foundation, and two from The Nature Conservancy. The remaining members are from natural resources or environmental management agencies in the six states bordering the Ohio River. The IWG had two to three meetings annually with the environmental team. These one to two day joint meetings included information dissemination and updates related to the status of the CEA study, status reports on specific research projects, and working sessions on integrative topics such as impact matrices for RFFAs, and indicators and a process for analyses of environmental sustainability (AES). More specifically, the IWG fulfilled the following purposes in the CEA study:

- Aided in identifying key issues and cumulative effects that should be addressed in the CEA study.

- Assisted the Central Planning Team in delineating and prioritizing key research needs relative to environmental issues and natural resources. Examples of completed research include fish passage studies at selected locks, determination of winter habitat requirements for selected fish species, and surveys of freshwater mussel populations at various River locations. In addition, the IWG has reviewed the completed research reports.

- Participated in the completion of RFFA matrices for VECs and their subcomponents related to aquatic ecological resources, floodplain/riparian ecological resources, and threatened/endangered/protected species.

- Reviewed work plans for addressing cumulative effects on the 12 VECs and their subcomponents; in addition, reviewed the identified methods and procedures relative to “best practice tools” for the specific issues and cumulative effects to be addressed. It should be noted that “best practice tools” infer both scientific validity and cost-effectiveness relative to their application.

- Conducted systematic reviews of draft chapters and appendices for the CEA study report and the SIP/PEIS.

- Provided periodic and continuing scientific information on emerging issues; examples include the incorporation of the environmental sustainability analyses and the need to consider nonstructural measures for navigation traffic management, along with proactive repair and rehabilitation of existing locks and dams, and lock extensions.

- Participated in the planning and implementation of a coordinated and collaborative long-term strategy for environmental monitoring and adaptive environmental management for the aquatic and floodplain/riparian ecological resources within and along the Ohio River mainstem. In fact, the IWG could become part of a long-term decision-making structure and process related to enhancing the environmental sustainability of key resources.

7.2 CORPS INTERACTION WITH THE PUBLIC

1. The Corps used two primary means to regularly update the general public with progress and issues throughout development of the SIP. The URL site on the Louisville District Web Page cited above for the Scoping Meeting Comments also contained links to a general fact sheet and compilations of Frequently Asked Questions (FAQs). Two FAQ sheets were maintained, one solely relating to economic modeling and analysis issues, the other for all other types of concerns.

2. Data related to use of the URL site www.lrl.usace.army.mil/ORMSS (not available as this is being written) is available for two time periods. For the time period 14 April 2003 to 21 July 2004, the URL site averaged 9 visits per day on weekdays and 15 visits per weekend. For this time period, the web site had 4,254 visits. Out of these 4,254 visits, 2,137 visits were by unique visitors. This means that the difference between these two numbers, 2117 visitors, or roughly half, were repeat visits. The average number of visits per four-week period is 151, with an average of 76 unique visitors per four-week period. For the period of 1/1/2005 to 9/13/2005, the URL site averaged 3 visits per day on weekdays and 6 visits per weekend. For this time period, the website had 870 visits. Out of these 870 visits, 295 were by unique visitors. This means that the difference between these two numbers, 575, were repeat visitors. The average number of visits per four-week period is 62, with an average of 32 unique visitors per four-week period.

3. Other presentations directed to specific technical audiences were accomplished as described in **Table 7-3**. Comments generated were considered in technical analyses conducted for this study.

TABLE 7-3. General Meetings

Dates/Meeting/Location	Audience	ORMSS Team Presentation(s)
January 2004/Transportation Research Board/Washington, D.C.	Academic and Business Transportation Officials	ORNIM
July 16-17, 2002/ Economic and Environmental Conference, US Army Corps of Engineers/New Orleans, LA	Water resource professionals from the Corps, academia, government agencies, and various NGOs	Traffic Management
June 2-5, 2005/International Association of Impact Assessment (I.A.I.A.) Conference/Boston MA	Environmental Agencies and NGOs	Study Status, Traffic Forecast Scenarios, Environmental Sustainability, Mussels, Monitoring and Adaptive Management, and Potential Applications of Methodologies

7.3 CORPS INTERACTION WITH INDUSTRY

Coordination with industry consisted of several briefings to groups including DINAMO and the Waterways Council, Inc. that focused on progress and preliminary findings. In May 03, the Corps discussed initial forecast scenarios and implications on traffic through several locks. All meetings are listed in Table 7-4.

TABLE 7-4. Meetings and Briefings With Industry Representatives

Dates/Meeting/Location	Audience	ORMSS Presentation(s)
March 2, 2001/Inland Waterways Conference	Inland Waterways Conference Panel	
Nov. 30, 2001/Inland Waterways User Board Meeting/Fort Lauderdale, FL	Inland Waterways User Board	
Apr. 25, 2002/Inland Waterways User Board Meeting/Chattanooga, TN	Inland Waterways User Board[1]	Study Status and Commercial Traffic Forecasting
July 2002/DINAMO[1]/Ligonier, PA	DINAMO (River Transportation) Representatives	
October 31, 2002/DINAMO/Emsworth, PA	DINAMO officials	
March 11-12, 2003/Inland Waterways Conference/Cincinnati, OH	River Transportation Officials	
July 30, 2003/DINAMO/Pittsburgh, PA	DINAMO officials	Study Methodology
September 23, 2003/Houston, TX	National Waterways Conference	
January 13, 2004/Washington, DC	Waterways Council, Inc.	
March 2004/Inland Waterways User Board Meeting/	Inland Waterways User Board	
September 2, 2004/Washington, DC	Waterways Council, Inc., Great Lakes and Ohio River and Mississippi River Divisions of the Corps	
February 23-24, 2005/Tampa, FL	Waterways Council, Inc., Great Lakes and Ohio River and Mississippi River Divisions of the Corps	
March 2005/Inland Waterways User Board Meeting/	Inland Waterways User Board	

[1]Industries represented by IWUB attending meeting included Cargill Marine & Terminal, Alter Barge, Inc. MEMCO Barge Line, Ingram Barge Co., Parker Towing Co., Peabody COALSALES Co., Shaver Transportation, Holcum (US), Inc., CONSOL Energy, Inc., Kirby Corp., and American Barge Line. Also attending was Volunteer Barge & Transport, Inc.

[2]Presentations also made by representatives from HDR, Inc., Balch & Bingham, LCC, J. Simmons Group, Transportation Institute (Houston), Atlantic Intracoastal Waterways Assoc., Transportation Research Board, and House Energy & Water Development Subcommittee.

7.4 DRAFT REPORT COORDINATION/REVIEW

1. To announce the availability of the System Investment Plan, a direct mailing was made to individuals and organizations on the mailing list developed specifically for the release of the report. A post card was used for the majority of the mailing list, primarily those individuals and agencies not required to receive a copy of the report. The post cards were mailed one week prior to the release of draft report. This post card contained the following information:

- Availability of the draft SIP for review
- Web site address of report
- How to view a copy of report
- How to obtain a copy of report
- Dates and locations of public meetings
- Dates of the public review period

2. The mailing directed interested parties to the ORMSS website. Both the mailing and the website explained how to obtain paper or electronic copies of the report. The website contained Frequently Asked Questions, updated at the time to the report release to summarize the report findings, answer questions about how to obtain a copy of the report, and inform interested parties about public involvement activities. Additionally, the report itself was placed on the website, so that interested parties were able to view it. An e-mail link will be provided for those who wish to submit comments.

3. Public meetings were held at six sites, in six different states, as listed below:

- Metropolis, Illinois
- Evansville, Indiana
- Covington, Kentucky
- Huntington, West Virginia
- Marietta, Ohio
- Beaver, Pennsylvania

4. Visual aids were developed for the public meetings: maps, handouts, PowerPoint presentations, etc. Press releases announced the release of the draft report and provided summary information on the report's results.

SECTION 8
OHIO RIVER MAINSTEM WITHOUT-PROJECT CONDITION FORMULATION AND ASSESSMENT (NO ACTION ALTERNATIVE UNDER NEPA)

8.1 BACKGROUND

1. Using the traditional Corps definition of the Without-Project Condition (WOPC), the WOPC for the Ohio River Navigation System is the most likely condition expected to prevail on the Ohio River Mainstem throughout the planning horizon in absence of additional project (Congressional) authorizations. For the ORMSS, this definition has been expanded to reflect the current philosophy concerning planning for a highly uncertain future. One of the most critical determinants of the need for future investments in the Ohio River Navigation System and at the same time the most uncertain is the demand for waterway commodity movements through all Ohio River locks.

2. To address the inherent difficulties associated with predicting traffic forecasts on the Ohio River, multiple scenarios were postulated that represent a reasonable range of futures of unconstrained traffic demand. Unconstrained forecasts are necessary as a starting point so that the processing limits (that could result in delays to navigation and divert some traffic off of the river) at any of the Ohio River locks can be ascertained and solutions determined. Specifically, the goal of this approach is to define a range of reasonable alternative scenarios that ultimately describe the potential demand for transportation of major commodities transported on the Ohio River. A consequence of applying a scenario-based approach to traffic forecasting is multiple representations of the without-project condition. However, scenarios are not evaluated with respect to numerical probability or likelihood of occurrence. A single most probable without-project condition therefore is not identified. Consideration of the impacts of various scenarios will greatly enhance the decision-making process. This scenario-based approach is consistent with the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G), the procedural and analytical framework for Corps feasibility studies. The WOPC is determined for each traffic scenario and will not necessarily represent the status quo in terms of Corps operations and maintenance of the existing system in the absence of new investment. Any reasonably expected and economically justified nonstructural measure within Corps authority is assumed implemented at the appropriate time. The WOPC includes operational measures which are routinely employed during periods of congestion. These

include the use of helper boats and revised lockage policies to improve project performance and ensure the best use of the existing facilities during main chamber closures. The WOPC also includes authorized improvements that are either under construction or are pending appropriation. The most likely WOPC does not include any proactive maintenance requiring an investment decision.

3. The Ohio River project that is authorized and currently under construction, Olmsted, and those in the Preconstruction Engineering and Design stage (Greenup and Myers) are incorporated into the WOPC in accordance with the anticipated construction schedules noted in **Section 2-2**.

4. The importance of the WOPC has not changed; it still serves as the basis against which impacts of project improvements or additions requiring Congressional authorization (in any "With-Project" Condition or "WPC) are measured. The net system-wide transportation savings (benefits less costs) and impacts to the valued environmental components (VECs) due to any WPC would be compared to those values in the corresponding WOPC (i.e. based on the same set of economic and environmental forecasts). Likewise, the environmental and social measures of any With Project plan would be compared to those of the appropriate Without-Project Condition.

5. After the various traffic demand scenarios are described in subsection 8.2, maintenance, operational, low-cost structural, and ecosystem restoration measures are considered and screened. WOPC alternatives are formulated by combining these measures in a systematic way as described in subsections 8.6 for navigation and 8.8 for ecosystem sustainability. Two general navigation alternatives are evaluated as part of the WOPC. One of these alternatives is screened from the analysis. One ecosystem restoration alternative is formulated for the WOPC. The navigation alternative is evaluated as described in Section 8.7 and the ecosystem alternative is evaluated in Section 8.9.

8.2 PROJECTED TRAFFIC DEMANDS

1. Traffic demand forecasts for this study represent a comprehensive update of previous forecasts completed in the spring of 1999 for the Myers and Greenup Locks Improvements Feasibility Report. New forecasts were prepared for all commodity groups, but because of the dominance of utility steam coal on the system and the uncertainties surrounding the regulatory future, alternative scenarios were developed only for utility coal and sorbent materials (lime and limestone) used for coal desulfurization. The dominance of these commodities shipped on the Ohio River is expected to continue through the planning period although other commodities continue to represent a significant percentage of traffic in the future as well.

2. Adjustments to the 1999 forecasts were required for utility coal due to regulatory changes that occurred since then and others likely to occur in the future pertaining to the electric utility industry. The current round of adjustments to the utility coal forecasts was

necessitated by existing and likely future regulatory changes (primarily related to air emissions) affecting the electric utility industry. Coal that moves by barge to electric utilities accounts for nearly half of all traffic on the Ohio River System (ORS). This market for coal continues to receive much attention from government regulators, the Congress, and the public. Regulation and law governing coal's use overseas, and stiff competition from competing exporting countries has been responsible for the near disappearance of the steam coal export market, particularly in Europe. For the ORS, the result has been the first prolonged period of coal traffic stagnation. While other commodities and barge-served markets face uncertainty, none matches the dominance of coal or level of uncertainty regarding future use. Environmental issues are acknowledged by industry experts to be the dominant issues expected to affect future coal utilization and sourcing (i.e. result in coal switching[1]) on the part of the electric utilities. In light of this, five alternative forecast scenarios were developed, three of which directly reflect alternative legislative approaches to emissions reductions. A "broad-based" or single projection for all other traffic is also made and incorporated into each of these scenarios. Details on forecasting methodology are provided in Section 6 of the Economics Appendix.

3. Section 8.2 presents the current traffic demand forecasts for the Ohio River for the 2010-2070 planning period. In total, five alternative traffic demand forecasts for utility steam coal and the lime and limestone as previously cited were developed. These forecasts were combined with a single forecast for all other commodity traffic. For all scenarios, the arrival rate throughout the year is expected to remain relatively uniform (i.e. non-seasonal) throughout the planning horizon. Furthermore, the expected tow size distribution at each facility throughout the planning horizon is expected to be about the same as shown in **Table 4-6**.

8.2.1 Traffic Forecast Scenarios

Of the five forecasts for the shipment of utility coal demands, two were based on information obtained from utility surveys[2] regarding their plans in light of environmental regulations. These scenarios are termed the Utility-Based and Utility Based-High scenarios. The difference between these two is that the Utility Based-High scenario assumes high economic growth. The remaining three scenarios used output of Hill and Associates[3] models, based on their National Power Model and other related models. The

[1] Coal switching refers to a plant changing the sources of their coal. Different coals have different characteristics (heat, water, sulfur content). Environmental regulations may require plants to alter their coal supplies.

[2] A total of 15 companies (utilities and non-utility generators) either currently or historically using the ORS was included in the survey. Coal shipped on the ORS in 2000 by these companies totaled about 115 million tons, or 99 percent of the utility coal and 80 percent of total coal movement on the ORS that year. Each company was asked to provide estimates of generation and coal use at their plants for 2005 and 2010.

[3] Hill and Associates is a management consulting firm specializing in the coal and electric utility industries. They maintain an extensive modeling system of the electric utility industry and have done consulting work for the Department of Energy (DOE), the Environmental Protection Agency (EPA) and other clients in government and private industry. The work of Hill and Associates is consistently cited by DOE in their Annual Energy Outlook.

first of these is a continued application of existing laws, specifically the National Ambient Air Quality Standards. This scenario is referred to as the NAAQS scenario. The second Hill scenario reflects implementation of the administration's multi-emissions proposal, the Clear Skies Initiative, as an amendment to the Clean Air Act. This proposal, referred to as the Clear Skies scenario could be expected to have a fairly profound impact on the use of coal by electric utilities, largely because of the proposal's implied mercury emissions restrictions. The final Hill scenario would be implementation of the Clear Skies initiative without the severe mercury restrictions that are included under Clear Skies. This scenario is referred to as the Modified Clear Skies Scenario. All of the forecast scenarios reflect the effects of coal switching by ORS-dependent utilities to meet the requirements of existing or proposed environmental regulations. The utility-based forecasts reflect the outlook of the utilities themselves. Additional details regarding the alternative forecast scenarios are provided in **Attachment 4** of the Economics Appendix.

8.2.2 Forecast Results

This section describes the future traffic projections, with particular emphasis placed on factors impacting coal movements through Ohio River locks. Traffic for the ORS and the Ohio River Mainstem is addressed.

8.2.2.1 ORS Traffic Demands

Projected unconstrained traffic demands for the ORS under each of the five alternative forecast scenarios for the period 2010-2060 are displayed in **Table 8-1**. Traffic from 2060 to 2070 is assumed to be constant. Over the longer term, the high and low alternatives that emerge are the Utility-Based High scenario and the Clear Skies scenario. The first of these forecasts reflects the outlook of the major utility users of the ORS along with the application of the ORS utility coal model in a high economic growth framework. The second reflects implementation of the administration's Clear Skies Initiative with its expected negative impact on coal usage. In year 2020, the forecasts range between 318 million tons under the Clear Skies scenario and 350.4 million tons under the Utility-Based High scenario. By year 2060, the range is between 368.7 and 511.0 million tons for these same scenarios. Annual growth for the 2000-2060 period ranges from 0.51 percent to 1.06 percent. This is compared to annual growth over the 1970-2000 period of 1.7 percent per year.

TABLE 8-1

Actual and Projected Unconstrained ORS Traffic Demand, 1970-2060
(Million Tons)

Scenario	Actual 1970	Actual 2000	2010	2020	2030	2040	2050	2060	Annual % Growth Actual 1970-2000	Annual % Growth Projected 2000-60
Utility-Based High	163.9	271.8	312.5	350.4	393.1	439.3	463.1	511.0	1.70	1.06
Utility-Based	163.9	271.8	312.5	336.4	369.8	402.2	418.0	449.9	1.70	0.84
NAAQS	163.9	271.8	305.7	348.5	379.3	412.4	429.9	461.5	1.70	0.89
Clear Skies	163.9	271.8	268.7	318.0	331.2	344.5	356.5	368.7	1.70	0.51
Modified Clear Skies	163.9	271.8	313.1	344.4	373.5	406.1	423.0	454.0	1.70	0.86

SOURCE: USACE Waterborne Commerce Statistics and LRD Navigation Planning Center

8.2.2.2 Ohio River Traffic Demands

Table 8-2 shows total projected unconstrained traffic demands for the mainstem Ohio River through 2060 with traffic assumed to be constant from 2060 to 2070. Traffic demands for the mainstem show similar patterns to those for the ORS. Ohio River mainstem traffic annually accounts for about 87 percent of total system traffic throughout the forecast period. In 2020, traffic demands range between 273.6 million tons under the Clear Skies scenario and 306.1 million tons under the Utility-Based High scenario. In 2060, the range is between 322.3 and 443.2 million tons. Annual growth between 2000 and 2060 under Clear Skies is 0.5 percent and under the Utility-Based High scenario 1.03 percent. Over the 1970-2000 period, growth rates for traffic on the Ohio River mainstem were substantially higher than for the ORS overall (2.1 versus 1.7 percent per annum). For the forecast period, growth rates for the ORS are slightly higher under all scenarios, indicating that traffic demand growth for tributary streams, especially the Tennessee River, are higher than the mainstem.

TABLE 8-2

Actual and Projected Unconstrained Ohio River Mainstem Traffic Demand, 1970-2060
(Millions of Tons)

Scenario	Actual 1970	Actual 2000	2010	2020	2030	2040	2050	2060	Annual % Growth Actual 1970-2000	Annual % Growth Projected 2000-60
Utility-Based High	129.6	239.0	273.3	306.1	342.2	380.0	403.4	443.2	2.06	1.03
Utility-Based	129.6	239.0	273.3	294.9	323.2	350.8	368.0	394.7	2.06	0.84
NAAQS	129.6	239.0	267.0	302.6	327.8	355.6	373.1	399.8	2.06	0.86
Clear Skies	129.6	239.0	235.1	273.6	286.1	298.9	310.6	322.3	2.06	0.50
Modified Clear Skies	129.6	239.0	271.3	297.4	320.5	347.5	364.6	390.5	2.06	0.82

SOURCE: USACE Waterborne Commerce Statistics and LRD Navigation Planning Center

8.2.2.3 Lock-Level Traffic Demands

1. Unconstrained traffic demand forecasts for the Ohio River mainstem locks are displayed in **Table 8-3**, again with traffic levels assumed constant between 2060 and 2070. (Traffic forecast on the Ohio River mainstem by commodity group is provided in the **Economic Appendix**.) These lock-specific forecasts are very sensitive to environmental regulations that can affect coal sourcing for various plants, and this in turn can significantly affect the coal movements through the Ohio River facilities. Due primarily to such differences in coal sourcing, forecasts can align quite differently at the locks. For example, the high forecast at one lock might not be the high forecast at another.

2. Under most of the forecast scenarios, forecast growth rates are the highest for the lower river locks. This reflects an increased interest in Illinois Basin and Northern Illinois coals on the part of the utilities, as well as increases in the movement of western coal on the Ohio River System. Utilities are expected to include more Illinois Basin, as well as Northern Appalachian, coals in their mixes. The increasing demand for coal from these sources, which is relatively high in sulfur content but lower in cost than coals now used from the Kanawa basin, is due to the fact that scrubbers are becoming more widespread, which render the sulfur content of coals less important. Many plants have added scrubbers during major modifications to their plants and new plants have incorporated scrubbers because of the environmental regulations regarding modified and new plants. Some utilities have reached the point where their least-cost option for meeting their environmental requirements is to add scrubbers. Northern Appalachian coal always has and is expected in the future to move primarily on the middle and lower Ohio River (serving, for example, the Florida coal market). Use of this coal in the scenarios is reflected in traffic growth downstream of and including Hannibal.

TABLE 8-3

Unconstrained Projected Lock Traffic Demand
(Millions of Tons)

Project/Scenario	2000	2010	2020	2030	2040	2050	2060	Annual % Change 2000-60
Emsworth:								
Utility-Based High	21.9	24.6	25.7	27.8	29.7	30.8	33.3	0.70
Utility-Based	21.9	24.6	24.8	26.1	27.5	28.3	29.8	0.51
NAAQS	21.9	22.1	30.1	32.2	34.3	36.0	38.2	0.93
Clear Skies	21.9	19.2	24.8	24.9	25.2	25.6	26.0	0.28
Modified Clear Skies	21.9	23.9	26.9	28.6	30.4	31.9	33.8	0.72
Dashields:								
Utility-Based High	22.4	25.0	26.2	28.3	30.2	31.3	33.9	0.69
Utility-Based	22.4	25.0	25.3	26.6	28.0	28.8	30.3	0.51
NAAQS	22.4	22.5	30.6	32.7	34.8	36.5	38.8	0.92
Clear Skies	22.4	19.7	25.3	25.4	25.8	26.2	26.6	0.29
Modified Clear Skies	22.4	24.4	27.4	29.1	30.9	32.4	34.4	0.72
Montgomery:								
Utility-Based High	25.2	27.3	28.5	30.8	32.9	34.1	36.9	0.63
Utility-Based	25.2	27.3	27.6	29.1	30.6	31.6	33.3	0.46
NAAQS	25.2	26.0	34.7	37.0	39.4	41.3	43.9	0.93
Clear Skies	25.2	22.2	28.3	28.5	29.1	29.6	30.2	0.30
Modified Clear Skies	25.2	27.8	31.7	33.8	35.9	37.6	39.9	0.77
New Cumberland:								
Utility-Based High	34.2	35.8	37.0	40.1	43.0	44.5	48.5	0.58
Utility-Based	34.2	35.8	35.7	37.7	39.8	41.0	43.7	0.41
NAAQS	34.2	35.9	47.2	50.4	53.5	55.8	59.3	0.92
Clear Skies	34.2	23.5	38.2	38.6	39.3	40.1	40.9	0.30
Modified Clear Skies	34.2	42.5	43.8	46.6	49.4	51.6	54.7	0.79
Pike Island:								
Utility-Based High	42.3	46.7	48.8	53.0	56.5	58.9	64.0	0.69
Utility-Based	42.3	46.7	47.3	50.1	52.8	54.8	58.3	0.54
NAAQS	42.3	47.7	58.9	63.0	66.8	69.9	74.2	0.94
Clear Skies	42.3	35.4	51.0	51.8	53.1	54.3	55.7	0.46
Modified Clear Skies	42.3	54.3	55.8	59.5	63.0	65.9	69.9	0.84
Hannibal:								
Utility-Based High	49.8	63.0	64.8	71.4	77.1	82.1	90.7	1.00
Utility-Based	49.8	63.0	62.2	66.6	71.0	74.7	79.9	0.79
NAAQS	49.8	66.8	72.6	78.3	83.8	88.8	95.0	1.08
Clear Skies	49.8	52.0	60.6	61.6	62.9	64.3	65.8	0.47
Modified Clear Skies	49.8	70.3	75.0	80.9	86.5	91.7	98.0	1.14
Willow Island:								
Utility-Based High	47.0	59.1	61.4	67.5	72.8	77.4	85.1	0.99
Utility-Based	47.0	59.1	59.0	63.1	67.2	70.6	75.5	0.79
NAAQS	47.0	63.5	69.3	74.6	79.9	84.6	90.5	1.10
Clear Skies	47.0	48.7	57.4	58.3	59.7	61.2	62.7	0.48
Modified Clear Skies	47.0	67.0	71.7	77.2	82.7	87.5	93.6	1.15

TABLE 8-3 (cont)

Unconstrained Projected Lock Traffic Demand (Millions of Tons)

Project/Scenario	2000	2010	2020	2030	2040	2050	2060	Annual % Change 2000-60
Belleville:								
Utility-Based High	50.9	63.3	65.7	72.0	77.5	82.3	90.1	0.96
Utility-Based	50.9	63.3	63.4	67.6	71.9	75.5	80.6	0.77
NAAQS	50.9	67.7	73.7	79.1	84.6	89.5	95.6	1.05
Clear Skies	50.9	52.9	61.7	62.9	64.4	66.0	67.8	0.48
Modified Clear Skies	50.9	71.2	76.1	81.7	87.3	92.4	98.6	1.11
Racine:								
Utility-Based High	51.5	63.9	66.3	72.6	78.1	82.9	90.8	0.95
Utility-Based	51.5	63.9	64.0	68.2	72.5	76.1	81.3	0.76
NAAQS	51.5	68.3	74.3	79.8	85.2	90.1	96.3	1.05
Clear Skies	51.5	53.5	62.3	63.5	65.1	66.7	68.4	0.48
Modified Clear Skies	51.5	71.8	76.7	82.4	88.0	93.0	99.3	1.10
Byrd:								
Utility-Based High	59.1	70.7	76.4	83.7	91.1	97.7	107.0	1.00
Utility-Based	59.1	70.7	73.4	78.6	84.1	88.6	94.7	0.79
NAAQS	59.1	56.9	63.2	67.3	71.9	76.0	80.8	0.52
Clear Skies	59.1	52.7	56.4	57.9	59.9	61.8	63.9	0.13
Modified Clear Skies	59.1	56.4	65.7	70.1	74.8	79.1	84.1	0.59
Greenup:								
Utility-Based High	74.0	83.9	92.9	103.0	114.2	124.2	137.0	1.03
Utility-Based	74.0	83.9	89.0	96.7	104.6	111.3	119.9	0.81
NAAQS	74.0	64.0	71.0	76.4	82.2	87.6	93.6	0.39
Clear Skies	74.0	58.5	64.6	67.4	70.6	73.6	76.9	0.06
Modified Clear Skies	74.0	63.8	72.4	78.0	83.8	89.3	95.4	0.43
Meldahl:								
Utility-Based High	64.6	72.1	77.7	85.6	94.7	102.5	112.5	0.93
Utility-Based	64.6	72.1	75.0	81.3	87.7	93.1	99.9	0.73
NAAQS	64.6	55.6	61.8	66.4	71.1	75.8	80.9	0.37
Clear Skies	64.6	50.2	54.9	57.5	60.4	63.3	66.4	0.05
Modified Clear Skies	64.6	55.4	62.6	67.3	72.0	76.7	81.9	0.40
Markland:								
Utility-Based High	56.0	65.6	68.9	75.4	82.9	88.0	95.9	0.90
Utility-Based	56.0	65.6	67.3	72.8	78.5	82.8	88.4	0.76
NAAQS	56.0	56.9	69.7	75.3	80.9	86.0	91.7	0.82
Clear Skies	56.0	51.7	63.6	66.8	70.2	73.5	76.9	0.53
Modified Clear Skies	56.0	56.2	66.8	72.0	77.3	82.2	87.6	0.75
McAlpine:								
Utility-Based High	55.2	65.3	70.2	76.8	84.4	90.5	98.4	0.97
Utility-Based	55.2	65.3	68.6	74.4	80.4	85.2	91.2	0.84
NAAQS	55.2	68.8	82.3	89.1	96.2	103.1	110.3	1.16
Clear Skies	55.2	54.7	72.8	76.3	80.1	83.9	87.6	0.77
Modified Clear Skies	55.2	71.0	77.2	83.5	90.1	96.4	103.0	1.05

TABLE 8-3 (cont)

Unconstrained Projected Lock Traffic Demand (Millions of Tons)

Project/Scenario	2000	2010	2020	2030	2040	2050	2060	Annual % Change 2000-60
Cannelton:								
Utility-Based High	54.1	66.1	71.7	78.6	86.7	92.8	101.2	1.05
Utility-Based	54.1	66.1	70.0	76.1	82.4	87.3	93.6	0.92
NAAQS	54.1	71.5	85.1	92.4	100.0	107.1	114.8	1.26
Clear Skies	54.1	58.0	72.8	76.5	80.5	84.2	88.2	0.82
Modified Clear Skies	54.1	74.1	80.9	87.7	94.8	101.5	108.7	1.17
Newburgh:								
Utility-Based High	63.0	75.1	83.7	93.2	103.3	110.2	121.0	1.09
Utility-Based	63.0	75.1	81.3	89.0	97.0	102.4	110.2	0.94
NAAQS	63.0	85.4	100.0	109.6	119.4	126.9	136.7	1.30
Clear Skies	63.0	69.8	83.0	86.9	91.4	95.4	99.7	0.77
Modified Clear Skies	63.0	87.7	96.3	105.5	115.0	122.1	131.5	1.23
Myers:								
Utility-Based High	72.0	85.1	97.9	110.4	125.5	131.5	145.5	1.18
Utility-Based	72.0	85.1	94.4	104.6	115.6	119.8	129.5	0.98
NAAQS	72.0	93.6	106.1	117.2	129.0	135.7	146.5	1.19
Clear Skies	72.0	77.6	88.6	93.0	98.4	103.2	107.8	0.68
Modified Clear Skies	72.0	94.3	102.0	112.6	124.0	130.3	140.7	1.12
Smithland:								
Utility-Based High	81.4	95.3	110.3	124.9	143.1	148.9	165.3	1.19
Utility-Based	81.4	95.3	105.9	118.0	130.7	134.5	145.6	0.97
NAAQS	81.4	105.8	119.9	133.2	147.4	152.0	164.6	1.18
Clear Skies	81.4	88.8	101.6	106.4	112.1	116.4	121.0	0.66
Modified Clear Skies	81.4	106.9	115.4	127.5	141.0	145.3	157.2	1.10
L/D 52: 1/								
Utility-Based High	91.8	107.5	121.2	134.7	148.9	158.4	172.4	1.06
Utility-Based	91.8	107.5	118.7	130.3	142.1	150.2	160.9	0.94
NAAQS	91.8	114.1	129.7	141.9	154.7	163.7	175.4	1.09
Clear Skies	91.8	98.5	113.1	120.6	128.5	135.1	142.1	0.73
Modified Clear Skies	91.8	116.2	127.2	138.7	151.2	159.9	171.3	1.05
L/D 53: 1/								
Utility-Based High	85.3	93.2	103.0	112.5	123.0	132.0	142.0	0.85
Utility-Based	85.3	93.2	102.1	111.1	120.5	128.5	137.1	0.79
NAAQS	85.3	92.0	102.8	108.0	117.1	124.0	132.1	0.73
Clear Skies	85.3	85.8	93.5	100.9	108.8	115.3	122.2	0.60
Modified Clear Skies	85.3	93.4	103.5	107.5	116.6	123.5	131.5	0.72

SOURCE: USACE Waterborne Commerce Statistics and LRD Navigation Planning Center

3. The utility-based scenarios show the lowest growth rates occurring at the uppermost locks on the Ohio, while the three scenarios developed by Hill and Associates show the lowest growth rate occurring at projects on the middle river. Generally speaking, the NAAQS, Clear Skies, and Modified Clear Skies scenarios are more pessimistic concerning the future of Central Appalachian coal than the utility-based scenarios.

8.3 MAINTENANCE MEASURES CONSIDERED

1. Maintaining the operation of any lock and dam facility requires a variety of measures ranging from routine actions performed every year to major work that could necessitate dewatering of a lock chamber to allow for repairs or replacement of various project components. Major work may involve scheduled or unanticipated (unscheduled) work.

2. Historically, lock improvement studies for ORS locks and dams have assumed unconstrained funding for major maintenance and major rehabilitation (discussed in Section 6.1) in developing the WOPC. The WOPC in navigation feasibility studies therefore typically include a mixture of non-structural and structural measures like component replacement and chamber rehabilitation not requiring congressional authorization. The Corps has authority for major rehabilitations and advanced replacements of major components (gates, valves, etc.) but recent history shows the Administration considers some component replacements and all major rehabilitation as a new start and the Administration is not currently budgeting for new starts (e.g. Markland Major Rehabilitation).

3. Therefore, for purposes of this analysis, any maintenance beyond the measures considered below is assumed to require an investment decision and is not included in the WOPC. These measures will be treated as with-project alternatives along with other structural improvements (described in Section 9).

8.3.1 Maintenance Measures Currently Implemented

Each of the measures described in this section have historically been implemented at Corps locks and dams.

8.3.1.1 Routine Operations and Maintenance

1. The routine or normal daily activities associated with operating and maintaining the projects are included in the SIP analysis. These are simply termed annual operation and maintenance (O&M) measures. Actions carried out under this category are typically handled by hired labor, but small contracts are used where feasible. Annual operating cost categories include all project site labor, overhead, equipment costs, and minor maintenance such as low-cost painting. Also included are minor contract actions such as services for grass cutting, etc. Such work does not require closures of

lock chambers, thus, there is no impact to navigation. There are normally few, if any, environmental impacts associated with this category of operating costs.

2. It is inevitable that "random minor" events that are independent of maintenance will arise that require the Corps to unexpectedly close a lock chamber for very short duration, ranging from several hours up to several days. These events involve the malfunction of equipment that can be repaired without the full repair fleet or the need to repair miscellaneous items such as floating mooring bits or wall armor. Random minor closures and associated random minor maintenance costs also reflect lock closures for periodic testing of lock equipment by either on-site or contract personnel and not the large repair fleet. Random minor closures also occur for things such as debris in lock, tow malfunctions, accidents, etc. Random minor costs are accounted for separately in economic analyses. For a detailed look as to how future levels of random minor events are projected and incorporated into the economic models, refer to **Attachment 3 of the Economics Appendix**.

8.3.1.2 Cyclical Maintenance

1. In addition to these everyday activities, all Districts perform maintenance and inspections of major lock and dam structures and operating machinery on cyclical schedules. For ORMSS purposes, this maintenance category is referred to as the Cyclical Maintenance program. This program varies for each district and project due to factors that include workload and available resources. For a more detailed look into each district's projected cyclical maintenance program, refer to Section 7 the **Engineering Appendix** . Costs are considered for maintenance of locks and dams separately.

2. Scheduled lock maintenance costs are costs related to periodic or cyclical chamber inspections that close a chamber, including any some relatively minor maintenance/repair costs. Both the inspections and significant maintenance require lock chamber closures for dewatering. The inspection-dewatering program is intended to provide an opportunity for USACE personnel to make structural assessments, note on-going problems, and make minor repairs when necessary. Inspection dewaterings typically require the chamber to be closed from 10 to 15 days. Significant maintenance dewaterings are required for major repairs to components such as miter gates, culvert valves, and/or operating machinery. Such dewaterings are typically required every 10 to 15 years depending upon the project site and condition and responsible district's maintenance program. Chambers will typically be closed from 30 to 45 days for significant maintenance depending upon the work to be accomplished and the chamber being repaired. Cyclical maintenance procedures typically do not address the long term failure probabilities (reliability) associated with fatigue/fracture and the end of useful design life and therefore it is assumed that cyclical maintenance does not have a significant affect on the overall reliability of the structures[4].

[4] This is mainly due to the fact that we are looking at failure modes that are associated with fatigue and fracture of critical members (miter gates and valves in particular)

3. Scheduled dam maintenance costs are attributed to maintenance of dam components (dam gates, operating machinery, concrete piers, etc.) This maintenance is critical to navigation but does not require a closure because the repair fleet can tie up outside the river wall keeping lock chambers open to traffic. Reliability modeling was not performed on dam components because it was not part of the project management plan (PMP). Deterministic scheduled dam maintenance costs are estimated from engineering judgment and are the same in all maintenance and improvement plans analyzed. Dam maintenance costs are included in the analysis to account for the full cost of operating the system.

8.3.1.3 Unscheduled Lock Repairs

Repair or replacement of major lock components that malfunction are performed as required and are by definition unscheduled with little or no advance notice to industry. These repairs may require extended closures of one or even both lock chambers, and are separate from the random minor closures described under routine maintenance and any cyclical maintenance. The unscheduled repairs of major lock components are in effect reactive maintenance. The major lock components included in this repair category include miter gates and machinery, filling and emptying valves and machinery, hydraulic and electric systems. These closures are considered reliability related. For additional details, see **Section 5 of the Engineering Appendix**.

8.3.2 Maintenance Measure Not Currently Implemented

One measure not currently implemented by the Corps was considered for implementation in the WOPC.

8.3.2.1 Miter Lock Gate Replacement Capability

1. The Great Lakes and Ohio River Division has begun to implement a system whereby miter gates can be repaired in a more efficient manner by using a new maintenance procedure for miter gate maintenance. This new strategy is referred to as the Miter Gate Quick Changeout System (MGQCS). The MGQCS will allow lock chamber closures for miter gate repair and maintenance to be considerably shortened in duration when compared to "traditional" methods. This system was evaluated in the June 1992 report prepared by the Louisville District (see **Table 3.1**) that recommended pursuing initiatives that would lead to the ability to change out gates quickly as miter gates are typically the main structural elements requiring maintenance during lock dewaterings.

2. Full implementation of the MGQCS has three requirements:

- A specially designed barge-mounted crane to lift the gate out of the lock.
- Gates that are modified such that they can be lifted with a crane and mitering surfaces can be adjusted quickly.

- Spare miter gates and storage piers where those gates can be stored. The spare gates would be modified in the same fashion as the existing gates.

3. At this time, the MGQCS is only partially implemented. The first item, a gatelifter crane, has been acquired. This derrick boat crane, the Henry Shreve, is based in Louisville at McAlpine L&D. The Shreve is officially a LRD asset and is scheduled based on LRD needs. It can be used in all of the 600-foot and 1200-foot locks since they are 110' wide. The required modifications to the existing miter gates have been made at some, but not all, of the Ohio River locks. All of the gates in the 600-foot lock chambers in the Louisville District (from Markland down to Smithland, to include Olmsted, listed in **Table 4-2**) have been modified. Of the 1200-foot chambers in the Louisville District, two gate leaves[5] at Newburgh, two gate leaves at Cannelton, and all eight gate leaves at Smithland remain to be modified. In the Huntington District (from Willow Island down to Meldahl, listed in **Table 4-2**), none of the gates have been modified. Current plans are for all gates at all projects below Mongtomery to be modified for lifting with the Shreve. Currently, spare gates are available only for the Olmsted project, which is currently under construction.

4. Other details of this system, including adding spare gates and storage facilities, and development of a schedule for how those gates would be rotated between main and auxiliary chambers, have not been worked out. Currently, auxiliary chamber gates that can be lifted at any Ohio River project with twin 110' wide chambers (i.e. downstream of Montgomery) can serve as a set of "spare" gates if emergency repairs are required to any of the same project's main chamber gates. A concept and design for a gate assembly/storage pier system has been developed, but a gate storage facility has been constructed only at McAlpine and Smithland. The storage facility at Smithland is to be used for both the Olmsted and Smithland projects since the spare gates can be transported short distances on the Shreve.

8.3.3 Assessment of Maintenance Measures

Routine and cyclical maintenance are necessary for continued operation and maintenance of the lock and dam system and are carried forward. Unscheduled repairs of component failures will also be required in a timely fashion to keep the system operating and is also carried forward. Additional implementation of the MGQCS by obtaining spare gates is also considered an investment and dropped from consideration for the same reasons as proactive maintenance. However, all gates below EDM are assumed to be modified for lifting with the Shreve by the beginning of the analysis period (2010), which will reduce times to make gate repairs somewhat, and this capability will be reflected in economic analyses. **Table 8-4** summarizes the assessment of maintenance measures.

[5] There are four gate sections, or leaves, per chamber at all locks, two each on the upper and lower end. All dual chambers have eight gate leaves.

TABLE 8.4
Maintenance Measures Carried Forward and Dropped From Consideration in WOPC

Summary of Maintenance Measures Carried Forward in WOPC:
Routine Maintenance
Cyclical Lock and Dam Maintenance
Unscheduled Repairs-
Maintenance Measures Dropped From Consideration in WOPC
Full Implementation Miter Gate Quick Changeout System Lock Gate Replacement
Proactive Maintenance - Scheduled Component Replacements
Major Rehabilitation

8.3.4 Cost Estimation for Reactive Maintenance Measures Carried Forward

1. Pertinent considerations for future implementation costs for the three maintenance measures retained in the WOPC are discussed below. Additional details are provided in the **Engineering Appendix**.

2. Future levels of routine maintenance and cyclical maintenance in each District are based on current practices and policies. Routine maintenance for all facilities also includes the day-to-day costs to operate the locks and dams. Annual routine maintenance costs were developed by tracking recent (1999-2003) 5-year operational costs and inflating them to current cost levels.

3. Costs and durations of any lock closures for unscheduled component repairs or replacement were determined for each site and based on engineering judgment or past experience where possible. The **Engineering Appendix** contains additional details on these costs.

8.4 OPERATIONAL EFFICIENCY AND LOW-COST STRUCTURAL MEASURES CONSIDERED

1. As previously noted, the periods of heaviest delays currently experienced at all Ohio River locks occur when the main chamber is closed for an extended period of more than about 10 days. Average delays during normal operations are typically on the order of a tenth of the average delays during significant main chamber closures. Therefore, the Corps and industry take special measures during main chamber closure events to reduce these delays, and the associated costs. These measures are described below. Of course, if delays during normal operations ever approach these delays, they could also be applied during normal operations. Currently, special operational measures during normal

operations are rarely used at Ohio River locks. On-going activities carried out by the Corps are funded entirely with Federal O&M funds, on-going activities by industry are privately funded.

2. The discussion below first addresses measures currently taken, and then additional measures that could be initiated are described and evaluated. These measures either increase vessel throughput capacity ("supply side") or seek to affect shipper behavior ("demand side"). (See *Litman, Todd, "Why Manage Transportation Demand?" TDM Encyclopedia, Victoria Transport Policy Institute, updated November 22, 2002, pp. 3 – 4.*) Additional details on these measures are provided in **Attachment 5 Traffic Management Analysis** to the Economics Appendix. See **Table 8-5** in section 8.4.3 for a summary of measures that are carried forward in the analysis.

8.4.1 Operational and Low-Cost Structural Measures Currently Implemented

The measures described in this section have been implemented for many years at Corps locks and dams.

8.4.1.1 N-up/N-down Lockage Policy

This strategy involves locking a given number (N) of tows in the same direction, then allowing the same number to proceed in the opposite direction. It takes advantage of the efficiency of proceeding with several successive "turnback"-style lockages rather than running tows through in alternate directions when queued on either side of the lock. Use of this strategy has been proven to lower delays over a "first-come-first-served" policy at virtually zero cost. This is a supply-side measure.

8.4.1.2 Helper Boats: Industry Self-Help

The use of helper boats by industry complements the N-up and N-down lockage policy. Helper boat operations are a collaborative effort between industry and the Corps. Due to traffic levels and fleet size, industry implements a helper boat policy any time a main chamber is closed on the Ohio. Industry helper boat operation significantly reduces lockage times for multi-cut lockages and typically works as follows: the last towboat to arrive at a congested project in the direction opposite of an on-going lockage operation will disconnect from its barges and move up to the lock, where it serves as a helper boat by assisting the tow locking through the project by extracting un-powered cuts of barges from the lock chamber. It will then move the barges for re-fleeting so that reconstruction of the tow does not interfere with lockage operations. Refleeting can occur at the locks on walls upstream or downstream of the lock gates, at mooring facilities or at private docks depending upon the situation. Helper boat operations are provided to each tow until all barges have moved through the lock. To be effective, the policy requires tows queued in both directions above and below the project. This is another supply-side measure that enhances capacity during a closure.

8.4.1.3 Advanced Notice of Main Chamber Closures

1. Two years before a scheduled closure, the Corps will send a notice to waterway users announcing its intent to close a lock and the expected date of closure. The notice will also include the expected delays during the closure, expressed as significant or minor, and the lockage policies that may be put into affect. Then, about six months before the scheduled closure, the Corps District and the towing companies will meet to finalize procedures for operating during the closure. A major consideration in the decision is the expected level of delays during the closure, which is estimated based on past levels of delays and current traffic levels compared to past traffic levels. If low levels of delay are expected, then the selected policy will likely be to continue to lock according to the order of arrival. However, even with low expected level of delays, special accommodations will be required because the auxiliary chambers are typically one-fourth to one-half the size of the main chambers. If major delays are expected, the announcement will also state that tows have priority in lockage over recreational craft. This is a demand-side measure as it provides industry information to better manage their vessels during a scheduled closure.

2. Other measures by the Corps intended to increase efficiencies and reduce delays during main chamber closures include prioritizing commercial over recreational lockages, which reduces the demand by recreational boaters during those periods of heavy congestion, and making available lockage reports on the Corps web page. Information contained in lockage reports, which is updated every few hours, includes the number of tows waiting in queue and river flow conditions at each facility. Coordination with industry is also conducted on a regular basis, not just during those times prior to an extended main chamber closure. These low-cost measures have proven useful and are accepted by the navigation industry and recreational boating public.

8.4.1.4 Tow Haulage

1. Tow haulage systems are relatively low-cost pieces of equipment that can be used to expedite the two-cut lockage process when there are no other towboats to pull the unpowered cut out of the chamber. Such units are not necessary at any 1200’ long lock as double cuts through those chambers are not permitted. There are two principal types of tow haulage systems: permanent and portable. Permanent units consist of rail tracks located directly alongside the chamber on top of the walls and a moveable tie-down unit that moves on the rails. The unpowered barges are tied to the moveable tie-down unit by a cable, and the unit moves along the rails to pull the barges out of the chamber. Portable systems consist of two winches that are anchored atop the upstream and downstream guidewalls. The winches “crank” the cable, pulling the barges out of the chamber. The second set of barges, which are powered by a towboat, can then enter and lock through the chamber. Upon completion of the second lockage, the first and second cuts are reconnected along the guidewall.

2. The only permanent tow haulage systems on the Ohio River are installed at the 600’ main chambers at Emsworth, Dashields, and Montgomery. Double lockages

through these main chambers are a common occurrence even during normal times. During the period 1998-2002, double lockages constituted between 16 and 22 percent of all commercial lockages at each of these projects. Installation of tow haulage units at locks less than 1200' in length are considered in the WOPC.

8.4.1.5 Mooring Cells

Mooring cells are structures that provide vessels a place to tie off while waiting for their turn to lock through. Without such facilities, the towboats must either push into the riverbank, which can cause erosion and damage to the shoreline vegetation, or wait out in the currents of the river, which wastes fuel. As noted in Section 6.5.3, mooring cells have been constructed by the Corps in upstream and downstream of most projects with the exception of Belleville, Racine, Greenup (a mooring cell was authorized as part of the auxiliary lock extension), Meldahl, McAlpine, and Smithland locks and dams. Adding mooring cells at these projects is considered in the WOPC.

8.4.1.6 Industry Adjustments during Main Chamber Closures

1. The objective of the towing industry during main chamber closures is to supply their customers to as near normal cycles of delivery as possible. They will try to accomplish this by pre- and post-closure shipping to build and/or replenish stockpiles, shipping via other routings for all or part of the trip, making deliveries from alternative sources, and rearranging their shipping plans to minimize trips through the projects.

2. At all times, shippers attempt to minimize the time they are pushing empty barges by arranging shipments in both directions. Their success depends on the demand for different types of commodities in the different origin and destination regions. If all movements were one-way with no backhauls, then the percent of loaded barges and empty barges through a project would each be 50 percent. The statistics on percent loaded through the projects show that, in general, the percent of loaded barges is significantly higher than 50 percent, which indicates a significant number of backhauls. The percent loaded is highest at the projects along the lower river, where the opportunities for backhauls are greater than on the upper river, where one-way coal traffic is more dominant. However during closures, the shippers on the upper river make temporary arrangements amongst themselves to maximize the throughput of the project in terms of tonnage since they are limited in terms of barges.

3. Towing companies also attempt to reduce the number of trips through projects where delays are significant. In some cases, they will employ their equipment in assembling barges above and below the congestion point so that they are prepared to get back onto their delivery schedules as quickly as possible once the main chamber is reopened. Arrival frequencies during extended closures have been observed to be less than during normal operations even without adjustments by industry due to limits on the numbers of tows and barges. The greatest reductions in tow arrival rates are at locks that are both near major ports and have significant delays during closures. These projects are the three upper projects near Pittsburgh and the mid river projects near Huntington.

8.4.1.7 Miscellaneous Measures

The Corps and industry maintain flexibility in dealing with delay situations, and often test new measures to try to decrease processing times. For example, the downstream approach area at Dashields was shortened during a recent main chamber closure by placing an anchored barge midway in the official approach area to serve as a temporary mooring area. The purpose was to reduce the time required for tows to approach the lock. Another test was a two-stage closure at Montgomery with about 5 days between the closures to clear the queues. During the first stage, work that required only a lowered water level was performed. Once this was completed, the chamber was refilled and opened for use. After the queue was cleared, the chamber was closed and de-watered to work on the gates and sills. Thus, instead of one continuous 26-day closure, there were two closures with the first lasting 8 days and the second 18 days. This was successful in clearing the queue and thereby reducing the overall level of delays experienced during the closure.

8.4.2 Operational Efficiency and Low-Cost Structural Measures Not Currently Implemented

1. Price-related traffic demand management measures are not currently used on the mainstem. Examples in this category considered in **Attachment 5 Traffic Management Analysis** to the **Economics Appendix** include scheduling of shipments (entire trips) or specific lockages, and a vehicle tracking system. Preliminary results described in that attachment indicate great uncertainty regarding the effectiveness of traffic management schemes. This is an area that requires a research effort beyond the scope of this study.

2. An example of a low-cost structural measure is extensions of the guidewalls, guardwalls, or middle wall at any project. Extensions to these walls have the potential of reducing interference between tows that are concurrently using the main and auxiliary chambers of any project. The interference reduction has the potential to more efficiently pass traffic when traffic reaches the level where both chambers are highly utilized.

8.4.3 Assessment of Operational and Low-Cost Structural Measures

Due to their proven effectiveness, all operational and low-cost structural measures currently implemented by the Corps and the towing and shipping industries will be carried forward and implemented in the Reactive Maintenance alternative for all traffic scenarios. These include the N-up/N-down lockage policy, the use of helper boats by industry, coordination with industry, permanent tow haulage units currently installed and portable units, rescheduling by industry during main chamber closures, existing mooring cells, and the miscellaneous measures described above in subsection 8.4.1. The use of helper-boats by industry effectively maximizes the capacity of the small 56’x 360’ auxiliaries on the upper Ohio and at the 110’x 600’ auxiliaries elsewhere. These practices, along with limiting tow sizes to five cuts during Main chamber closures on the

upper Ohio, are reflected in lock capacities reported in **Table 6-1**. Annual throughput, or capacity, is unaffected, but average delay per tow is lower than it would be otherwise.

Guide and Guard Wall Extensions

Guide and guard wall extensions are not expected to provide the capacity expansion necessary to handle future traffic volumes nor will they reduce delays when the main chamber is closed for maintenance (when interference between chambers is not a problem). Wall extensions do not meet current and future needs, so they were not carried forward into the economic modeling of the WOPC. However, such features will be considered as part of lock modernization alternatives for the WPC.

Additional Tow Haulage Units

Additional permanent tow-haulage units are not considered necessary at any of the other locks that are less than 1200' long. At the 600' auxiliaries, such units would have their greatest need during closures of the main chambers. However, during those times, industry self-help is a much better measure to pull unpowered cuts from the auxiliary chambers as that process is faster than tow haulage and queues quickly develop, thereby providing a steady supply of helper boats. They are not considered appropriate at the 360'x56' auxiliaries at Emsworth, Dashields, and Montgomery as those chambers can only lock one barge at a time and often times (during main chamber closures) tows require more then two cuts. Portable units are considered sufficient at these other small locks.

Additional Mooring Cells

Preliminary evaluations cited in the Myers and Greenup Locks Improvements – Interim Feasibility Report concluded that there is no potential for economic benefit from adding mooring cells at any lock and dam. This measure is dropped from consideration for navigation improvements. However, this measure may be appropriate from an environmental perspective and was considered as a feature of the without-project condition

Table 8-5 summarizes the assessment of operational and low cost structural measures.

8.4.4 Cost Estimation for Reactive Maintenance Operational and Low-Cost Structural Measures Carried Forward

Special lockage policies (n-up/n-down) and advanced notice of main chamber closures are implemented at negligible cost by the Corps. The additional transportation costs to industry due to delays during main chamber closures are based on hourly rates for tow boats and crew. Costs of additional or temporary mooring cells would likely be based on historic construction costs.

TABLE 8.5
Operational and Low Cost Structural Measures
Carried Forward and Dropped From Consideration in WOPC

Operational and Low-Cost Structural Measures Carried Forward:	
Operational	Low Cost Structural
N-up/N-Down Lockage Policy	Existing Tow Haulage
Advanced Notice of Main Chamber Closures	Mooring Cells
Adjustment of Shipment Schedules by Industry	Temporary Mooring Facilities During Main Chamber Closures
Industry Self Help	
Operational and Low-Cost Structural Measures Dropped From Analysis	
Operational	Low Cost Structural
Traffic Scheduling	Guide/Guard Wall Extensions
Additional Mooring (for navigation)	Additional tow haulage units

8.5 ECOSYSTEM MEASURES

As introduced in 6.5, the Corps and several other agencies have existing authorities to affect ecosystem sustainability on the Ohio River. **Table 6-5** lists opportunities for enhancing ecosystem sustainability that were identified during the study in consultation with Ohio River resource experts. This list of opportunities is carried over to **Table 8-6** and matched with existing authorities currently in place within the Corps and other agencies. A comprehensive list of authorities of other agencies is discussed later in section 8.5.4, which elaborates on that topic and explains in more detail what those authorities allow.

TABLE 8-6
Existing Ecosystem Authorities

Opportunities for Enhancing Ecosystem Sustainability[1]	Corps Continuing Authorities					Ohio River Ecosystem Restoration Program	Navigation Stewardship[2]	Existing Project Authorities	Corps as First Responders at Locks and Dams	Other Agencies and NGO's
	Section 204	Section 206	Section 1135	Section 216	Section 312					
Enhance fish passage around or through dams		x		x		x	x			
Dismantle federal tributary dams										
Dismantle non-federal tributary dams		x								
Increase seasonal flooding in grasslands, bottomland hardwood forests, and other habitats			x							
Allow more natural flows to mimic natural regimes including seasonal and extreme floods and droughts	x		x	x		x		x		
Restore unique mainstem habitats such as canebrakes, river bluffs and mussel beds	x		x	x		x		x		
Protect tailwaters and provide structures to serve as refugia for fish	x	x	x	x		x		x		
Create spawning shoals and other in-stream features to enhance habitat diversity in pools	x	x	x	x		x		x		
Identify and expand areas of submerged and emergent aquatic vegetation	x	x	x	x		x		x		
Protect and manage mussel populations and their habitat on a site-specific basis	x									x

TABLE 8-6
Existing Ecosystem Authorities

Opportunities for Enhancing Ecosystem Sustainability[1]	Corps Continuing Authorities					Ohio River Ecosystem Restoration Program	Navigation Stewardship[2]	Existing Project Authorities	Corps as First Responders at Locks and Dams	Other Agencies and NGO's
	Section 204	Section 206	Section 1135	Section 216	Section 312					
Mark critical locations to prevent mooring near mussel beds or special shoreline areas									x	x
Mark shallow mussel beds to reduce direct impacts of tow traffic										x
Provide the navigation industry with charts showing locations of sensitive resources and include rationale for avoiding such resources	x	x	x	x		x				x
Protect existing aquatic habitats, restore lost habitats and diminished resources	x	x	x	x	x x					x
Reintroduce native fauna and expand the range and populations of native fauna from reduced levels	x		x			x		x		x
Control exotics, including minimization of existing populations and prevention of new introductions	x	x	x	x		x				x
Reduce bacterial contamination from combined sewer overflows										x
Address point and non-point sources affecting aquatic nutrient balance		x	x					x		x
Minimize catastrophic contamination events through reduction of spills, accidents, and improvement of spill response procedures								x	x	X

TABLE 8-6
Existing Ecosystem Authorities

Opportunities for Enhancing Ecosystem Sustainability[1]	Corps Continuing Authorities					Ohio River Ecosystem Restoration Program	Navigation Stewardship[2]	Existing Project Authorities	Corps as First Responders at Locks and Dams	Other Agencies and NGO's
	Section 204	Section 206	Section 1135	Section 216	Section 312					
Continue remediation of CERCLA, brownfields, and other contaminated sites	x				x					X
Reconnect and restore floodplains on the mainstem and tributaries		x	x			X[3]				
Protect or restore riparian habitat diversity, including islands, on the mainstem and tributaries		x	x			X[3]		x		
Maintain or restore tributary deltas and connections between rivers and embayments		x				x				
Reforest lower reaches of tributaries to reduce siltation into embayments and mainstem		x				X[3]				
Restore wetlands in upper ends of tributary embayments to reduce siltation and create fish and wildlife habitat		x								X
Conduct economic evaluation of watershed functions and benefits							x			X

[1] See Table 6.5 and Section 6.4.2

[2] Discussion of the Navigation Stewardship Program can be found in 6.5.1

[3] Modifications to the existing Ecosystem Restoration Program may include changes in geographic scope and/or definition of project sponsor.

8.5.1 Existing Corps Authorities and Regulatory Responsibilities

1. In recent decades, specific provisions of the Water Resources Development Acts and Flood Control Acts created authorities and opportunities for the Corps to enhance environmental sustainability. Four important existing authorities are:

Sec. 204 (Water Resources Development Act of 1992 - WRDA) Beneficial Use of Dredged Materials -- Authorizes "projects for the protection, restoration, and creation of aquatic and ecologically related habitats, including wetlands, in connection with dredging for construction, operation, or maintenance by the Secretary of an authorized navigation project."

Sec. 206 (WRDA - 1996) Aquatic Ecosystem Restoration --Authorizes "development of aquatic ecosystem restoration and protection projects that improve the quality of the environment, are in the public interest, and are cost effective."

Sec. 1135 (WRDA – 1986, as amended) Project Modifications for Improvement of Environment – "Provides authority to review and modify the structures and operations of water resources projects constructed by the Corps for the purpose of improving the quality of the environment when it is determined that such modifications are feasible, consistent with the authorized project purposes, and will improve the quality of the environment in the public interest. If it is determined that a Corps water resources project has contributed to the degradation of the environment, restoration measures may be implemented at the project site or at other locations that have been affected by the construction or operation of the project, if such measures do not conflict with the authorized project purposes."

Sec. 216 (Flood Control Act- 1970) – Authorizes "investigations for modification of completed projects or their operation when found advisable due to significantly changed physical or economic conditions and for improving the quality of the environment in the overall public interest. Initial appraisal reports are prepared under 216 using operations and maintenance (O&M) funds. The cost of preparing the initial appraisal report is limited to $20,000. Results from this report can be used to support initiation of a reconnaissance study through normal budgetary process. Following the initial appraisal, the 216 study process is of the same as a normal General Investigations study. A feasibility study under Section 216 authority would be appropriate for large scale ecosystem restoration projects linked to existing Civil Works projects, but whose costs would be too large for Section 1135, Section 206, or Section 204 authorities."

2. Although many sustainability improvements can be attained through existing authorities, none (alone or in combination) provides a comprehensive approach for maintaining and improving a complex and extensive ecosystem such as the Ohio River corridor. As ORMSS got underway, a broader authorization, designated specifically for the Ohio River, was sought to establish an overarching program for its ecosystem that

would allow restoration and protection of integral ecosystem components not necessarily included under existing program authorities.

3. To address ecosystem sustainability needs, integrate existing authorities, and explore other possibilities, ORMSS undertook development of the **Ohio River Ecosystem Restoration Program (ERP)**, described in more detail in the CEA in the Environmental Appendix. The purpose of an Ohio River ERP is to restore significant ecosystem function, structure, and dynamic processes that have been degraded. Although this program was authorized in WRDA 2000, the program has not been funded to date and is now a candidate for de-authorization. Ecosystem restoration efforts would involve a comprehensive examination of problems contributing to system degradation, and the development of alternative means for their solution. The program would be initiated and monitored by a partnership of Federal and state resource agencies and regional environmental interest groups. If implemented, projects under the ERP would aid in reestablishing many physical and dynamic processes necessary to more closely approach a natural, self-regulating ecosystem.

4. The Detailed Project Report for the Ohio River ERP was produced in 2000 and identified more than 250 potential environmental restoration projects to enhance sustainability of instream habitat, islands, wetlands, bottomland hardwood forests, and other shoreline/riparian habitat. It is important to note, however, that a Program Implementation Plan (PIP) must be prepared as a first step in initiating the program. This plan would develop details of how the program would operate and how projects would be identified, developed, and approved. The PIP would help ensure a comprehensive approach to Ohio River restoration, as opposed to a piecemeal approach of seeking approval of individual environmental projects. For each project carried forward under the program a feasibility study with appropriate analysis under the National Environmental Policy Act (NEPA) would be conducted. Other requirements, including cost-sharing (65% Federal/35% non-federal), are requirements of this program.

5. Congress has also given the Corps of Engineers the authority to regulate certain programs that have sustainability implications on or along the waterway. The most relevant authorities consist of issuing Sections 10 and 404 permits that affect navigability on the river and the filling of the waters of the United States. Since both of these permit authorities require compliance with NEPA, impacts on the environment and cumulative effects to aquatic and riparian resources must be considered before permits can be issued.

6. The Ohio River Basin Comprehensive Study would provide for a complete watershed assessment of the Ohio River Basin. The basic authority for the Comprehensive Study is contained in the resolution adopted by the Committee on Public Works of the United States Senate dated 16 May 1955. The Study would provide an opportunity to re-evaluate existing multipurpose water resources projects in the Ohio River basin (mainstem and tributaries) for primary and other allied purposes, to include ecosystem restoration.

7. Finally, the Corps, like all other Federal agencies, is required to comply with provisions of NEPA under 40 CFR 1500-1508 when seeking authorization for new projects, issuing permits, performing operation and maintenance of existing projects, or for any other decision-making by the agency. To comply, impacts to the environment must be assessed and the interested public must have opportunity to comment on proposed actions prior to commencement of work. If significant impacts are expected to occur, an Environmental Impact Statement must be prepared, and a mitigation plan must be developed, justified, and implemented to avoid, minimize, or compensate for the impacts.

8.5.2 Sustainability Focus for Mitigation and Design

8.5.2.1 Mitigation

1. As background for the ORMSS study, a comprehensive investigation was conducted to determine mitigation opportunities and authorities available to the Corps. While potential measures identified in mitigation plans are typically focused on replacement-in-kind for anticipated adverse effects of planned projects, such plans can include measures directed toward enhancing the environmental sustainability of potentially affected resources and ecosystems. Such measures could be perceived as "sustainability-focused mitigation measures." To illustrate, the ORMSS study has considered the impacts of past, present, and future actions, along with the impacts of the proposed SIP. Consideration of the impacts of historical actions of the Corps on the environment of the Ohio River Mainstem, along with the historical actions of others, suggests the need to consider potential sustainability-focused restoration of earlier damages to the resources and ecosystems. Further, since future actions by the Corps and others have been addressed in the CEA study; it is appropriate, and required by Corps policy, that mitigation be incorporated into future proposed actions by the Corps. Further, such mitigation could also be focused on enhancing environmental sustainability. Accordingly, opportunities for enhanced sustainability exist for future site-specific navigation projects involving major maintenance and/or rehabilitation, infrastructure replacements, and lock modernizations.

2. The relationship between mitigation and ecosystem restoration and protection is described in Section 19-21 (g) of Chapter 19 of Engineering Pamphlet (EP) 1165-2-1 (Digest of Water Resources Policies and Authorities) as follows:

> Mitigation deals, in part, with the concept of ecosystem restoration and protection by its recognition of the importance of certain features of the ecosystem. Mitigation addresses these ecosystem features by attempting to eliminate and/or lessen the impact of our water resource activities upon these features. Restoration and protection activities, on the other hand, will often utilize the same techniques as used in mitigation; however, the purpose of our activities will be to restore some ecological condition that has been degraded, either by our activities or those of others. Consequently, the procedures used to justify our activities, whether they are for mitigation or restoration purposes, will typically be the same. The

only distinguishable difference between mitigation and restoration activities is when they are applied.

3. Based on the above relationship, it can be concluded that mitigation is typically applied in anticipation of the adverse impacts of a Corps project or activity, while ecosystem restoration is done to repair the environment from experienced stresses, whether such stresses are due to Corps projects or actions, or by others, or combinations thereof. Finally, it can be observed that the Corps' Planning Guidance Notebook (PGN) and the Digest of Water Resources Policies and Authorities infer the need for consideration of mitigation measures across time; i.e., both measures to lessen past damages and restore degraded ecological conditions, as well as measures to avoid, minimize, and/or compensate for anticipated undesirable effects. Such measures can also include a sustainability focus.

4. The policy basis for sustainability-focused mitigation can be found in the earlier-described Environmental Operating Principle (EOP) # 1 – strive to achieve environmental sustainability. This principle can be applied to ecosystem restoration via recognition that certain natural resources, ecosystems, or species are stressed and are continuing to deteriorate relative to their sustainability. For new projects or actions, sustainability considerations could be used as the basis for identifying avoidance, minimization, or other means for enhanced mitigation, and inclusion of appropriate mitigation features in project design, construction, and operation and maintenance. This EOP, along with the other six, have now been incorporated in both an Engineering Circular (EC 1105-2-404; in May, 2003), and an Engineer Regulation (ER 200-1-5; in October, 2003).

5. Current statutory authorities support the concepts of sustainability-focused mitigation, as do specific Corps policies and regulations associated with ecosystem restoration, existing and new projects, and water quality management and streambank erosion. For example, the current statutory authorities for ecosystem restoration and mitigation for Corps plans, programs, and projects are contained in selected sections of four WRDAs (Sections 904, 906, 907, and 1135 of WRDA 1986, Sections 306 and 307 of WRDA 1990, Section 204 of WRDA 1992, and Sections 206 and 207 of WRDA 1996). Commonly used words in these sections include "protection" and "restoration", with the former typically denoting future mitigation, and the latter restoration of previous damages. Mitigation of Corps contributions to historical degradation of natural and environmental resources is specifically included in some of the above sections. Navigation-specific statutory authority related to lock and dam replacement is currently based on Section 205 of WRDA 1992 (funding of major rehabilitation modifications to enhance operating efficiency beyond the original project design). Correction of shoreline damages resulting from existing Federal navigation projects is addressed in Section 111 of the Rivers and Harbor Act of 1968 (PL90-483), as amended by Section 940 of WRDA 1986. Such corrections are specific examples of mitigation for one type of environmental effect of navigation projects; i.e., shoreline erosion and damage.

6. A related major law that is intertwined with water resources planning is the Fish and Wildlife Coordination Act (FWCA) of 1958. This law emphasizes that fish and wildlife resources are to be conserved in the planning and implementation of water resources development projects. Several sections of the FWCA incorporate provisions whereby enhanced mitigation could be included in new or modified projects. Another important feature of the FWCA is the requirement that active consultation and coordination occurs between the Corps and the USFWS and/or the NMFS.

7. Stated policies regarding the ecosystem restoration mission of the Corps are found in ER 1105-2-100 (PGN), ER 1165-2-501 (Civil Works ecosystem restoration), and EP 1165-2-502 (ecosystem restoration – supporting policy information). Specific authorities for ecosystem restoration are divided into three categories. First, Congressionally authorized studies and provisions in existing laws can be used. One example of a law in the first category is Section 216 of the 1970 River and Harbor and Flood Control Act; Section 216 is mainly useful for large-scale ecosystem restoration at completed projects. The second category encompasses programmatic authorities, including Section 1135 of WRDA 1986, as amended (project modifications for improvement of the environment); Section 206 of WRDA 1996 (aquatic ecosystem restoration); Section 204 of WRDA 1992, as amended, and Section 207 of WRDA 1996 (beneficial uses of dredged material); and Section 312 of WRDA 1990, as amended (environmental dredging). The third category involves the use of existing operation and maintenance authorities for specific projects. Two common themes arise from the three categories of ecosystem restoration authorities. First, cost sharing is typically required for the design and construction of ecosystem restoration projects. Second, such projects must be environmentally and economically justified via the application of a Cost Effectiveness/Incremental Cost Analysis procedure applied to the anticipated environmental benefits and associated costs of various measures comprising the restoration action. Further, it was determined that the Corps can engage in the planning and implementation of ecosystem restoration projects where previous Corps projects or actions are the sole contributor to degraded resources, or where they are partial contributors along with projects and actions by other governmental agencies and private developments. Finally, in certain circumstances, ecosystem restoration planning and implementation of a project can be accomplished when the entire existing degradation is a result of actions by others.

8. The Digest of Water Resources Policies and Authorities (EP 1165-2-1) includes information on mitigation planning requirements for new projects resulting from the discharge of dredged or fill material as addressed under the auspices of the Clean Water Act, and new project reports prepared under the auspices of Section 906 of WRDA 1986 and the FWCA. Further, mitigation requirements resulting from jeopardy and adverse modification opinions under the Endangered Species Act are reflected in the development of reasonable and prudent measures. Regarding existing projects and mitigation of experienced negative impacts, Section 216 of the River and Harbor and Flood Control Act of 1970 can be used to study the situation and develop appropriate measures.

9. Mitigation measures, per se, for both new and existing projects must be environmentally justified based on the potential loss of significant fish and wildlife resources, and economically justified by the consideration of the cost effectiveness of various mitigation alternatives. A key issue to note is the need for careful planning and evaluation of a variety of mitigation measures, both singly and in combination, in the development of a justified mitigation project. Further, due to the requirements of the FWCA, the policies and recommendations of the USFWS are important relative to enhanced mitigation planning. Coordination by the Corps with the USFWS and the NMFS, as appropriate, is a central feature of the requirements of the FWCA.

10. ER 1110-2-8154 addresses water quality and environmental management for Corps projects. As such, it is a uniquely important Corps regulation related to enhanced mitigation. The national policy of the Federal government regarding water quality management is articulated along with the Corps' companion policy, specific commitments, and three management objectives. Regarding mitigation of past losses of sustainability, ER 1110-2-8154 indicates that the Corps can address situations where degraded conditions regarding water quality and/or aquatic or riparian habitats are a result of Corps actions alone, and/or combinations of actions by other governmental agencies and the private sector. Further, Chapter 18 of EP 1165-2-1 (Digest of Water Resources Policies and Authorities) stresses the importance of water quality standards in water quality management planning and development of mitigation projects. Standards can be used as one basis for determining sustainability and the significance of degraded conditions and anticipated impacts from new water resources projects.

11. Corps policies regarding mitigation projects for prior streambank erosion are included in the PGN (ER 1105-2-100), Chapter 15 in the Digest of Water Resources Policies and Authorities (ER 1165-2-1), Section 14 of the Flood Control Act of 1946, Section 103(a) of WRDA 1986, and Section 202(a) of WRDA 1996. These policies are primarily focused on remediating erosion problems threatening public facilities and certain non-profit public services.

12. Another opportunity for enhancing and/or achieving environmental sustainability is via the internal review of future activities and projects to determine if certain practices or design features could be used to enhance sustainability. Project planners and designers can be encouraged to consider resource and ecosystem sustainability in the traditional planning process. Further, environmental staff within the Corps could both participate in and review the products of the planning process. The environmental staff could also coordinate with other federal and state regulatory and resource agencies to aid in "scoping" the activities and projects toward a greater sustainability focus.

8.5.2.2 Design

1. The subject of sustainability should apply not only to specific authorities and mitigation, but also to good environmental design of structures built on or adjacent to the river. Ultimately, this is the responsibility of all who have the potential to affect the

river's environmental components. The Corps of Engineers has a major role on the river and its structures are evident the length of the mainstem.

2. The Corps' Environmental Operating Principles were adopted on 26 March 2002 and include seven principles that collectively reaffirm its commitment to the environment. As they might apply to building structures, five of the seven are particularly relevant:

- Strive to achieve environmental sustainability. An environment maintained in a healthy, diverse and sustainable condition is necessary to support life.
- Recognize the interdependence of life and the physical environment. Proactively consider environmental consequences of Corps programs and act accordingly in all appropriate circumstances.
- Seek balance and synergy among human development activities and natural systems by designing economic and environmental solutions that support and reinforce one another.
- Continue to accept corporate responsibility and accountability under the law for activities and decisions under our control that impact human health and welfare and the continued viability of natural systems.
- Seeks ways and means to assess and mitigate cumulative impacts to the environment; bring systems approaches to the full life cycle of our processes and work.

3. The Corps can strive to meet these principles in two ways. The first is through the application of "Green Engineering". According to the US EPA (http://www.epa.gov/oppt/greenengineering/index.html), "green engineering is the design, commercialization, and use of processes and products, which are feasible and economical while minimizing 1) generation of pollution at the source and 2) risk to human health and the environment. Green engineering embraces the concept that decisions to protect human health and the environment can have the greatest impact and cost effectiveness when applied early to the design and development phase of a process or product."

4. Principles of Green Engineering as developed by more than 65 engineers and scientists at the Green Engineering: Defining the Principles Conference, held in Sandestin, Florida in May of 2003 are:

- Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
- Conserve and improve natural ecosystems while protecting human health and well-being.
- Use life-cycle thinking in all engineering activities.
- Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
- Minimize depletion of natural resources.
- Strive to prevent waste.

- Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.
- Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.
- Actively engage communities and stakeholders in development of engineering solutions.

5. The second way of integrating sustainability into structures is to consider the design of the structures themselves. Several of the sustainability opportunities identified in 6.4 can be addressed or influenced within the design. Foremost is the potential for providing fish ladders or other means of fish passage within or around the lock structures. When considered in the early phase of design, the additional cost would be low as a percentage of the total cost. Another sustainability feature the Corps could consider at its structures is the dam gate design that allows for better control of pool fluctuations thereby minimizing adverse effects to fish spawning in upstream embayments. The Corps has recently designed an "environmental" dam gate it has installed on Braddock Dam on the Monongahela River that provides for greater oxygenation of water and more efficient release of Volatile Organic Compounds (VOCs) that pass through it. This gate could be used where dissolved oxygen or VOCs are a problem.

6. In the early phase of the site-specific design process, the Corps needs to convene and solicit the input of professionals with expertise in sustainability. In accordance with Environmental Principle #7, the Corps needs to "respect the views of individuals and groups interested in Corps activities, listen to them actively, and learn from their perspective in the search to find innovative win-win solutions to the nations' problems that also protect and enhance the environment."

8.5.3 Operational Capabilities

1. In addition to statutory authorities and mitigation, the Corps can directly affect the sustainability of river-based resources through the operation and maintenance of the existing navigation system. The three Corps Districts with jurisdiction along the Ohio River are currently involved with an ongoing threatened and endangered species Section 7 consultation with the U.S. Fish and Wildlife Service for the effects of operation and maintenance of the Ohio River navigation system and its navigable tributaries on endangered species within the Ohio River basin.

2. Most navigational activities have evolved within each district based on the specific needs of the particular district. In some cases, there is general guidance provided by higher authorities that gives the districts a framework for the work. Within that guidance, each district will tailor the activity to best meet their respective needs.

3. For activities that have the potential for affecting listed species, the Corps districts with jurisdiction on the Ohio River and navigable tributaries will coordinate and establish a general protocol or Standard Operating Procedures (SOPs). This will specifically address ways the activity could be conducted to minimize any impacts.

Development of the protocols or SOPs would be coordinated with the USFWS and state resource agencies (if interested). More specifically, the following measures are examples of operational procedures that could be adopted to enhance sustainability of endangered species. Actions that benefit these species, by their very nature, will support the sustainability of most other species.

8.5.3.1 Geographic Information System O&M and Environmental Database

The three Corps districts with jurisdiction on the Ohio River and its navigable tributaries could establish a Geographic Information System (GIS) that would be shared by the three districts and USFWS. The Corps could maintain the mussel database and keep it up to date. The GIS could be used annually to aid in discussions with the USFWS that address the seasonal dredging plan. The locations of mussel surveys conducted in the main stem and navigable tributaries along with an attached database providing the pertinent information regarding each survey could be maintained. The GIS could include the entire Ohio River Navigation System and be maintained as a working repository for:

- Environmental documentation
- Dredge and Disposal coordinate locations and quantities
- Other relevant appropriate information

8.5.3.2 Dive Surveys

Prior to maintenance dredging of the navigation channel each year, the Corps could conduct initial dive surveys of all new dredge and disposal sites and previously used sites if they haven't been disturbed in the past 5 years. This information could be added to the GIS mussel database and would aid in discussions with the USFWS that address the seasonal dredging plans.

8.5.3.3 Sampling

In order to facilitate captive propagation and reintroduction efforts, each district may require Corps biologists, divers or contractors performing mussel surveys for any reason to collect and hold any listed species. Retention would only be effected at the direction of the UFSWS. Any individual(s) collected would be held only until possession could be passed to an appropriate state or Federal agency representative or other designee (for example, a zoo or aquarium).

8.5.3.4 Navigation Chart Review and Revisions

The CELRD, in consultation with the USFWS, could examine the feasibility of modifying the navigation charts used by the tow pilots to include environmentally sensitive areas. With this information available, the pilots would know the locations of these areas so they can avoid them. Navigation representatives feel that the pilots would be receptive to this if they know what to avoid.

8.5.3.5 Annual Dredging Plan Coordination

The Corps would consult with the State Fish and Wildlife Agencies every year during development of their annual dredging plans. Each Corps district would meet with the appropriate state FWS and their field office(s). This meeting would include review of existing mussel databases, dredging needs and available disposal areas and early identification of environmental issues or concerns specific to the annual plan.

8.5.3.6 Dredge Disposal Habitat Creation

The Corps would use dredge spoil to construct Least Tern habitat wherever feasible. Prior to establishment of sand bars, pre-disposal surveys have been and will continue to be conducted to properly plan and restore this type of riverine habitat such that it does not impact existing mussel beds.

8.5.3.7 Continued Monitoring

The Corps would continue to support monitoring efforts of the FSWS and state agencies. Such support has typically included the assistance of Corps biologists in conducting field surveys and sometimes includes transportation assistance, especially by boat.

8.5.4 Other Agencies' Authorities and Regulatory Responsibilities

1. According to CEQ's Forty Most Asked Questions about NEPA, "all relevant, reasonable mitigation measures that could improve a project are to be identified, even if they are outside the jurisdiction of the lead agency or the cooperating agencies, and thus would not be committed as part of the Record Of Decisions of these agencies (Sections 1502.16(h), 1505.2(c)). This will serve to [46 FR 18032] alert agencies or officials who can implement these extra measures, and will encourage them to do so. Because the EIS is the most comprehensive environmental document, it is an ideal vehicle in which to lay out not only the full range of environmental impacts but also the full spectrum of appropriate mitigation."

2. In recognition that enhancing long-term ecosystem sustainability is a goal of many other agencies and organizations, a summary of some potentially applicable authorities that can be used to address them is provided in **Table 8-7.**

Table 8-7 Environmental Sustainability Authorities of Other Federal Agencies			
Agency	**Law/Program**	**Key Components**	**Relevance to Sustainability**
All Federal	National Environmental Policy Act (NEPA)	• Requires preparation of an environmental assessment (EA) which would then lead to preparation of Finding of No Significant Impact (FONSI) or an environmental impact statement (EIS) as appropriate, for new construction projects by private and governmental agencies.	Includes water quality & habitat impacts of new projects along the Ohio River such as power plants, Corps projects, permitted activities, and riverfront developments.
	Executive Order 11988, Floodplain Management & Executive Order 11990, Protection of Wetlands	• Prevents federal agencies from contributing to the adverse impacts of floodplain development & modification. • Requires federal agencies to minimize destruction, loss, or degradation of wetlands and to preserve and enhance natural and beneficial values of wetlands.	Restricts federal development in floodplains and wetlands wherever there are practicable alternatives with potential benefits for fish and other aquatic and riparian resources.
	Executive Order 13112, Invasive Species (1999)	• Requires federal agencies to prevent the introduction of invasive species and provide for their control and to minimize their economic, ecological and human health impacts.	Helps to maintain and/or restore the ecological integrity of aquatic and riparian ecosystems.
U.S. Environmental Protection Agency	Clean Water Act (CWA)	• Section 402 establishes National Pollutant Discharge Elimination System (NPDES) for regulating pollution discharges into U.S. waters. • Section 316(a) requires dischargers of heated water effluent to comply with state temperature standards or demonstrate that exceedences are not harmful to fish and wildlife. • Section 316(b) requires	Protects aquatic life within general context of water quality improvements and minimization of impacts from construction or other activities within waters of the US.

Table 8-7 Environmental Sustainability Authorities of Other Federal Agencies			
Agency	**Law/Program**	**Key Components**	**Relevance to Sustainability**
		cooling water intake structures to reflect best available technology to minimize adverse environmental effects. • Section 401 of Clean Water Act requires applicants proposing any activity, which may result in discharge to U.S. waters, to obtain certification of compliance with state water quality standards. This section is administered by each individual state. • Section 404 authorizes the Administrator of EPA to prohibit the specification of any defined area as a disposal site, and he is authorized to deny or restrict the use of any defined area for specification as a disposal site, whenever he determines that the discharge of such materials into such area will have an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas, wildlife, or recreational areas. • Gives EPA authority to implement pollution control programs. • Requires establishment of water quality standards. • Recognizes need to address nonpoint source pollution.	
	Oil Pollution Act	• Strengthened EPA's ability to prevent & respond to catastrophic oil spills.	Protects aquatic resources from pollution & damage from oil spills.
	Phase 1 & 2 NPDES Program	• Also developed within the CWA, requires municipalities	Reduces pollution characteristics of

Table 8-7 Environmental Sustainability Authorities of Other Federal Agencies			
Agency	**Law/Program**	**Key Components**	**Relevance to Sustainability**
		and certain industrial and construction sites to adopt Best Management Practices to control nonpoint sources of pollution.	stormwater discharges that may adversely affect aquatic resources in the Ohio River.
	Site Remediation Statutes	• Includes CERCLA, RCRA, • SARA and related state programs that focus on cleanup and restoration of contaminated sites.	Reduces groundwater and soil pollution sources which may adversely impact aquatic resources in the Ohio River.
	National CSO Control Policy	• Published by USEPA, calls for communities to implement long-term plan for combined sewer overflows (CSOs) to comply with the CWA. • Administered through each state's NPDES permit program.	Should reduce pollution from major urban sources with potential benefits for aquatic resources.
	TMDL Program	• Section 303 of Clean Water Act regulates the maximum load of a pollutant a water body can receive and still attain water quality standards.	Presents a more holistic option to water quality management that may be more beneficial to aquatic life than traditional regulatory approaches.
	Safe Drinking Water Act	• Provides for establishment of primary regulations for the protection of public health and secondary regulations related to taste, odor and appearance of drinking water.	Helps protect public water supplies and improves quality of resources.
US Fish & Wildlife Service	Emergency Wetlands Resources Act	• Authorizes purchase of wetlands from Land and Water Conservation fund. • Requires states to include wetlands in Comprehensive Outdoor Recreation Plans. • Provides funding for the Migratory Bird Conservation Fund.	Benefits sustainability by encouraging federal-state cooperation in wetlands protection and outlines funding mechanisms.
	Endangered Species Act	• Authorizes determination & listing of threatened & endangered species and	Establishes framework for protection of threatened &

Table 8-7 Environmental Sustainability Authorities of Other Federal Agencies			
Agency	**Law/Program**	**Key Components**	**Relevance to Sustainability**
		critical habitat. • Prohibits unauthorized taking, possession, sale & transport of endangered species. • Provides for land acquisition to protect endangered species. • Requires Federal Agencies to consult with the USFWS or NMFS concerning effects of actions on listed species and critical habitats.	endangered species and critical habitats that are important components of the ecosystems.
	Fish & Wildlife Act	• Requires USDI to take steps for management & protection of fish & wildlife resources through research, acquisition of land & water & other means.	Establishes a comprehensive national fish & wildlife policy applicable to fish and other aquatic and riparian resources.
	Fish & Wildlife Coordination Act	• Requires that whenever water resources projects are planned by a federal agency, that agency shall consult with the USFWS and with appropriate state agencies with a view toward wildlife conservation.	Provides for equal consideration and coordination of fish and wildlife conservation with other aspects of water resources development.
	National Wildlife Refuge System Administration Act & National Wildlife Refuge System Improvement Act	• Provide guidance for management and public use of refuge system, including development of comprehensive conservation plan for each refuge.	Guides management & public use of Ohio River Islands National Wildlife Refuge.
	Migratory Bird Conservation Act	• Provides for the acquisition and maintenance of public land for habitat preservation of migratory birds.	Applies to land, water and transitional areas, e.g., riparian areas.
	Migratory Bird Treaty Act	• Implements various treaties and conventions between the U.S., Canada, Mexico, Japan and the former Soviet Union for the protection of migratory birds. Prohibits taking, killing and	Protects migratory birds utilizing riparian and floodplain areas.

Table 8-7 Environmental Sustainability Authorities of Other Federal Agencies			
Agency	**Law/Program**	**Key Components**	**Relevance to Sustainability**
		possession.	
	North American Wetlands Conservation Act	• Provides funding and implementation of the North American Waterfowl Management Plan & North American nations wetlands agreement.	Provides funding support for migratory bird conservation in the Ohio River valley.
	Refuge Recreation Act	• Authorizes USDI to administer conservation areas for recreational use when such uses do not interfere with an area's primary purpose.	Allows recreational use of Ohio River Islands National Wildlife Refuge.
US Dept. of Trans-portation and Aquatic Nuisance Species Task Force	National Invasive Species Act	• Requires all vessels operating in US waters that are equipped with ballast tanks to comply with guidelines designed to prevent and reduce the dispersal of aquatic nuisance species.	Helps reduce the further introduction and dispersal of non-native, invasive species that can disrupt aquatic ecosystems.
USDA Natural Resources Conservation Service	Farm Security and Rural Investment Act of 2002 (aka Farm Bill)	• Includes various incentive programs to promote installation of riparian buffers. • Swampbuster provisions withhold certain USDA benefits from farmers who convert or modify wetlands. • Offers opportunities for wetlands mitigation.	Helps improve and/or preserve environmental functions & values of riparian areas in the Ohio River floodplain.
U.S. Coast Guard	Spill Response	• Includes emergency response activities for river-related spills and accidental discharges and is related to the Oil Pollution Act and Section 301 of the Clean Water Act.	Minimizes adverse impacts of spills and discharges on aquatic resources and on water quality.
Federal Emergency	National Flood Insurance Act	• Encourages adoption of state & local floodplain regulations	Limits development impacts in riparian

Table 8-7 Environmental Sustainability Authorities of Other Federal Agencies			
Agency	**Law/Program**	**Key Components**	**Relevance to Sustainability**
Management Agency (FEMA)		restricting certain types of development within floodplains.	areas. Helps protect stream/floodplain connectivity.
State agencies	State Water Quality Certification	• Section 401 of the Clean Water Act (CWA) requires certification from state or interstate water control agencies that a project is in compliance with established effluent limits and water quality standards.	Provides opportunity for state or interstate scrutiny of such actions on fish and other aquatic resources.
	State Fishing Regulations	• Establish regulations that consider fish habitat and reproduction. Ohio River state resource agencies have established an Ohio River Fisheries Management Team to coordinate a variety of management issues and programs.	Has potential to enhance environmental sustainability of Ohio River fish communities through long-term collaborative fisheries management efforts.
KY Dept. of Fish & Wildlife Resources	Kentucky Mussel Refuges Act	• Establishes sanctuaries near KY islands within Ohio River Islands National Wildlife Refuge.	Prohibits commercial mussel harvesting and collecting from these refuges.
Ohio River Valley Sanitation Commission (ORSANCO)	ORSANCO Monitoring	• Encompasses ongoing water quality and aquatic ecology monitoring programs by the Ohio River Valley Water Sanitation Commission. • Helps ensure water quality standards are consistent among Ohio River states.	Helps track trends in water quality and biological communities and provides database that can inform environmental decision-making. Reduces discrepancies in interjurisdictional waters of the Ohio River.

In addition to programs of other agencies listed above, there are numerous grants administered by Federal agencies. Several of these that could also be used to improve ecosystem sustainability are listed below:

USFWS:

- Federal Aid in Sport Fish Restoration
- Federal Aid in Wildlife Restoration
- Clean Vessel Act

- State Wildlife Grant Program
- Landowner Incentive Program
- North American Wetlands Conservation Grant
- Neotropical Migratory Bird Conservation Act Grants
- Pirvate Stewardship Programs
- Coorperative Endangered Species Conservation Fund
- Partners for Fish and Wildlife Assistance

USEPA:

- Wetland Program Development Grants
- Five Star Restoration Program
- State Revolving Fund

NRCS::

- Wetlands Reserve Program
- Healthy Forest Reserve Program
- Conservation of Private Grazing Lands
- Cooperative Conservation Partnership Initiative
- Conservation Reserve Program
- Conservation Technical Assistance
- Grazing Lands Conservation Initiative

8.6 WITHOUT-PROJECT ALTERNATIVES

Without Project Condition alternatives are developed by combining the measures surviving the initial screening. Because maintenance and its effect on the satisfactory performance of the aging locks is a key concern, considerable effort was devoted to identifying the least-cost maintenance policy for all locks. This encompasses consideration of both repair costs and any associated navigation delay costs due to additional congestion around the locks. Efficient operation of the existing facilities is a very important consideration, especially during closures of any main chamber maintenance when all traffic is funneled through a small auxiliary chamber. Two WOPC alternatives are described below for the initial screening.

8.6.1 Federal Disinvestment

In essence, this option would close the Ohio River Mainstem System down, either all at once or in a "piecemeal fashion" dictated by the order in which components fail due to age or fatigue. There would not be any component replacement, only routine maintenance and possibly cyclical maintenance. Structures could be removed after closed (decommissioned) and the river could return to a more natural state. The objective of this study is to determine a long-term maintenance and lock modernization strategy to

provide reliable navigation along the Ohio River Mainstem. Companies using the Ohio River System (ORS) ship over $30 billion worth of commodities by barge, saving over $2 billion in transportation costs annually. These savings result in additional national output estimated at over $11 billion, which makes possible approximately 100,000 jobs and $3 billion in income.[6] Closure of the Ohio River would necessitate that this traffic be diverted to alternative markets or more costly land-based transportation modes or possibly even eliminated from the economy. The potential economic impact of this alternative would be severe. This large economic benefit of the navigation system along the Ohio River mainstem justifies a continued Federal Interest to ensure future navigability of this system. Further, disinvestment in the system would fail to meet two of the three study objectives for the ORMSS. Therefore, the Federal Disinvestment alternative is eliminated from further detailed analysis at this point.

[6] Regional Economic Development Impacts on the Ohio River Basin due to Commodity Savings Along the Ohio River System, September 1999, Marianne Matheny, NAB and Dennis Robinson, IWR

8.6.2 Reactive Maintenance Alternative

The Reactive Maintenance Alternative (RMA) would keep the existing system operating with all of the maintenance measures and operational and low cost structural measures carried forward as listed in **Tables 8-4 and 8-5**, respectively. Any and all repairs and component replacements would only be in reaction to component failures, or unscheduled, but would be accomplished quickly under emergency conditions. Annual and cyclical maintenance would be performed. Existing operational policies during periods of high congestion would be implemented and features such as all existing mooring cells and existing tow haulage units would be maintained. Also included are the following authorized improvements previously noted in Section 2.2.1.

- Olmsted L/D – Olmsted L/D is modeled throughout the period of analysis. Since this investment is under construction, this project is assumed operational by 2010 and no federal costs beyond 2010 are included.

- Myers auxiliary chamber extension – Myers auxiliary lock extension is under construction so Myers is included in the WOPC as a twin 1200' x 110' project. However, the project is not expected to become operational until 2012 so Federal costs beyond 2010 are included

- Greenup auxiliary chamber extension and main chamber rehab – Greenup is included in the WOPC as a twin 1200' x 110' project with a rehabbed main chamber. Federal costs beyond 2010 are only included for the major rehabilitation.

- McAlpine lock replacement – This investment became operational in 2009 and no federal costs beyond 2010 are included.

This alternative represents the WOPC.

8.7 EVALUATION OF THE REACTIVE MAINTENANCE ALTERNATIVE (WITHOUT PROJECT CONDITION)

Alternative WOPC System Investment Plans are evaluated for each traffic demand scenario to determine performance both at the lock and system-wide levels. Additional details are contained in **Sections 8 and 9 of the Economics Appendix**. Economics are addressed in Section 8.7.1; environmental issues are included in Sections 8.7.2 and 8.7.3. The focus of this analysis is evaluation of total costs, including Operations and Maintenance expenditures by the Corps and the costs incurred by commercial navigation. Corps and navigation industry costs are weighted equally.

8.7.1 Economic Performance

8.7.1.1 Methodology

1. The principal factor driving the variation in costs of WOPC alternatives is the performance of critical lock components required to keep the chamber open. Component performance in the form of annual probabilities (hazard rates) that these components may fail is evaluated through reliability analyses and assessed to determine repair or replacement needs through ORNIM.

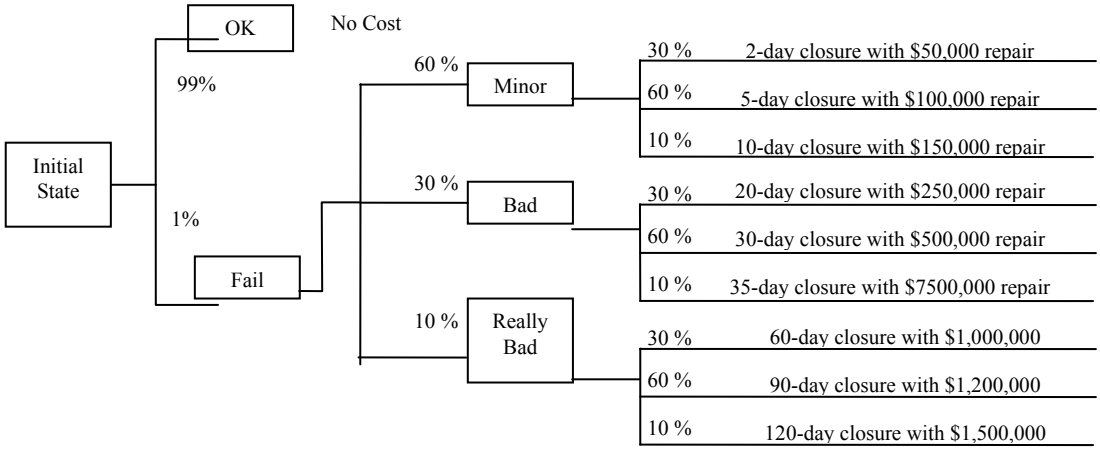
2. The RMA defers all repairs and replacement of critical components until after failure. The key outputs of the economic analysis of this alternative are the costs due to unexpected failures of the major components, both to repair or replace the failed component and the associated lock chamber closure times and associated navigation delay costs directly attributable to the closures. The critical inputs to this analysis are the hazard rates for each component, where a hazard rate for a given year is defined as the probability of failure during a given year assuming that no failure had occurred up to the beginning of the year, the potential failure scenarios and their likelihoods (given that a failure occurs), and the economic consequences associated with those scenarios.

3. All reliability models are developed to look at "significant" levels of failure that result in closure of a chamber and have an effect in the overall economic evaluation. For example, modeling of fuses in an overall electrical system is not warranted because their failure is not a major consequence in terms of money or safety. However, electrical power controls are modeled because their failure can have a major impact on both navigation and replacement costs. This same process is applied to all major components analyzed using reliability methods. The reliability models attempt to address failure mechanisms that are not addressed by routine maintenance, such as fatigue life and loss of strength due to corrosion. Therefore, it is assumed that overall reliability of major components such as miter gates and culvert valves are not significantly affected by routine or cyclical maintenance. Such maintenance helps to keep gates aligned and in proper working order but it does not address issues such as fatigue life and corrosion. For more details on how the reliability results are incorporated into the economic models please refer to the Section 7 of the **Economics Appendix**.

4. The basic economic evaluation process for any alternative can be represented by a repair "event tree" as shown in **Figure 8-1**. The probability of <u>any</u> failure for year (t) is given by the hazard rate, 1% in this case. Conversely, the probability that there are no failures in year (t) is given by one minus the hazard rate, or 99% here. The potential degrees of failure (noted as minor, bad and very bad in this illustration) and the necessary repair cost and associated chamber closure requirements are assigned probabilities based upon engineering judgment[7]. In this example, there are three possible repair options for each degree of failure. Repairs due to a minor failure of the component would cost between $50,000 and $150,000 and involve a lock closure of between 2 and 10 days.

[7] The probability of any particular degree of failure in year (t) is the product of the hazard rate in year t {h(t)} and the conditional probability of the degree of failure given that there the component fails.

Figure 8-1
EXAMPLE EVENT TREE



5. All event trees except those for the lock and approach walls at Emsworth, Dashields, and Montgomery account for single modes of failure. Event trees for these walls accounted for multiple modes of failure and were developed by aggregating (lumping) the individual event trees for all failure modes. The results from this aggregation process were checked against the total costs based on separate analyses of the individual failure modes. Additional details on the event tree derivation are provided in the **Engineering Appendix**. The reliability of twenty components was analyzed at each mainstem lock chamber; however, only those with some minimal threshold likelihood of failure during the analysis period were carried forward for economic analysis with this methodology. The subset of components varied from site to site.

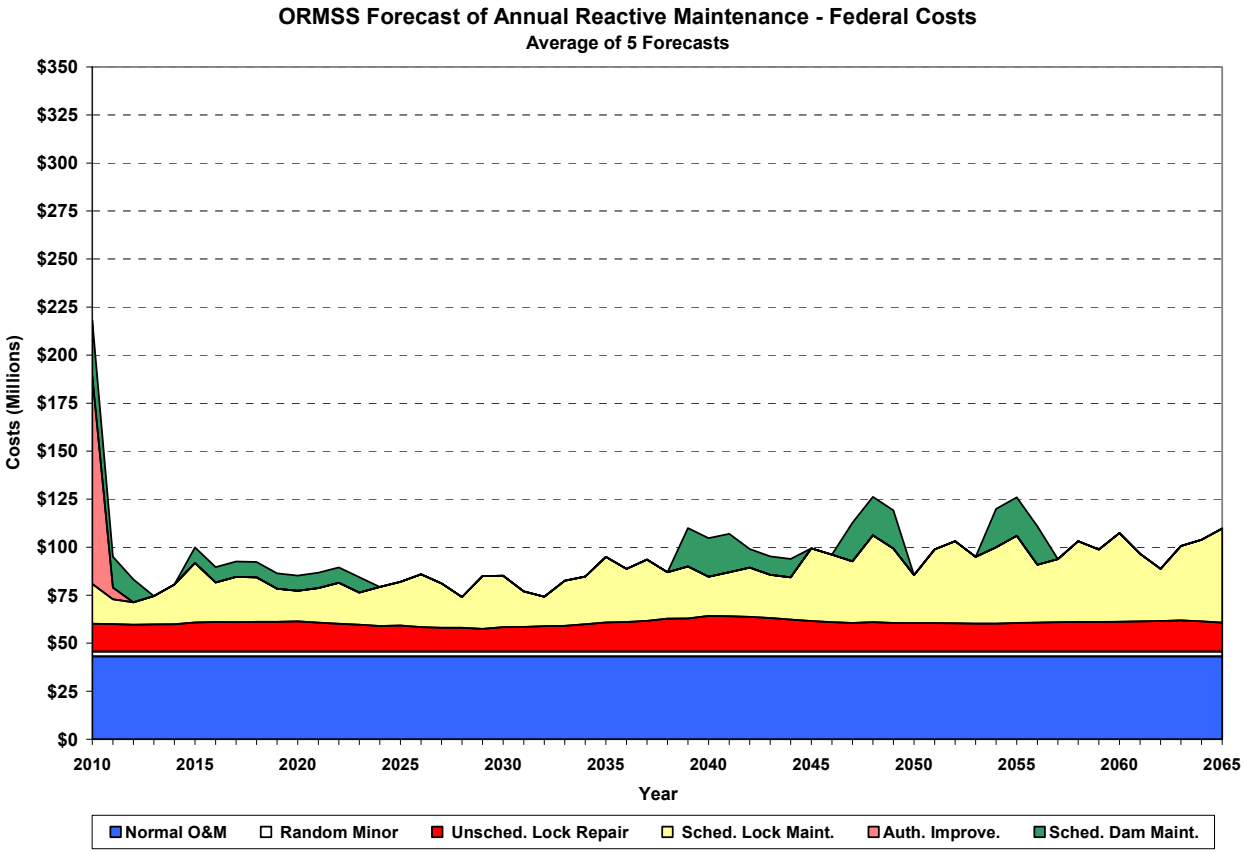
8.7.1.2 Ohio River Mainstem and Project Costs

1. The total costs for the Reactive Maintenance Alternative include operations and maintenance costs incurred by the Corps, including routine maintenance, cyclic (scheduled) maintenance, and unscheduled repair costs at all nineteen Ohio River facilities, as well as costs to construct all authorized improvements. Given the engineering hazard functions and event trees for the lock components considered, ORNIM was run for each project to calculate the expected repair costs under each of the five different traffic forecast scenarios. **Attachment 3 of the Economics Appendix** provides a more detailed discussion of this analysis.

2. **Figure 8-2** shows forecast reactive maintenance funding needs over time aggregated for all nineteen Ohio River facilities and averaged over all five traffic scenarios. Much of the work for authorized improvements occurs prior to 2010 and is not shown in **Figure 8-2**. The high costs for authorized improvements reflect the completion of the Myers auxiliary lock extension and major rehabilitation of the Greenup main lock chamber. The high cost for scheduled dam maintenance reflects the completion of the on-going MR of Emsworth dams. Economic costs for all "sunk costs" prior to the year

2010 are included in all economic cost tabulations for the WOPC as well as WPC alternatives as presented in Section 10. Overall, this analysis shows an average annual expenditure of around $100.0 million is required to sustain navigation on the Ohio River from 2010-2070 with a reactive maintenance strategy.

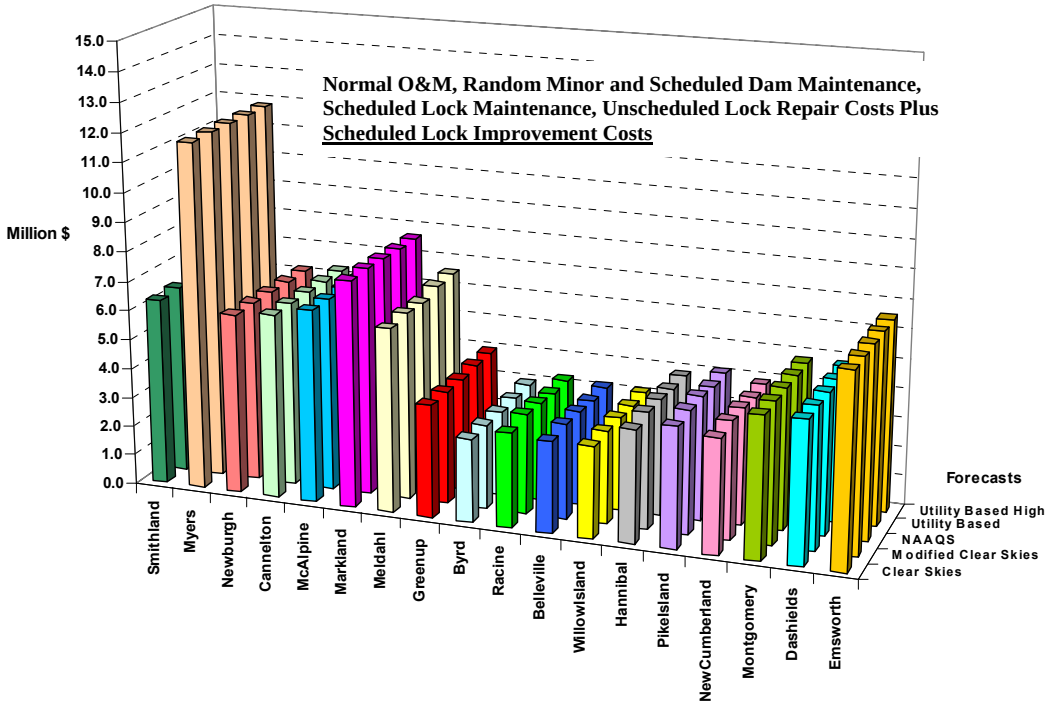
FIGURE 8-2



3. **Figure 8-3** displays average annual Federal costs for the reactive maintenance strategy by project and by traffic forecast averaged over all five forecasts. The graph displays all maintenance cost categories as well as the costs for authorized improvements. High reactive maintenance needs are seen on the upper and lower Ohio projects.

4. Section 4 of **Attachment 3 Project Maintenance Analysis** displays each project's component-level, expected transit costs and repair costs for each traffic forecast scenario with a reactive maintenance strategy.

FIGURE 8- 3
Reactive Maintenance
Average Annual Project Costs
(2010-2070, 5 1/8%, FY 03$)



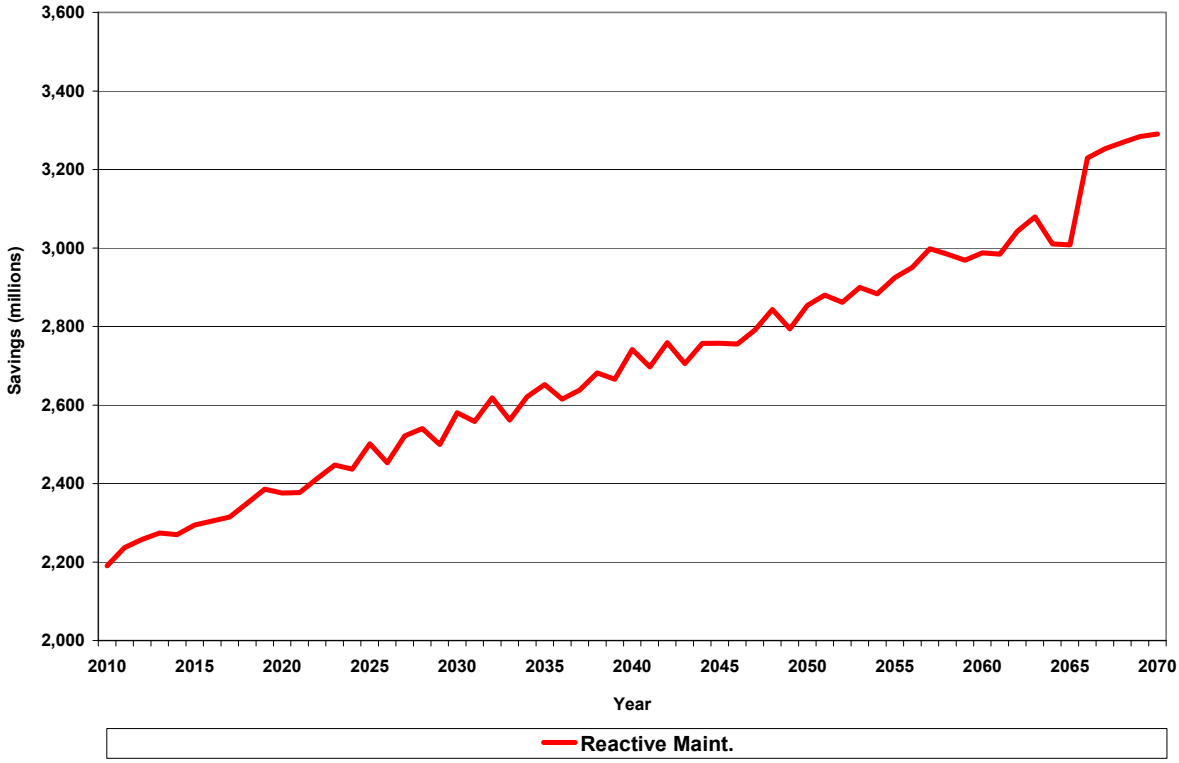
8.7.1.3 Ohio River Mainstem Benefits

1. The primary benefit for Federal investment in the inland waterways is the collective transportation cost savings for barge shipment over the least-costly alternative routing or transportation mode. The benefit is referred to as transportation rate savings. Corps regulation recognizes transportation rate savings or cost reduction as a National Economic Development (NED) benefit. (See **Attachment 6 of the Economics Appendix** for a detailed discussion on derivation of transportation rate savings.)

2. In ORMSS, the total or National Economic Development (NED) benefits are calculated from the total equilibrium waterway traffic transportation rate savings less any eroded savings from congestion or delay due to unscheduled repair closures. Equilibrium waterway savings for each traffic scenario are determined by the ORNIM, where equilibrium is defined to occur when every movement fully assigned to the waterway has a lower cost-per-ton by water routing than by land, resulting in a positive rate-savings, while every movement fully assigned to the land routing has a lower cost-per-ton by land than by water. Two iterations of ORNIM are required; the first to determine the equilibrium traffic and associated total transportation savings compared to the lowest cost alternative transportation option for all commercial traffic that considers only scheduled closures (cyclical maintenance in the case of the WOPC). A second iteration then

determines impacts due to unscheduled lock chamber closures and the added delay costs or reduced savings due to those closures and recalculates the transportation savings. **Figure 8-4** displays system transportation savings including reduced savings averaged over all 5 traffic forecast scenarios for the base-level reactive maintenance WOPC. Average annual system NED benefits are $2.46 billion from 2010-2070.

FIGURE 8-4
Reactive Maintenance System Transportation Annual Savings
Average of 5 Forecasts



8.7.1.4 Ohio River Mainstem Statistics

1. **Table 8-8** summarizes the expected mainstem system benefits, eroded transportation savings and costs by cost category for the reactive maintenance alternative for each of the five traffic forecast scenarios. Average annual system benefits range from $2.25 to $2.46 billion, reflecting reduced or eroded savings due to unscheduled repairs of $76 to $124 million annually.

TABLE 8-8
Reactive Maintenance*
(Without Project Condition)
Average Annual Costs and Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Reactive Maintenance Benefits					
Equilibrium Waterway Savings	$2,328.6	$2,493.5	$2,476.0	$2,536.4	$2,580.5
Reduced Savings from Unscheduled Repair	($75.8)	($119.8)	($124.1)	($107.7)	($120.3)
Total System Benefits	**$2,252.8**	**$2,373.7**	**$2,351.8**	**$2,428.7**	**$2,460.1**
Reactive Maintenance Costs					
Scheduled Lock Maintenance	$ 23.1	$ 23.1	$ 23.1	$ 23.1	$ 23.1
Scheduled Dam Maintenance	$ 6.9	$ 6.9	$ 6.9	$ 6.9	$ 6.9
Scheduled Lock Improvements**	$ 5.8	$ 5.8	$ 5.8	$ 5.8	$ 5.8
Unscheduled Lock Repair	$ 14.0	$ 15.1	$ 15.0	$ 14.7	$ 15.0
Normal O&M	$46.7	$46.7	$46.7	$46.7	$46.7
Random Minor	$2.4	$2.4	$2.4	$2.4	$2.4
Total System Costs	**$99.0**	**$100.1**	**$100.0**	**$99.8**	**$100.1**
Net Benefits	**$2,153.8**	**$2,273.6**	**$2,251.8**	**$2,328.9**	**$2,360.1**
BCR	**22.7**	**23.7**	**23.5**	**24.3**	**24.6**

**Sums and differences may reflect rounding error.*

*** Scheduled Lock Improvements are 50% cost shared with the Trust Fund and include the authorized 600' extension of the auxiliary chamber at Myers in 2010 and rehabilitation of the Greenup main chamber in 2010-11. Other authorized improvements are modeled as complete and on-line before 2010 and those costs are not included.*

2. Total system costs in **Table 8.8** are the expected average annual Federal and Trust Fund expenditures needed to maintain Ohio River navigation infrastructure under the reactive maintenance strategy. Refer to Section 8.3.1 for details of each maintenance cost category. The Federal costs represent the costs to the Federal government to maintain, repair, or improve the navigation projects. Scheduled lock and dam maintenance costs are what the Federal government pays for the scheduled cyclical maintenance of the mainstem projects. Scheduled improvement costs are the Federal and Trust Fund costs remaining as of 2010 to complete authorized mainstem projects (Greenup and J.T. Myers). Unscheduled repair costs are the Federal costs associated with the unscheduled repair and replacement of lock components. Normal O&M is a fixed cost to the Federal government to staff and supply the project regardless of the project's ability to accommodate any traffic. Random minor costs are also incurred equally in all traffic scenarios. Total system costs are the average annual Federal expenditures expected to maintain Ohio River navigation infrastructure under the reactive maintenance

strategy. The Federal costs represent the costs to the Federal government to maintain, repair or improve the navigation projects. Average annual system costs range from $99.0 to $100.1 million. Net benefits range from $2.15 to $2.36 billion.

3. It is instructive to consider the average annual delays and annual tonnages processed at several representative locks in the WOPC, Montgomery for the upper Ohio River comprised of EDM and Racine for the middle Ohio River. At Montgomery, the average annual delays determined by the ORNIM in every year (2010-2070) exceed by an order of magnitude or more the average delays shown in Table 6.2 for the period 1994-2003. These delays are likely due to frequent unscheduled lock closures to repair failed components. The tonnages processed through Montgomery nearly equal demands until around 2020 when tonnage processed falls below demands in **Table 8-3** in many years, ranging from 0.5 million to 2.0 million below those demands. At Racine, annual average delays range from 1.0 to about 5 hours per tow in years when the main chamber is dewatered, compared to about 0.5 hours per tow during 2000-2004. These delays cause the diversion of 0.2 to 1.0 million annually of the tons demanded as shown in **Table 8-3**.

8.7.2 Impacts to Valued Environmental Components

1. Potential direct and indirect effects of the 10 navigation-related measures included in WOPC Reactive Maintenance Alternative (RMA) are presented in **Table 8-9**. The 10 measures are divided into maintenance actions, operational actions, and low-cost structural actions. Further, each action is briefly described. The major portion of **Table 8-9** is associated with "cells" containing descriptive information on the effects (impacts) of the 10 measures on the six major Valued Ecological Components (VECs); namely, water quality, fish, mussels, riparian resources, recreation, and health and safety. These six VECs were designated as major based on inputs from the Interagency Working Group and various publics, recognition of their inherent importance in the environment of the Ohio River Mainstem, and their susceptibility to damage from multiple governmental and private actions in the Mainstem environs. **Table 8-9** also includes codes in the upper parts of cells to denote whether the anticipated effects are detrimental or undesirable (denoted by a "-" sign), beneficial or desirable (denoted by a "+" sign), or a mixture (denoted by a "-/+" sign).

TABLE 8-9

POTENTIAL ENVIRONMENTAL EFFECTS ON MAJOR OHIO RIVER VECS

IN THE WITHOUT PROJECT REACTIVE MAINTENANCE ALTERNATIVE

WOPC Action	Description of Action	Impacts on Major VECS					
		Water Quality	**Fish**	**Mussels**	**Riparian Resources**	**Recreation**	Health & Safety
Maintenance Actions							
Routine Maintenance	Small jobs and minor repairs. See Table 8.2 for details.	Impacts are anticipated to be very limited; if care is taken in handling lubricants and other materials, BMPs are used to minimize erosion, and Corps standard procedures followed. Environmental Management Systems type approaches could contribute to long term reduction of cumulative maintenance impacts; e.g. lawn maintenance alternatives to reduce mowing and use of fertilizers & herbicides.				No impacts to recreation are anticipated because lock closures do not occur during routine maintenance.	**Impacts are anticipated to be very limited, if care is taken in handling harmful materials and equipment.**
Cyclical Maintenance	Scheduled inspections and repairs to major components, including chamber dewatering	+/- In the long-term, cyclical maintenance would benefit water quality, by ensuring safe passage of vessels through the locks and lessening the need for emergency repairs. Short term negative impacts to	-/+ Dewatering would interfere with limited upstream movement of fish through locks and possible damage to tailwater areas. Cyclical maintenance, however, would minimize	-/+ Lock dewatering could alter flows to downstream mussel habitat and possibly directly damage beds, depending on their location. As with fish, cyclical maintenance, could minimize unscheduled repairs that	- Chamber dewatering would increase queues and potential barge toe-ins and tie offs that can damage riparian resources. Operational and low coast structural actions can prevent some of this damage.	- Chamber dewatering would limit or perhaps eliminate lockages by recreational vessels as commercial vessels would be given priority. If maintenance procedures required long-term closures, measurable economic losses related to recreation could occur.	**Impacts are anticipated to be very limited, if care is taken in handling harmful materials and equipment.**

		water quality may include increased turbidity during dewatering & decreases in oxygen levels.	unscheduled repairs that could cause greater damage to fish habitat. Chamber dewatering would increase queuing and potentially directly scour fish habitat or interfere with spawning and feeding.	could cause greater damage to mussels and their habitat. Chamber dewatering would increase queuing and potentially cause direct damage to mussel beds or interfere with reproduction and feeding.			
Unscheduled Repairs	Includes all unscheduled repairs to major components, often under emergency conditions.	- Negative impacts can occur to water quantity and to fish, mussels, and riparian resources, if failure of major L & D components alters water levels or releases harmful substances into the aquatic environment. The extent of the damage in part would be related to the duration of emergency conditions, as well as time of year. Emergency repairs may overlook measures/opportunities to avoid, minimize or mitigate for environmental impacts, increasing risk of experiencing otherwise avoidable impacts. Emergency repairs with unscheduled closures may exacerbate impacts of queuing.				- Negative impacts to recreation would occur relative to the duration of a lock closure and time of year it occurred.	- **Because emergency conditions are less predictable than routine or cyclical maintenance, special precautions are essential to ensure worker safety in these circumstances.**
Operational Actions							
N-Up/N-Down Lockage Policy	Involves locking a given number of tows (N) in the same direction, then allowing the same	+ Reduces queuing that wastes fuel	+ Facilitates tow movement	+ Facilitates tow movement near L & Ds,	+ Reduces queuing and possible bank	+ Facilitates movement of tows through locks and	**+ Facilitates orderly procession of**

	number to proceed in the opposite direction to increase lock efficiency and reduce queuing.	and can increase turbidity; lowers potential for accidental spills of materials shipped.	through sensitive tailwater habitat.	reducing potential damage to nearby mussel beds.	scour and erosion and damage to shoreline vegetation if vessels push into banks while waiting in queue.	reduces time recreational vessels must remain in queues.	**tows through locks and decreases potential for accidents that may cause injury or spills of hazardous and other harmful materials.**
Advanced Notice of Main Chamber Closures	Notification of towing industry and other river users prior to main chamber closures promotes better management of vessels during closures.	+ Similar to N-up, N-down in reducing harmful effects of queuing. Additionally, would benefit WQ by reducing traffic on river during closures.	+ Similar to N-up, N-down in reducing harmful effects of tows in tailwater habitat. Additionally, would benefit fish habitat somewhat by reducing traffic on river during closures.	+ Similar to N-up, N-down in reducing harmful effects of queuing near or on mussel beds. Additionally, would benefit mussels by reducing traffic on river during closures.	+ Similar to N-up, N-down in reducing harmful effects of queuing and tying off along banks. Additionally, would benefit riparian resources by reducing traffic on river during closures.	+ Reduces number of tows passing through locks and reduces time recreational vessels must remain in queues, if allowed to use operational lock chamber.	**+ Reduces number of tows passing through locks and decreases potential for accidents that may cause injury or spills of hazardous and other harmful materials.**
Adjustment of Shipping Schedules	Involves efforts by towing industry to plan pre- and-post closure shipments, ship via other routes or modes, deliver from alternative sources, and rearrange shipments to minimize trips through L	+ Impacts very similar to Advanced Notice of Lock Chamber Closures.	+ Impacts very similar to Advanced Notice of Lock Chamber Closures.	+ Impacts very similar to Advanced Notice of Lock Chamber Closures.	+ Impacts very similar to Advanced Notice of Lock Chamber Closures.	+ Impacts very similar to Advanced Notice of Lock Chamber Closures.	**+ Impacts very similar to Advanced Notice of Lock Chamber Closures.**

	& Ds.						
Industry Self-Help	Involves helper towboats that assist tow locking by extracting unpowered cuts of barges from lock chamber and then moving them in a refleeting site away from the L & D to increase lock efficiency and reduce queuing.	+ Impacts very similar to N-up/N-down policy.	+ Impacts very similar to N-up/N-down Policy. Damage to fish habitat could occur in refleeting areas depending on locations.	+ Impacts very similar to N-up/N-down Policy. Damage to mussel habitat could occur in refleeting areas depending on locations.	+ Impacts very similar to N-up/N-down policy.	+ Impacts very similar to N-up/N-down policy. Boater education about refleeting areas could avoid potential conflicts between commercial and recreational vessels.	**+ Impacts very similar to N-up/N-down policy.**
Low-Cost Structural Actions							
Tow Haulage	Involves using equipment that expedites the two-cut lockage process when helper boats are not available; increases lock efficiency and reduces queuing. Not available or feasible at every L & D project.	+ By reducing queuing, impacts are very similar to N-up/N-down policy & self-help.	+ By reducing queuing, impacts are very similar to N-up/N-down policy & self-help.	+ By reducing queuing, impacts are very similar to N-up/N-down policy & self-help.	+ By reducing queuing, impacts are very similar to N-up/N-down policy & self-help.	+ By reducing queuing, impacts are very similar to N-up/N-down policy & self-help.	**+ By reducing queuing, impacts are very similar to N-up/N-down policy & self-help.**
Mooring Cells	Located at arrival points to locks and used to tie off while tows wait in queues; eliminate or reduce queuing along banks; reduce turbidity and air impacts from engine idling.	-/+ Negative impacts to WQ during installation would be limited primarily to increased turbidity, although additional adverse impacts	-/+ Negative impacts to fish habitat could occur during installation. Further, heavy use of mooring areas would restrict fish use for feeding and	-/+ Negative impacts to mussel habitat could occur during installation. Such impacts may extend throughout the use of the mooring area. Positive impacts would	-/+ Negative impacts to mussel habitat could occur during installation depending on proximity to shore and scouring by vessel prop wash. Positive impacts	-/+ Limited negative impacts to recreation may occur when mooring cells are installed. If such cells are clearly marked, recreational vessel accidents should be minimized. The overall reduction in queuing near locks should make	**-/+ Negative impacts to H & S could occur during installation unless proper safety precautions are taken. Once installed, mooring cells minimize dispersed barge**

		would occur if fuel spilled. Positive impacts would be related to reductions in queuing and fuel consumption.	reproduction. Positive impacts would be related to reductions in queuing and prevention of more dispersed damage to fish habitat.	be related to reductions in queuing and prevention of more dispersed damage to mussel habitat.	would be related to reductions in mooring along banks that can damage riparian vegetation and cause erosion and bottom scouring,.	recreational lockages safer and more efficient.	**traffic, which otherwise may cause accidents.**
Temporary Mooring Cells during Lock Closures	**Same as above, but placed on shorter-term basis.**	-/+ **Impacts similar to more permanent mooring cells, but shorter term.**	-/+ **Impacts similar to more permanent mooring cells, but shorter term.**	-/+ **Impacts similar to more permanent mooring cells, but shorter term.**	-/+ **Impacts similar to more permanent mooring cells, but shorter term.**	-/+ **Impacts similar to more permanent mooring cells, but shorter term. Need to be clearly marked (even if temporary) so recreational river users become aware of them and can avoid accidents.**	-/+ **Impacts similar to more permanent mooring cells, but shorter term. Need to be clearly marked (even if temporary) so recreational river users become aware of them and can avoid accidents.**

2. Based upon a careful review of the descriptive information in **Table 8-9,** the following general observations can be made:

- Regarding the three maintenance actions, the small jobs and minor repairs associated with routine maintenance would cause only localized and limited effects on the six VECs. Cyclical maintenance actions related to major lock components would be expected to require lock chamber dewatering. Short-term detrimental effects could occur relative to increased water turbidity, interference with upstream movement of fish, disruptions in downstream mussel habitat, damage to riparian resources due to the queuing of tows and their bank toe-ins and tie-offs, and disruption of recreational boat lockages. For emergency conditions requiring unscheduled repairs to major components, negative (detrimental) impacts would be expected on all VECs. The duration of the emergency conditions and the time of the year would influence the extent of the impacts.

- Regarding the four operational actions in **Table 8-9**, each is expected to reduce tow queuing prior to passage through the locks, and to facilitate tow movement through the locks in a more timely manner. As a result, beneficial impacts (effects) on the six VECs are expected from reductions in localized water turbidity levels, decreases in aquatic and riparian habitat disruptions, and lowered potentials for accidental spills of barged materials.

- Relative to the three low-cost structural actions in **Table 8-9**, tow haulage is expected to reduce queuing and thus provide beneficial impacts (effects) on the six VECs. Such beneficial effects would result from reductions in localized water turbidity levels; decreases in disruptions to habitats for fish, mussels, and riparian resources; and lowered accident potentials. Both permanent and temporary mooring cells are expected to cause negative and positive effects on the six VECs. Depending upon their location, negative effects could occur from mooring cells if they are over or near mussel beds, if they disrupt fish habitat, or if they are near erodible shorelines. Positive effects related to appropriately located mooring cells could result from reductions in queuing and the minimization of dispersed damages to habitats.

3. From the perspective of the potentially impacted VECs, the following can be noted from **Table 8-9**:

- Because of the localized and limited nature of effects from routine maintenance, the water quality VEC would not be affected. However, this VEC would be negatively impacted, albeit on a localized basis and for the short term, by cyclical maintenance and unscheduled repairs. These impacts, resulting from lock closures, queuing and construction activities would be partially attenuated by the 4 operational actions and the 3 low-cost structural actions described in **Table 8-9**. These scheduled and unscheduled repair activities are necessary to maintain the current level of commercial traffic on the Ohio River. Accordingly, the WOPC

alternative, which is comprised of the 10 actions in **Table 8-9**, would not cause large-scale detrimental effects on the water quality VEC. Rather, beneficial effects would accrue over the long term by minimizing localized turbidity levels from tow queuing, particularly in tailwater areas below the locks.

- An important exception to the above generalization may occur when unscheduled repairs are necessitated by extraordinary events such as the pool loss at Bellville in 2005 or the failure of major lock components that result in long closures with minimal warning to the barge industry. Emergency repairs under such conditions may preclude opportunities to avoid or minimize environmental impacts while increasing impacts from queuing and construction site activities. Additionally, beneficial effects associated with the 4 operational and 3 low-cost structural actions may be reduced due to delays or inability to provide such measures during the emergency response. The negative consequences of such events could impact all six of the VECs addressed in **Table 8-9.**

- Routine maintenance, in combination with standard measures to avoid spills or other impacts related to such activity, is not expected to have any affect on the Fish VEC. Cyclical maintenance and unscheduled repairs would be expected to produce temporary, localized impacts, including sediment resuspension and deposition, disruption of seasonal feeding or spawning patterns, and disruption of fry and larval life stages. The severity of such impacts would be reduced by implementation of the 4 operational actions and the 3 low-cost structural actions. Additionally, completion of such repairs will contribute to the maintenance of efficient movement of commercial traffic through the locks, which would result in reduced impacts to fish during normal operations.

- The mussels VEC comprises the resource group that is most sensitive to construction and queuing related impacts. However, mussels are not expected to be seriously affected by routine maintenance activities so long as accident and spill prevention standards are observed. Mussels would be susceptible to impacts from cyclical maintenance and unscheduled repairs, including turbidity, scouring and sediment deposition, that could disrupt feeding and spawning activities. In some cases, the duration of impacts such as sediment deposition could continue beyond the actual periods of disturbance. The effectiveness of operational and structural practices designed to minimize such impacts would be enhanced by carefully documenting the location of mussel populations in proximity to the project and potential queuing areas prior to initiation of such disturbances. In the case of mooring cells, care must be taken to avoid or minimize potential impacts related to the location and construction of such structures.

- Riparian resources are unlikely to be impacted by routine maintenance activities, but can be damaged by barge toe-ins and tie-offs during periods of queuing necessitated by maintenance or repair activities. The 4 operational measures, plus tow haulage, can somewhat reduce such impacts. Where available, mooring cells have the potential to nearly eliminate queuing related impacts.

- It is highly unlikely that recreational activities would be influenced by routine maintenance. In the case of lock closures required for cyclical maintenance or unscheduled repairs, passage through the auxiliary lock may be suspended. Access to visitor facilities at the lock and dam project may also be closed during the construction phase. These inconveniences are somewhat compensated by the general availability of alternative recreational opportunities elsewhere on the Ohio River. When recreational access is not closed, the operational and low-cost structural measures associated with movement of commercial traffic through the construction area would have limited positive impacts on recreational activity. Ultimately, completion of maintenance and repair activities is necessary to long term provision of recreational opportunities during periods of normal operation.

- Health and safety impacts of routine maintenance should be very limited, in proportion to continued observance of routine safety standards at the lock and dam project. During cyclical maintenance or unscheduled repairs, risk factors become elevated and more proactive safety standards are required. Closure of the lock and dam area to visitors and temporary suspension of recreational lockages are examples of such proactive measures. The 4 operational measures and 3 low-cost structural options also contribute to safety by helping reduce congestion in the vicinity of the construction activity.

8.7.3 Cumulative Effects

The final consideration related to the direct and indirect effects of the WOPC alternative, referred to as the Reactive Maintenance Alternative (RMA), is focused on two issues – the anticipated relative contribution of the RMA to current and future cumulative effects on the six VECs, and the influence of the RMA on the current and future environmental sustainability (ES) of the six VECs. These two issues are addressed for the six VECs as follows:

- Relative to cumulative effects on the water quality VEC, Chapter 3 of the Cumulative Effects Assessment report in the Environmental Appendix denotes multiple governmental and private actions which are currently, and projected to continue to be contributors to cumulative water quality effects. Under current conditions, the negative water quality effects of the RMA are expected to be localized, short-term, and minor in their relative effects. However, continuing through the 60-year planning horizon for WOPC, lock closure and repair activities associated with cyclical maintenance and unscheduled repairs are expected to become more frequent and to require, on average, longer closures. The increased frequency and extent of repair activities would be the direct result of "wear and tear" of progressively aging lock components in the absence of proactive maintenance, rehabilitation, or replacement measures. The rate at which repair frequency and associated impacts would occur is directly related to traffic levels at each lock and/or to deterioration of materials due to aging. Further, the rate at which such traffic levels change is illustrated in the 5 traffic scenarios. As a

result, long-term effects from the RMA would produce increasing levels of negative impacts to water quality, thus contributing to a reduction of overall ES of the water quality VEC.

- Over the long term progression of increasingly frequent and complex repairs necessary to maintain an aging infrastructure, the potential occurrences of extraordinary or catastrophic events would be expected to increase. The cumulative effect of such events, as well as the impacts of emergency responses to such events, would be in addition the more predictable cumulative effects that are described in this section.

- In general, the long term impacts of the RMA will have similar effects for each of the VECs discussed here. Fish, mussels, and riparian resources would all experience increasing levels of negative impacts in proportion to the rate at which repair frequency and associated impacts would increase. Mussels are considered the most "at risk" VEC in this context and would thus be the most likely to exhibit declines in overall ES in response to the increased frequency and extent of reactive repair efforts to maintain an aging infrastructure.

- The cumulative impact to recreation interests of increasingly frequent and protracted periods of closure could result in declines in the use of certain portions of the river for recreational purposes. The decline of such recreational activities could result in economic losses to service providers in these areas and/or declines in property values or development potential of the riverfront.

- Health and safety risk factors would rise in direct proportion to the cumulative increase of repair activities. Such factors would be even more elevated whenever repair efforts must be undertaken in response to emergency conditions.

8.8 EVALUATION OF ENVIRONMENTAL SUSTAINABILITY MEASURES

8.8.1 Methodology

1. **Tables 8-6 and 8-7** in Section 8.5 identify a spectrum of program authorities by which the Corps, other state or federal agencies, or private organizations, may be able to initiate efforts to improve the environmental sustainability of certain Ohio River resources. **Table 8-6** compares a list of opportunities for enhancing Environmental Sustainability (ES) with existing authorities and related programs or responsibilities of the Corps. A category is also included for other agencies and NGOs, which is expanded upon in **Table 8-7** to address ES authorities of other federal agencies.

2. In this Section, the ES measures have been organized into 4 groups that reflect progressive levels of implementation complexity. This organization is independent of navigation alternatives. This grouping of ES measures is organized as follows:

- Group A: Measures for which authority already exists and which involve minimal costs. These measures would increase awareness of key VECs, focus on impact prevention, and could be implemented relatively quickly.

- Group B: Measures for which authority already exists, but which would require some costs for planning and/or construction. These measures focus on key VECs and incorporate restoration and enhancement.

- Group C: Measures for which some authority already exists, but new authority may be needed for some opportunities. Planning and construction costs may be relatively high. These measures generally encompass broad descriptions of opportunity that may need refinement and the focus tends toward broader-level environmental needs.

- Group D: Measures which require new authorities or are primarily addressed through authorities of other agencies (e.g., USEPA). Planning and construction costs may be relatively high. These measures generally encompass broad descriptions of opportunity that may need refinement, and the focus tends toward broader-level environmental needs.

3. The potential effects of individual ES measures are summarized in **Table 8-10** for each of the major VECs. In this presentation, these enhancement opportunities have been organized according to the groupings described above. As authorities exist for measures in Groups A and B, the WOPC alternative for the purpose of environmental sustainability comprises those measures. This alternative is termed the "minimal plan" for ES. The other groups are included in WPC alternatives.

8.8.2 Sustainability in the Without-Project Condition

Based upon a comparison of the information presented in **Table 8-10** (potential effects of ES enhancement measures) and **Table 8-6** (existing authorities), the following generalizations can be made regarding potential implementation of the ES measures:

- Although the four measures in Group A are considered less difficult to implement than measures in the other groups, some obstacles to implementation must still be considered. As indicated in **Table 8-6**, although the marking of mooring areas in proximity to lock and dam projects may be within the Corps' authority, markings to control or redirect navigation on other parts of the river would require coordination with other agencies where such authorities reside (e.g., U.S. Coast Guard).

TABLE 8-10

POTENTIAL EFFECTS OF ES ENHANCEMENT MEASURES ON MAJOR VECS IN THE WITH PROJECT ALTERNATIVE

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	**Fish**	**Mussels**	**Riparian Resources**	**Recreation**	**Health and Safety**
Group A – Measures for which authority already exists. Such measures would involve minimal costs, increase awareness of key VECs, focus on impact prevention, and could be implemented quickly.						
Mark critical locations to prevent mooring near mussel beds or special shoreline areas.	+ + Reduces turbidity in areas near mussel beds where vessels previously moored.	Enhancement of mussel habitat benefits fish and other animals that feed on mussels.	+ + + Helps protect mussel beds from direct damage and scouring from tows and other vessels.	Helps protect sensitive shoreline areas vulnerable to loss of vegetation and erosion.	Decreases number of potential sites on river where conflict may occur between tows and recreational vessels.	+ Decreases vessel operations in shallow water areas.
Mark shallow mussel beds to reduce direct impacts of tow traffic.	+ + Similar to above action in reducing turbidity.	Similar to above action in enhancing mussel habitat for fish and other animals that feed on mussels.	+ + + Similar to above action in helping to protect mussel beds from direct damage and scouring from tows and other vessels.	Similar to above action in helping to protect sensitive shoreline areas vulnerable to loss of vegetation and erosion.	Clearly delineates areas recreational vessels should avoid.	+ Decreases vessel operations in shallow water areas.

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	**Fish**	**Mussels**	**Riparian Resources**	**Recreation**	**Health and Safety**
Provide the navigation industry with charts showing locations of sensitive resources and include rationale for avoiding such resources.	+ + Similar to above action in reducing turbidity.	Helps protect spawning areas, other fish habitat and provides education on need to protect sensitive resources.	+ + + Helps protect mussel beds and other benthic habitat and provides education on need to protect sensitive resources.	Could also include important riparian resources, including wetlands and islands; Provides education on the value & protection of such resources.	Clearly delineates areas recreational vessels should avoid while also providing education on the value and protection of such resources.	+ Decreases vessel operations in shallow water areas.
Minimize catastrophic contamination events through reduction of spills, accidents, and improvement of spill response procedures.	+ Although several related measures are already in place, additional refinements would protect all aquatic resources from the immediate and long-term effects of contamination events.				+ Activities that protect or improve aquatic resources typically enhance recreation.	+ Reduction of incidents and improvement of responses would benefit navigation industries and the general public.
Group B – Measures for which authority already exists, but which would require some costs for planning and/or construction. Such measures focus on key VECs and incorporate restoration and enhancement.						

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	Fish	Mussels	Riparian Resources	Recreation	Health and Safety
Allow flows to mimic natural regimes including seasonal and extreme floods and droughts.	+ + Would reduce potential oxygen and thermal stratification upstream from L & Ds.	Would benefit typical river fishes by more closely approximating natural patterns.	+ + + Would benefit mussels adapted to rivers by more closely approximating natural patterns.	Would benefit native vegetation and seed banks dependent on seasonal patterns to sustain them.	Would enhance recreational experience of being on a river rather than the more lake-like environment currently provided by flow regimes.	- Low flows could increase groundings and spills. High flows would adversely affect navigation safety by increasing difficulty of maintaining vessel control.
Restore unique mainstem habitats such as canebrakes, river bluffs, and mussel beds.	+ + Would reduce erosion. Wetland restoration also would help filter runoff from upland areas.	Would help diversify fish habitat and feeding areas, particularly benefiting shoreline species.	+ + + Would enhance habitat for all mussel species and perhaps benefit specific endangered species.	Would enhance diversity of riparian habitats and also provide educational opportunities related to value of riparian resources.	Would enhance recreational experience by providing diverse shoreline habitats more typical of the pre-settlement river.	

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	Fish	Mussels	Riparian Resources	Recreation	Health and Safety
Protect tailwaters and provide structures to serve as refugia for fish.		+ Enhances habitat diversity and offers some protection from river traffic.	+ May simultaneously provide some protection for mussels.		+ Would make tailwater fishing more challenging and interesting and would attract more fish.	- In-stream structures in tailwaters could result in greater navigation hazards near Locks and Dams.
Create spawning shoals and other in-stream features to enhance habitat diversity in navigation pools.		+ Enhances habitat for reproduction and may diversify fish communities.	+ Enhanced fish habitat may also enhance mussel diversity and protection.		+ Would potentially make fishing more challenging and interesting and may attract more fish species.	+/- In-stream structures would need to be evaluated prior to placement to avoid creation of navigation hazards.
Identify and expand areas of submerged and emergent aquatic vegetation.	+ + Removes sediment and some contaminants.	Enhances fish habitat and protection.		+ + Creates a transition zone between riparian areas and open water that may provide habitat and food for some riparian species.	Visually enhances the recreational experience.	+ Aquatic macrophyte beds provide visible evidence of shallow water areas to be avoided by commercial and recreational traffic.

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	Fish	Mussels	Riparian Resources	Recreation	Health and Safety
Protect and manage mussel populations and their habitat on a site-specific basis.		+ Enhancement of mussel habitat benefits fish and other animals that feed on mussels.	+ May help restore species with specific habitat requirements.			
Control exotics, including minimization of existing populations and prevention of new introductions.	+ + Prevents adverse effects from exotics such as carp species.	Lowers potential competition with native fish species.	+ + + Increases sustainability of native mussels in several ways, including controlling predation by exotic fish species and competition from Zebra mussels.	Control of exotic plants improves health & sustainability of native riparian plant assemblages.	Maintains a more balanced ecosystem beneficial to fishing, birding, and wildlife watching.	+/- Could improve efficiency of navigation movements. Some control options (e.g., chemical) would be required to follow EPA label restrictions to ensure public protection.

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	Fish	Mussels	Riparian Resources	Recreation	Health and Safety
Protect or restore riparian habitat diversity, including islands, on the mainstem and tributaries.	+ + Reduces shoreline erosion and sediment inputs.	Enhances fish habitat and protection.	+ + + Islands enhance habitat and protection for native mussels and other benthic organisms. Side channels along islands are especially productive.	Enhances the many benefits of riparian areas and provides related educational opportunities.	Creates or enhances additional areas for birding, and wildlife watching.	
Maintain or restore tributary deltas and connections between rivers and embayments.	+ + Prevents siltation (and related turbidity) that can disconnect tributaries from the mainstem.	Restores important connections between tributaries and mainstem fish populations.	+ + + Restores important connections between tributaries and mainstem that facilitate recovery of mainstem mussel populations.	Enhances the transition zone between riparian areas and the mainstem and provides related educational opportunities.	Creates or enhances additional areas for fishing, birding, and wildlife watching.	

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	**Fish**	**Mussels**	**Riparian Resources**	**Recreation**	**Health and Safety**
Reforest lower reaches of tributaries to reduce siltation into embayments and mainstem.	+ Reduces turbidity and suspended solids in mainstem.	+ Enhances water clarity, especially for sight-feeding fishes.	+ + + Lowers siltation that interferes with mussels' filter feeding.	Enhances the transition zone between riparian areas and the mainstem and provides related educational opportunities.	Creates or enhances additional areas for fishing, birding, and wildlife watching.	
Group C – Measures for which some authority already exists, but new authority may be needed for some opportunities. These measures generally encompass broad descriptions of opportunity that may need refinement; planning and construction costs may be relatively high. The focus tends toward broader-level environmental needs.						
Increase seasonal flooding in grasslands, bottomland hardwood forests, and other habitats.	+ Removes sediment, nutrients, and some contaminants.	+ Can create additional spawning and feeding habitat for certain species.		+ Restores natural patterns essential to sustaining riparian resources.	+ Creates or enhances additional areas for fishing, birding, and wildlife watching.	- Low flows could increase groundings and spills. High flows would adversely affect navigation safety by increasing difficulty of maintaining vessel control.

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	Fish	Mussels	Riparian Resources	Recreation	Health and Safety
Protect existing aquatic habitats, restore lost habitats and diminished resources.	+ + Restored wetlands help filter runoff.	Enhances, expands, and diversifies mainstem fish habitat.	+ + + Enhances and protects habitat for native mussels, including endangered species.	Enhances riparian areas and provides related educational opportunities.	Creates or enhances additional areas for fishing, birding, and wildlife watching .	
Reintroduce native fauna and expand the range and populations of native fauna from reduced levels.		+ Beneficial in restoring the wide variety of fish species endemic to the Ohio River	+ + + Beneficial in restoring the wide variety of mussel species endemic to the Ohio River	Enhances riparian areas and provides related educational opportunities.	Creates or enhances opportunities for fishing, birding, and wildlife watching.	
Reconnect and restore streams with floodplains on the mainstem and tributaries.	+ + Restores hydrological connections beneficial to water quality.	Restores important connections between floodplains and mainstem fish populations.	+ + + May restore hydrological connections beneficial to mussels.	Enhances riparian areas and provides related educational opportunities.	Creates or enhances opportunities for fishing, birding, and wildlife watching.	

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	**Fish**	**Mussels**	**Riparian Resources**	**Recreation**	**Health and Safety**
Restore wetlands in upper ends of embayments to reduce siltation and create fish and wildlife habitat.	+ + Restored wetlands help filter runoff.	Provides high quality fish spawning and nursery areas.	+ + + May facilitate connections between mussel populations.	Enhances riparian areas and provides related educational opportunities.	Creates or enhances opportunities for fishing, birding, and wildlife watching.	
Group D -- Measures which require new authorities or are primarily addressed through authorities of other agencies (e.g., USEPA). Such measures may require more extensive planning and implementation costs. These measures focus on broader-level environmental needs.						
Enhance fish passage around or through dams.		+ Aids riverwide distribution of migratory and other fish species.	+ Aids riverwide distribution of fish hosts critical to mussel success.		+ Promotes a wider distribution of angler preferred species throughout the river.	- Attracting flows into fish passage facilities must be evaluated to ensure flows do not adversely affect vessel entry and exit of lock chambers and approaches.

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	Fish	Mussels	Riparian Resources	Recreation	Health and Safety
Dismantle unneeded federal tributary dams.	+ + Promotes flowing water (lotic) conditions that enhance oxygenation and sediment transport.	Enhances movement of fish within tributaries and between tributaries and mainstem.	+ + + Enhances mussel distribution within tributaries and between tributaries and mainstem.	May allow for vegetation and wildlife habitat restoration near former dams.	May create new riffles and pools for fishing, canoeing and new shorelines for parks and trails.	+/- Could provide safety harbors. May create opportunities for vessel entry into shallow waters.
Dismantle unneeded non-federal tributary dams.	+ + Promotes flowing water (lotic) conditions that enhance oxygenation and sediment transport.	Enhances movement of fish within tributaries and between tributaries and mainstem.	+ + + Enhances mussel distribution within tributaries and between tributaries and mainstem .	May allow for vegetation and wildlife habitat restoration near former dams.	May create new riffles and pools for fishing canoeing and new shorelines for parks and trails.	+/- Could provide safety harbors. May create opportunities for vessel entry into shallow waters.

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	**Fish**	**Mussels**	**Riparian Resources**	**Recreation**	**Health and Safety**
Reduce bacterial contamination from combined sewer overflows.	+ + Direct beneficial effects to alleviate the river's most challenging water quality problem.	Improved water quality directly benefits fish.	+ + Improved water quality directly benefits native mussels.	Direct beneficial effects in riparian areas where CSOs are located.	+ Improves conditions for those fishing, canoeing, and bird and wildlife watching.	+ Reduces bacterial contamination and increases safety of water contact.
Address point and non-point sources affecting aquatic nutrient balance.	+ + Directly benefits water quality by reducing nutrient levels and other substances in effluents and runoff.	Improved water quality directly benefits fish.	+ + + Improved water quality directly benefits native mussels.	Water quality improvements enhance experience for all types of river and shoreline resources.	Water quality improvements enhance experience for all types of river and shoreline recreation.	

Opportunities for ES Enhancement	Impacts on Major VECS					
	Water Quality	**Fish**	**Mussels**	**Riparian Resources**	**Recreation**	**Health and Safety**
Continue remediation of CERCLA, brownfields, and other contaminated sites.	+ + Directly benefits groundwater and surface water quality where contamination has occurred. Reduces sediment contamination	Improved water quality directly benefits fish in streams on site and in localized river reaches.	+ + + Improved water quality directly benefits mussels in streams on site and in localized river reaches.	Offers revegetation and habitat restoration and related educational opportunities.	Over time, may provide areas for parks, playgrounds, trails, and wildlife watching.	+ Would reduce risks of exposure to contamination and potential release of contaminants to the aquatic environment.
Conduct economic evaluation of watershed functions and benefits.	+ + Emphasizes importance of good water quality to ecological sustainability, public health and economic viability.	Could highlight the importance of fish in a watershed's ecological balance and contribution to economic benefits of recreation.	+ + + Could highlight the importance of mussels in a watershed's ecological balance.	Could highlight the importance of high quality riparian resources in a watershed's ecological balance and in recreational and residential land values.	Could highlight the opportunities high quality ecological systems offer for recreation and enhanced value of recreation economics.	+ Could lead to reduction of contamination of the aquatic environment stemming from the watershed.

- This group of sustainability measures will be more successful when added to the Reasonable and Prudent Measures identified through consultation under Section 7 of the Endangered Species Act. These measures would be incorporated into normal Operations and Maintenance.

- Adding the location of sensitive resources to navigation charts with a discussion of the need to avoid impacts to such resources could reach a wider audience of recreationists in addition to navigation interests. Such an approach could also be focused on a wider spectrum of sensitive resources. In 2003, a special edition of Ohio River Navigation Charts was issued commemorating the Lewis and Clark expedition; a similar special edition could be issued celebrating the recovery of aquatic and riparian resources and addressing ongoing protection needs.

- While much progress has been made over the past 30 years in the areas of spill reduction, prevention and response, some additional progress could be realized through the coordinated efforts of multiple agencies in conjunction with navigation and the other industrial interests associated with such events. Additional progress is also needed to compensate for the effects of continued (albeit gradual) concentrations of such activities on or near the river. Implementation of group A measures would have positive effects on health and Safety through reducing the likelihood of vessel operations in sensitive shallow water areas and lessening the potential for contamination of the aquatic environment.

- The ten measures included in Group B constitute approaches that focus more directly on enhancement or restoration of the key VECs, as opposed to the focus on increased awareness and impact prevention of Group A. The Corps possesses at least some form of authorization for all measures in this group. Regardless of where the primary authorization for such actions resides, these measures will require some coordination and cooperation among federal and state agencies, navigation interests, recreationists, and other stakeholders.

- Allowing flows to mimic natural regimes, including floods and droughts, could be a very cost effective approach to environmental restoration by simply restoring the most constrained life-cycle aspects of a broad spectrum of native aquatic and riparian species. This measure also illustrates the nexus of the traditional Corps role as the primary federal agency responsible for managing an expanding range of water resource goals (flood control, navigation, recreation, and restoration) and the potential benefits of applying water-engineering solutions to the goals of restoring diverse and sustainable native aquatic/riparian communities.

- Some measures in group B (i.e., allowing flows to mimic more natural extremes) could adversely impact Health and Safety by increasing risks to vessel operations. Placement of instream structures must be carefully evaluated to avoid increasing risks to vessel operations, while establishment of aquatic macrophyte beds would provide visible evidence of shallow water areas and would warn boaters of

potential hazards. Controlling exotics could improve vessel efficiencies by reducing weight and drag from attached zebra mussels. Conversely, control methods, especially chemical and some physical, would require considerable exercise of caution to prevent creating other Health and Safety problems.

- The Mainstem is not only affected by activities along its shores and within its floodplain, but also by land use practices and activity within the basin. These effects often reach the river via the tributaries. A holistic approach to sustainability, therefore, needs a basin perspective. The Ohio River Basin Comprehensive Study would provide the Corps with the opportunity to review basin-wide water resources.

- Many of the other recommendations in Group B would benefit from the ability to manage flow regimes as described above. Restoration of unique habitats, more productive tailwaters, enhanced aquatic habitat diversity, aquatic vegetation, riparian habitat diversity, tributary-embayment-mainstem connectivity, and riparian reforestation are all functionally linked to the hydrologic cycles of riverine systems. The ultimate effectiveness of this spectrum of recommendations would lend itself well to experimental approaches designed to adjust management approaches in response to results experienced.

- The ORMSS cumulative effects studies (see Section 6.4.1 of this report) identified several specific resources that are most at risk with respect to sustainability under current and foreseeable future conditions on the Ohio River mainstem. These at risk resources are included in Group B recommendations addressing mussel populations and habitat, islands, aquatic vegetation, and riparian habitat diversity.

- The control of exotic species that are presently established in the Ohio River mainstem may require strategies of direct intervention, either to reduce numbers of exotics or to protect sensitive resources from damage. This may be especially important during the early years of invasion, when exotic populations and consequent impacts tend to peak. Control of exotics may also benefit somewhat from management approaches that restore or mimic natural regimes. To the extent that exotics compete with natives for food, spawning habitat, and other needs; the restoration of natural habitats and hydrologic conditions should favor the natives. Monitoring of fish populations in the Ohio River suggests, at least anecdotally, that native suckers are recovering, in numbers and diversity, at the expense of the non-native common carp.

- Preventing new introductions of exotic species, or constraining the expansion of existing invasive populations requires a broader spectrum of authorities, inter-agency cooperation, and regulatory enforcement. Shipping, aquaculture, landscaping, and immigration have been the source of past introductions and will continue to contribute new introductions so long as the source practices (e.g., lax regulation of bilge water management) continue.

- Group C includes five measures that are generally similar in concept and objectives to the Group B recommendations, but less specifically focused. Implementation of these measures would require relatively more refinement or specification, with a corresponding increase in the degree of cooperation and coordination required among stakeholders. The Corps possesses at least some form of authorization for all measures in this group. Measures included in group C are in the WPC rather than the WOPC.

- The most specifically focused recommendation in this group addresses the restoration of wetlands in the upper ends of embayments. Wetlands are one of the at-risk resources identified in the cumulative effects analysis (see Section 6.4.1) and embayments generally occupy only a small proportion of the area of each pool on the river. As illustrated in **Table 8-10**, wetlands restoration could generate a broad spectrum of direct and secondary benefits. However, competing demands exist for access to and use of embayments, especially in the more populated pools, contributing to the potential complexity of collaborative efforts to implement this recommendation. Increasing seasonal flooding could create additional risks to vessels due to associated high flows.

- The seven recommendations in Group D include opportunities that require new authorities or are primarily addressed through authorities of other agencies. The Corps has no existing authority in two of these measures and relatively limited authority in several others. To the extent that lack of authorization and/or funding constraints limits these opportunities, implementation is more likely to be realized under a WPC that addresses such constraints.

- Three of the Group D recommendations involve actions (fish passage, dismantling federal or non-federal dams) that would likely require participation by the Corps. Such measures could benefit Health and Safety through provision of safety harbors; however, dam removal could create opportunities for vessels to be operated in shallow water. Fish passage suggests an opportunity that could be designed into future renovations or modernizations of locks on the Ohio mainstem. Fish passage designs would require careful evaluation to ensure flows are designed to attract target fish species without affecting vessel operations during lock entry and exit. Dismantling tributary dams represents an expansion of the environmental restoration focus beyond the mainstem and illustrates the potential ecosystem sustainability benefits of recognizing the interconnectedness of the mainstem and its tributaries. Reducing sources of bacterialcontamination and restoration/reuse of previously used sites would benefit Health and Safety by reducing public exposure and lessening contamination potential in the aquatic environment. This expanded focus could also be applied to several of the recommendations presented in Groups B and C.

8.9 REMAINING PROBLEMS AND OPPORTUNITIES

8.9.1 Commercial Navigation Delays

From **Table 8-8**, the economic benefits to commercial waterway users are eroded to varying degrees depending upon traffic scenario, but range from $76 to $123 million **annually** due to delays caused by congestion at the locks. A portion of these congestion costs are due directly to main chamber closures required to repair failed components. It may be possible to reduce the congestion costs through either proactive maintenance or extending the 600' auxiliary locks or construction of new locks at EDM. Of course the trade-off would be increased Federal maintenance and construction costs. These alternatives are formulated and analyzed in the With Project Condition in Sections 9 and 10.

8.9.2 Environmental Considerations

The recommendations for achieving Environmental Sustainability on the Ohio River, presented in **Tables 8-6 and 8-10**, address what needs to be done. However, the discussion in this Section does not go into detail regarding how to achieve these goals. The ES conferences that resulted in these recommendations did present some conclusions regarding how to proceed. Following are some brief notes regarding such recommendations:

- Maintain and expand existing means of interagency communication and collaboration.
    - Annual or bi-annual restoration practitioner's conferences
    - Maintain/expand email network of ORMSS IWG and maintain communications within this group
    - Continue to convene IWG meetings as needed

- Implement the Ecosystem Restoration Program, which is presently authorized but unfunded. NOTE: Because the Ohio River Ecosystem Restoration Program has yet to receive Congressional appropriations, the program is now a candidate for de-authorization.
    - Funding is needed to initiate program planning, develop ES project review procedures, and solicit ES project proposals
    - Seek authorization to expand ERP to include ES projects on tributaries of the Ohio River
    - Seek authorization to include nongovernmental organizations as local, cost sharing project sponsors

Recommendations for implementing a strategy to achieve desired ES outcomes for the Ohio River are presented in Section 10.7.

SECTION 9
FORMULATION OF ALTERNATIVE SYSTEM INVESTMENT PLANS (ACTION ALTERNATIVES UNDER NEPA)

This section discusses the development and screening of improvement plans for Ohio River facilities required to address the problems and needs identified in the without-project condition assessments. Investment plans are defined by the timing and specification of proactive maintenance and/or modernization projects at each lock and dam facility and are evaluated for each of the traffic forecast scenarios described in Section 8.2. Measures considered and carried forward for navigation alternatives are presented in Sections 9.2 and 9.3 and ecosystem measures are addressed in Section 9.4. Navigation and ecosystem sustainability components are addressed separately in this Section for clarity. Alternatives for navigation are formulated in Section 9.6. Environmental alternatives are formulated to address problems related to sustainability of Ohio River Environmental Ecological Components. Formulation of ecosystem sustainability alternatives is provided in Section 9.8. Alternatives are evaluated in Section 10. This section completes the third step of the plan formulation process addressing With-Project plans (Section 2.4.3).

9.1 GENERAL METHODOLOGY AND GUIDELINES

1. A broad range of improvement measures were identified to address economic and environmental concerns at all Ohio River locks and dams. All options that have practical application, reasonable development costs and significant beneficial economic and environmental effects were carried forward for more detailed evaluations. The detailed evaluations considered navigation and ecosystem benefits and associated environmental or ecosystem impacts. SIPs were developed by layering improvement measures at each project through time after assessing the system-wide benefits and costs. Refinements were considered in an iterative fashion until improvements were optimized. At that point the final or best SIP was identified for the corresponding traffic scenario.

2. The process used to formulate alternatives is the same used in evaluating the reactive maintenance alternative (the WOPC). Evaluations were made for the same five traffic scenarios. Although the basic scenarios are the same, the “induced traffic” expected to be brought about by larger locks at Emsworth, Dashields and Montgomery (EDM) is be considered in the evaluation. Induced traffic is the subject of subsection 9.2. As with the WOPC, maintenance, operational efficiency and low-cost structural measures

are identified, except that options may now include investment decisions involving proactive maintenance. The last type of measure is capacity-increasing improvements at all locks and dams, including lock extensions and new locks, for which Congressional Authorization would be required for implementation.

9.2 MAINTENANCE, OPERATIONAL EFFICIENCY AND LOW-COST MEASURES CONSIDERED

9.2.1 Reactive Maintenance Measures

All maintenance measures considered for the Reactive Maintenance (WOPC) and described in Sections 8.3.1 and 8.3.2, namely routine maintenance, cyclical maintenance, unscheduled repair of failed components, and full implementation of the MGQCS will also be assessed in the formulation of WPC plans.

9.2.2 Proactive Maintenance Measures

Proactive maintenance measures include scheduled repairs or replacement of major lock components. Two such measures are considered, work on individual components and major rehabilitation usually involving work on multiple components.

9.2.2.1 Scheduled Component Replacement

As the projects age (most of the projects will be nearly 100 years old by the year 2060), many of the major components will need to be replaced in order to keep the chamber usable for passing traffic. Past experience on Ohio River system locks has indicated that items such as miter gates, culvert valves, etc., tend to need replacement, called advanced maintenance in this report, after about 40 to 70 years of operation. The timing of advanced maintenance varies depending upon site-specific conditions, original design parameters, traffic levels, etc.

9.2.2.2 Major Rehabilitation

As discussed in Section 6, major rehabilitation (MR) involves major component replacement and or repair work that costs more than a monetary threshold ($10.6 million as of Fiscal Year 2005) that is adjusted annually. Additional details on requirements of MR projects are provided in Engineering Pamphlet (EP) 1130-2-500.

9.2.2.3 Assessment of Maintenance Measures

1. Routine maintenance, cyclical maintenance, and unscheduled lock repairs are required to operate a viable navigation system and must be carried forward. The two additional proactive maintenance measures considered are ways to more efficiently operate and maintain this system, and are also carried forward in the WPC. The goal of

proactive maintenance is to avoid unexpected component failures and the potential for long lock closures and large navigation delay costs.

2. One restriction on major rehabilitation is considered necessary at this stage of study. Future major rehabilitations of the EDM lock walls to address stability issues with additional rock anchors is not considered feasible. This is due to the presence of significant zones of deteriorated and cracked concrete, which are located beneath 10 to 14 inch thick concrete overlays that were placed in the late 1980's. The lock wall anchoring systems placed during these previous rehabilitations lie within zones of (original non-air entrained) concrete that have been characterized through testing to be in an extensive to moderate degree of deterioration. Any rehabilitative measures to further anchor the lock walls at these facilities would require extensive replacement of significant zones of deteriorated concrete to allow additional anchors to be placed. As much as 3-feet of concrete would need to be removed from the faces of some walls (Emsworth River Wall). Restoring the effectiveness of the existing anchors is not possible since they are embedded in a continuous shroud of grout and buried beneath the concrete overlays. It is also noted that due to the deteriorated state of concrete beneath the concrete overlay, installation of additional anchors may not be completely effective or could even further damage the structural integrity of the walls due to the deteriorated state of the concrete. Therefore, total replacement of the walls is the only major rehabilitation alternative formulated to restore long-term wall stability. Such reconstruction would ultimately create significant impacts to river traffic. From an economic perspective, such reconstruction is not practical due to long chamber closure times and the associated navigation delay costs that would be required. Therefore, major rehabilitation of EDM was screened from the analysis as a maintenance option in the WPC

3. Full implementation of the MGQCS by adding spare gates and storage facilities would require a considerable planning and investment and is not considered feasible in the WPC. With-project measures carried forward include the replacement of lock miter gates before failure but do not evaluate any benefit of spare gates. This is considered sufficient for this study. However, the capability reducing times to repair and replace gates with the Shreve during proactive maintenance on the gates is in all WPC alternatives. Gates are liftable so that if an emergency were to arise in a main chamber, the Corps could pull a set of auxiliary gates out to serve as a "spare" set of gates for the main chamber as a last resort. Economic evaluations reflect these capabilities.

4. Maintenance measures carried further and those dropped from the analysis are shown in **Table 9-1**.

TABLE 9.1
Maintenance Measures Carried Forward and Dropped From Consideration In WPC

Summary of Maintenance Measures Carried Forward in WPC: Routine Maintenance Cyclical Maintenance Unscheduled Repairs Scheduled Component Replacement Capability to Lift Lock Gates Major Rehabilitation (Other than EDM) **Maintenance Measures Dropped From Consideration in WPC:** Spare Gates for Miter Gate Quick Changeout System Major Rehabilitation at EDM

9.2.2.4 Cost Estimation for Maintenance Measures Carried Forward

1. Pertinent considerations for future implementation costs for measures retained are discussed below. Costs for routine and cyclic maintenance and unscheduled repairs and replacements are as described previously for the reactive maintenance alternative. The cost for a scheduled replacement of a component is typically lower than for an unscheduled replacement of the same component required after a failure in the reactive maintenance alternative. Another consideration for scheduled or cyclic maintenance cost of lock components with proactive maintenance is that the frequency and cost of this maintenance depends in part on physical condition of the components as well as on the intensity of use. Less reliable components require more intensive and frequent levels of this maintenance in an effort to keep them in service longer than may be justified. Component replacement introduces new equipment for which this cyclic maintenance can be relaxed somewhat and thereby reduce these cyclic maintenance costs somewhat compared to these costs in the reactive maintenance alternative.

2. Major Rehabilitations for either the main or auxiliary chambers were determined based on the timing of scheduled component replacements. It may prove more beneficial to combine replacement of several of the components together in one or two closures. Such bundling may result in a cost savings due to “economies of scale” by eliminating duplicative efforts and reducing the duration of work activities (and even more importantly the total duration of any main chamber closure) compared to performing the same work at different times. Replacing multiple components at the same time would only require one dewatering of the main chamber and the associated “mobilization” comprised of all activities required to prepare for the job. On the other hand, completing the component replacements at different times would require two or more mobilizations and dewaterings. The duration of the bundled activities could be as short as required for the most involved replacement work, whereas the duration would be the sum of the

multiple durations if performed separately. Another potential difference could occur if none of the component replacements meet the requirements of the MR program but the bundling effort does. In that case, bundling the work would require an additional effort of a Major Rehabilitation Evaluation Report. Funding each component replacement would be from the Federal Operations and Maintenance account, whereas the MR would be funded 50 percent from the Federal Construction General account and 50 percent from the Inland Waterway Trust Fund. The latter funding arrangement would be required to realize the overall (repair + delay to navigation) cost savings.

3. Costs for the potential bundling of components was estimated to be 80 percent of the sum of the individual component replacement costs. If the cost of this work exceeds the threshold, the work would qualify as a major rehabilitation project. The duration of any main or auxiliary chamber rehabilitation varied and depended on the components included in the MR project.

9.2.3 Operational Efficiency and Low Cost Structural Measures

All operational efficiency measures currently implemented and carried forward for the WOPC as discussed in Section 8.4 will also be considered for the WPC. These measures include N-up/N-down lockage policy, helper boats operated by industry, coordination between the Corps and industry prior to any extended main chamber closure, existing tow haulage units and mooring cells, industry adjustments during main chamber closures, and various other miscellaneous measures. Two additional measures considered for WPC plans are classified as "demand management" measures, congestion fees and Corps-imposed traffic scheduling. As cited by the Transportation Research Board's Committee for the Study of Freight Capacity for the Next Century, traffic demand management is a means of forestalling expensive capital investments as these policies encourage shippers to shift to other arrival schedule, route, mode and/or product source options. Demand management measures could therefore reduce system delays. These measures are summarized below. See **Attachment 5 of the Economics Appendix** for a more detailed discussion of Traffic Management measures.

9.2.3.1. Congestion Fees

A lockage fee could cause shippers to shift to either alternative transportation modes or markets, thereby reducing the amount of lock congestion for all remaining waterway shipments. Thus it serves to ration lock use to those movements with the highest transportation savings. The result would be an increase in total rate savings net of delay costs for shippers that continue to use the waterway. A congestion lockage fee could reduce arrivals (queues) and, therefore, delay costs at a congested lock during closure.

9.2.3.2 Corps-Imposed Tow Scheduling

Price-related traffic demand management measures are not currently used on the mainstem. Corps-imposed tow scheduling is one example. Locks nearing their practical capacity limits can benefit from a traffic-scheduling program that assigns tow arrival times. The goal of such a scheduling program is to reduce delays and their associated costs. Using lock scheduling to reduce delays that occur due to random arrivals during the normal course of using the Ohio River mainstem is not currently practiced and is generally opposed to by the shipping industry.

9.2.3.3 Assessment of Operational Efficiency and Low Cost Structural Measures in With Project Condition

All operational and low cost structural measures carried forward for the WOPC are retained for evaluation in the WPC due to their proven effectiveness.

Congestion Fees

Although a detailed analysis of congestion fees has not been conducted for this study, a general analysis of traffic management alternatives was completed (see **Attachment 5 Traffic Management Analysis** of the **Economics Appendix**) and some preliminary determinations have been made. A congestion lockage fee could be used to influence shipping decisions for shippers with marginal transportation rate savings. Congestion fees are generally considered to be an alternative to providing additional capacity at a public facility that is characterized by persistent delays and queues. In the case of the Ohio River mainstem locks and dams, congestion is associated with periodic closures of the main chambers rather than persistent congestion due to a system approaching capacity. The best way to manage these short-term and periodic episodes of congestion is with temporary nonstructural management measures such as industry self-help and N-up/N-down lockage policies. The implementation of long-term congestion fees based on short-term and periodic congestion would tend to distort the transportation practices of shippers in an uneconomical way. Congestion fees are not carried forward as part of the SIP WPC because they do not address the maintenance and structural investment needs of the mainstem. The Navigation Economic Technologies (NETS)[1] is conducting research on this measure and, based on their findings, this measure could be reconsidered in subsequent studies.

[1] Each NETS research effort includes a work team consisting of Corps personnel and outside experts from the academic community, other agencies, and other interested parties. Each research activity also is peer-reviewed by a team of independent academic experts. For more information, see the NETS web site http://www.corpsnets.us/index.html.

Corps-Imposed Traffic Scheduling

A preliminary research effort into the physical practicality and economic feasibility of lock scheduling is underway as part of this study. Results-to-date are found in **Attachment 5 Traffic Management** Analysis of the **Economics Appendix**. Evaluation of lock scheduling was based on limited one-project simulation intended to verify the random nature of arrivals and the effects on delays given an equal time interval between tow arrivals and assuming a lock open at all times. Results indicated a reduction on average of less than one hour per tow. Expansion of this concept to a series of tows would require that tows adjust speeds and schedule departures to accommodate multiple scheduled arrival times. It is expected that the average reduction in delays over a series of locks would be lower than for a single arrival situation. This result indicates that lockage scheduling is unlikely to be an effective solution to transportation problems caused by delays on the navigation system. The NETS is also studying traffic scheduling and based on their findings, this measure could be considered in subsequent studies.

Summary

None of the measures considered that are not currently implemented are retained in the WPC. **Table 9-2** summarizes the results of this assessment.

TABLE 9-2
Operational and Low Cost Structural Measures Carried Forward and Dropped From Consideration in WPC

Operational and Low-Cost Structural Measures Carried Forward:

Operational	Low Cost Structural
N-up/N-Down Lockage Policy	Tow Haulage
Advanced Notice of Main Chamber Closures	Mooring Cells
Adjustment of Shipment Schedules by Industry	Temporary Mooring Facilities During Main Chamber Closures
Industry Self Help	

Operational and Low-Cost Structural Measures Dropped From Analysis:

Operational	Low Cost Structural
Traffic Scheduling	Guide/Guard Wall Extensions
Congestion Fees	
Traffic Scheduling By Corps	

9.2.4 Cost Estimation for Operational and Low Cost Structural Measures Carried Forward

As for the WOPC, costs for these measures if appropriate are based on actual implementation or historic costs.

9.3 LOCK MODERNIZATION MEASURES CONSIDERED

9.3.1 Locks and Dams at New Sites

This measure would involve construction of locks and dam(s) at a new site and could be applied to address all problems at any existing facility, in effect being a replacement project. A new project could be constructed either upstream or downstream from the present facility. If constructed upstream, the elevation of a river segment would be lowered; resulting in a shallow channel between the old and new sites. Dredging to maintain the authorized navigation channel depth would be required. If constructed downstream, the elevation of a river segment would be raised. In either case, relocation or adjustment of facilities such as outfalls, boat ramps, and submarine crossings (pipelines) may be needed to adjust to the new pool elevations. Such costs would increase total project costs. Beneficial effects include provision of greater lock capacity and reduction of maintenance costs compared to the older project.

9.3.2 Third Locks

Another option considered for all facilities is the construction of a third lock, either landward of the land chamber or riverward of the river chamber. An additional lock chamber at any site would increase the capacity to process traffic and thereby reduce traffic delays.

9.3.3 Lock Extensions

This measure includes extensions of the lock chambers that are less than 1200’ in length to increase the capacity of existing projects.

9.3.4 New Locks

Construction of one or two new and larger locks at any site could replace any of the existing small locks at EDM or small auxiliary locks at other sites to increase lock capacity.

9.3.5 Assessment of Lock Modernization Measures

Locks and Dams at New Sites

Locks and dams at new sites are not considered applicable for consideration in this analysis. The associated dredging and disposal requirements could have serious negative environmental and social ramifications. A downstream project would raise the pool between the old and new sites. This would not require dredging, but could submerge or otherwise adversely impact shore side facilities designed for existing pool levels, requiring costs to adjust such facilities. The construction cost of a new project at any location is excessive when compared to measures that increase capacity at existing sites as described below. The adverse environmental and social impacts, including facility adjustment costs that would be incurred by non-Federal entities, of such a major project would be significant. Therefore, this measure has been dropped from further consideration.

Third Locks

A third lock would increase a project's capacity to move traffic and thereby increase total system benefits for any given traffic level. However, this option would incur considerable cost in light of other available measures described below, while incurring considerable environmental impacts owing to major land disturbances and excavation in the case of new landward chamber. This measure has been dropped from consideration.

Lock Extensions

1. Lock extensions are an alternative way to increase a project's capacity to pass traffic and thereby increase total system benefits, but is best suited for small locks that are in good physical condition. Due to the age and small size of the locks at Emsworth, Dashields, and Montgomery, extensions of these auxiliaries is not a practical option. Extension of all 600' long auxiliary chambers downstream of Montgomery are carried further. Extensions of 200', 400' and the maximum extent of 600' have been considered. The data in **Table 9-3** show the predominance of tow sizes through all relevant projects in recent times that were greater than 1,000', therefore 600' extensions are the only measure considered appropriate for the Ohio River. As expected, the percentage of tows greater than 1,000' increases as one proceeds downstream, ranging from nearly 2 in 3 at Myers to 3 in 10 at New Cumberland. On the premise that tow size distributions stay about the same during closures of the main chamber as they are during normal operations, this means that a significant percentage of tows would be required to double cut through locks of 1,000' or less. Based on this consideration, extensions of less than 600' for auxiliary chambers on the Ohio River are not considered appropriate. Six hundred foot extensions of these auxiliary chambers would substantially reduce delays during closures of a 1200'x110 chamber, so this measure will be considered for all WPC plans.

TABLE 9-3
Percentage of Tows Greater Than 1000' in Length
Ohio River Locks and Dams Below Montgomery L/D
1998-2002

% Tows Greater Than 1000' In Length					
	1998	1999	2000	2001	2002
Myers	65.6%	66.2%	68.1%	68.8%	65.5%
Newburgh	58.4%	59.6%	61.2%	61.9%	61.0%
Cannelton	55.4%	57.3%	58.5%	59.3%	58.2%
McAlpine	52.0%	51.1%	49.9%	49.3%	47.3%
Markland	50.7%	52.0%	50.7%	54.4%	51.7%
Meldahl	61.8%	62.8%	63.6%	67.2%	63.4%
Greenup	56.3%	58.0%	60.9%	63.5%	60.6%
Byrd	52.7%	54.4%	55.0%	59.1%	55.8%
Racine	53.1%	54.7%	53.0%	56.9%	57.5%
Belleville	52.8%	56.9%	56.2%	60.1%	60.9%
Willow Island	48.8%	50.5%	52.1%	55.9%	57.6%
Hannibal	46.3%	47.5%	49.4%	55.3%	54.4%
Pike Island	34.8%	34.2%	36.3%	38.5%	38.1%
New Cumberland	30.7%	28.4%	29.6%	31.8%	35.5%

2. A 600' extension of the existing auxiliary chamber results in a project with twin 1200' chambers. The twin 1200' configuration has the ability to efficiently process traffic during closures of either 1200' chamber, as well as handle future, higher volumes of traffic during the later years of the project. Lock extension plans were evaluated at Meldahl, Markland, Cannelton and Newburgh. (Improvements at all of these sites, in conjunction with the authorized projects at Greenup and Myers, would result in all projects on the lower 641 miles of the Ohio River mainstem having twin 1200'x110' locks.) Based on traffic forecasts, these projects were considered most likely in need of additional auxiliary capacity. As these projects already have a 1200' main chamber, extending the auxiliary to 1200' is not expected to induce any additional traffic onto the river.

New Locks

1. Construction of new locks to replace small locks is another way to increase a project's capacity, but is only considered at EDM due to the age and under-sized locks. Extensions of small auxiliary chambers are the better plan at all other sites. At EDM, the auxiliary chamber would be replaced in any plan, but the old main chambers could either be retained and patched up for use as auxiliary chambers or replaced. For this study, it was determined that the old chambers could be retained since the new river chamber could then serve as the new main chamber. Lock sizes considered for the new river chamber at any of these sites was 110' in width and either 600' or 1200' in length. Widths less than 110' are not practical at EDM in light of the 110' wide chambers downstream on the Ohio River and the 110' wide (and 720' long) chamber upstream at Braddock Locks and Dam on the Monongahela River, the primary navigation artery to the Upper Ohio River. The specific improvements developed at each site are shown in **Table 9-4**.

TABLE 9-4
Improvements Considered For Emsworth, Dashields, and Montgomery

Land Chamber	River Chamber
Maintain and Use as Auxiliary	New 110' x 600'
Maintain and Use as Auxiliary	New 110' x 1200'

2. Since the largest existing lock at these sites is 600 feet long, these sites present a constraint on system traffic demand. Therefore, introducing a 1200-foot lock at all three of these sites was analyzed for the potential to induce additional traffic.

3. In light of this situation, a special traffic survey was conducted with the purpose of identifying traffic that could be induced by waterway improvements on the Upper Ohio segment. This survey was conducted by analysts at TVA. Details of the process and results are provided in the Economics Appendix. As a result of these efforts, 11 potential commodity movements totaling 954,000 tons were identified that were considered to be representative of the type and volume that could be expected to be induced annually by improvements (construction of 1200'x110' locks at all three projects) on the Upper Ohio. A listing of this potential traffic is provided in **Table 9-5**.

TABLE 9-5

Potential Annual Induced Traffic With Larger Locks At Emsworth, Dashields, and Montgomery

	Commodity Tonnage
Coal & Coke	25,000
Chemicals	80,000
Ores & Minerals	40,000
Iron & Steel	379,000
All Other	430,000
TOTAL	954,000

5. For any plan that does not involve construction of 1200' locks at these three projects, the traffic forecasts will be the same as the respective WOPC forecast.

Summary

Lock modernization measures carried further and those dropped from the analysis are shown in **Table 9-6**.

TABLE 9-6
Lock Modernization Measures Carried Forward and Dropped From Consideration in WPC

Lock Modernization Measures Carried Forward in WPC:

600' Extensions of all 600'x110' Auxiliary Locks – Meldahl, Markland, Cannelton and Newburgh only.
New 600'x110' or New 1200'x110' Lock To Replace 360'x56'Lock & Repair Existing 600'x110' Lock- Emsworth, Dashields, and Montgomery only.

Lock Modernization Measures Dropped From Consideration in WPC:

Extensions less then 600' for any 600'x110' Auxiliary Lock
Third Locks (At Any Project)
Lengths of New Locks at EDM between 600' and 1200'
Widths of New Locks at EDM Less Than 110'

9.3.6 Cost Estimation for Lock Modernization Measures Carried Forward

1. The level of detail in terms of designs and cost estimates is only conceptual because this document is not authorizing any major project improvements. The large-scale capacity improvement designs primarily involved either new lock chambers or extensions of the existing lock chamber to a nominal length of 1200 feet. Costs for new 110'x600' and 110'x1200' lock chambers at EDM were estimated based on Conceptual Design Reports prepared by INCA (1997, 1998, see Table 3-1). Conceptual designs and costs developed up to this point incorporate "float-in" technology that eliminates the use of cofferdams. This strategy will be reconsidered along with traditional "in-the-dry" lock construction, involving the use of cofferdams, during subsequent Feasibility-level studies to ensure the most cost efficient construction method is identified. In summary, the costs for all modernization strategies considered at EDM are summarized in **Tables 9-7 through 9-9**.

TABLE 9-7
Emsworth Lock Modernization Measure Costs

		Total Cost
River Chamber	**Land Chamber**	**Rounded**
New Lock 600' x 110'	**Repair Land Chamber To Serve As Future Auxiliary Chamber**	**$250,000,000**
New Lock 1200' x 110'	**Repair Land Chamber To Serve As Future Auxiliary Chamber**	**$290,000,000**

TABLE 9-8
Dashields Lock Modernization Alternative Costs

		Total Cost
River Chamber	**Land Chamber**	**Rounded**
New Lock 600' x 110'	**Repair Land Chamber To Serve As Future Auxiliary Chamber**	**$210,000,000**
New Lock 1200' x 110'	**Repair Land Chamber To Serve As Future Auxiliary Chamber**	**$275,000,000**

TABLE 9-9
Montgomery Lock Modernization Alternative Costs

		Total Cost
River Chamber	**Land Chamber**	**Rounded**
New Lock 600' x 110'	**Repair Land Chamber To Serve As Future Auxiliary Chamber**	**$240,000,000**
New Lock 1200' x 110'	**Repair Land Chamber To Serve As Future Auxiliary Chamber**	**$325,000,000**

2. In general, there are two types of projects on the Ohio River where the main chamber is 1200-ft and the auxiliary chamber is 600-ft. The first is representative of many of the projects on the lower river (Newburgh) where there are 6 laterals for filling and emptying the existing auxiliary lock chamber. For these types of projects, extension costs will be determined with the conceptual designs and costs for Newburgh. The other type is similar to the Meldahl project where higher pool differentials required 11 laterals to fill and empty the lock chamber. Extension costs of similar projects will be determined with conceptual designs and costs for Meldahl..

3. As described in the Engineering Appendix, three cost estimates were developed for Newburgh and for Meldahl, where the cost estimates for JT Myers were used as a basis for Newburgh and the authorized cost estimate for Greenup was used as a basis for Meldahl. In each case, the intermediate cost was selected as the best estimate for this stage of study. The cost to extend the auxiliary chamber at Newburgh was $140 million, and Meldahl extension cost was $162 million. The appropriate cost was applied to each extension of the 600' auxiliaries along the Ohio River.

9.3.7 Refinements To Accommodate Environmental Concerns

1. Detailed, project specific recommendations cannot be effectively presented in a programmatic document. Appropriate environmental studies and recommendations for ecosystem protection and mitigation would be conducted during, and in close coordination with, the process of project feasibility study and design. This maximizes the opportunity to produce projects in which desired environmental outcomes are designed into the project. Specific examples of such an approach include design of aeration function at dam gates to ensure optimal oxygen levels in downstream reaches and design features to optimize aquatic habitats in the vicinity of the project, and designs to facilitate fish passage through locks and dams.

2. The opportunity to realize desired environmental outcomes at the project specific level will be enhanced by the presence of proactive programs designed to monitor ecosystem conditions and identify restoration needs on a regional or watershed scale. This perspective helps to determine conditions that are achievable and improves opportunities to identify key restoration measures that might be overlooked at the project specific level. Although some elements are in place, a comprehensive approach for the Ohio River has not yet been realized.

3. Several ecosystem restoration measures have been identified that could address both project specific and more systemic issues on the Ohio River. These measures were addressed in Sections 8.5 and 8.8 of the preceding chapter as well as in Sections 9.4, 9.7 and 9.8 of this chapter. Further analysis and recommendations are presented in Section 10.2 and 10.3.

9.4 SUSTAINABILITY MEASURES (NOT RELATED TO LOCK CONSTRUCTION) CONSIDERED

9.4.1 Existing Authorities

All existing authorities, implementation of Reasonable and Prudent Measures, and the corresponding array of measures considered in the WOPC to address ecosystem sustainability are carried forward for WPC evaluations. See Section 8.5 and **Tables 8-6 and 8-7**.

9.4.2 Seeking Additional Authorities

1. While there are numerous existing federal authorities available to begin addressing ecosystem sustainability needs, some of the necessary actions can only be taken with additional new authority. Also, there are some needed actions for which it is not clear whether authority currently is adequate or if new authority is needed. For example, modification of existing dams to enhance fish passage might be considered under Section 1135, Section 216, the Ohio River ERP, or possibly navigation project authorities. However, depending on the nature and cost of providing such facilities,

implementation could involve their inclusion in a mitigation plan as a component of a site-specific feasibility study recommending a new navigation authorization or as a separate project independent of any navigation improvements.

2. **Table 9-10** provides an assessment of major ecosystem sustainability enhancement opportunities and possible authorities for implementation. These opportunities were identified in consultation with Ohio River resource experts and are carried forward from Tables 6-5 and 8-6. One action (dismantle federal tributary dams) was identified that clearly could not be performed through existing authority. Considering authorities and programs of the Corps of Engineers, along with those of other governmental agencies and non-governmental organizations, there are numerous potential avenues to improve long-term ecosystem sustainability. Some common problems related to use of the authorities and programs include 1) lack of consensus on high priority needs, 2) real or perceived obstacles to collaborative efforts, and 3) inadequate funding. In other words, the Ohio River currently lacks a multi-agency comprehensive plan (i.e., a unity of vision) that would assure environmental sustainability and the dedicated financial resources to execute such a plan.

3. To address the problem of consensus on high priority needs, the ORMSS process brought together groups of specialists familiar with conditions of Ohio River resources to begin developing consensus on high priority needs. Through establishment of the Interagency Working Group, the study process substantially reduced obstacles to collaborative efforts by developing working relationships and trust among a variety of interests. However, it is essential that these parties continue to work together on common interests to further the relationship building process and to pursue elimination of obstacles. The lack of adequate funding remains a very large impediment to making real progress toward more sustainable ecosystems.

4. For the near term, it may be more fruitful for the collaborating interests to jointly pursue additional funding under existing authorities than to seek new authorities. There are many good examples in various regions of the US (e.g., Upper Mississippi River, Florida Everglades, fisheries restoration in the Pacific northwest) where growing recognition of needs and public support for solutions have resulted in significant funding for ecosystem restoration. Although authorities exist to address many opportunities, some of these could only be applied on a small scale, at certain locations, or within prescribed requirements. Over the long term, additional authority could be pursued to address opportunities at a greater scale, in additional areas, or with fewer restrictions. The actual measures would include seeking the necessary authorization where necessary.

TABLE 9-10
Major Ecosystem Sustainability Enhancement Opportunities

Opportunities for Enhancing Ecosystem Sustainability	Without Project	Potential Authorities for Implementation[1]					
		Mitigation related to Specific Navigation Project Authorization	Specific Authorization	Congressional Deauthorization	Specific Congressional Authorization for Ecosystem Projects	Comprehensive Watershed Management Planning	Modified Ohio River Ecosystem Restoration Program[2]
Enhance fish passage around or through dams	x	o					
Dismantle federal tributary dams				o			
Dismantle non-federal tributary dams	x				o		
Increase seasonal flooding in grasslands, bottomland hardwood forests, and other habitats	x	o			o		o
Allow more natural flows to mimic natural regimes including seasonal and extreme floods and droughts	x	o			o		o
Restore unique mainstem habitats such as canebrakes, river bluffs and mussel beds	x						
Protect tailwaters and provide structures to serve as refugia for fish	x	o					
Create spawning shoals and other in-stream features to enhance habitat diversity in pools	x	o				o	o
Identify and expand areas of submerged and emergent aquatic vegetation	x					o	o
Protect and manage mussel populations and their habitat on a site-specific basis	x						o

TABLE 9-10 Major Ecosystem Sustainability Enhancement Opportunities							
Opportunities for Enhancing Ecosystem Sustainability	**Without Project**	**Potential Authorities for Implementation[1]**					
		Mitigation related to Specific Navigation Project Authorization	Specific Authorization	Congressional Deauthorization	Specific Congressional Authorization for Ecosystem Projects	Comprehensive Watershed Management Planning	Modified Ohio River Ecosystem Restoration Program[2]
Mark critical locations to prevent mooring near mussel beds or special shoreline areas	x						
Mark shallow mussel beds to reduce direct impacts of tow traffic	x						
Provide the navigation industry with charts showing locations of sensitive resources and include rationale for avoiding such resources	x						
Protect existing aquatic habitats, restore lost habitats and diminished resources	x	o			o		
Reintroduce native fauna and expand the range and populations of native fauna from reduced levels	x	o			o		o
Control exotics, including minimization of existing populations and prevention of new introductions	x	o			o		o
Reduce bacterial contamination from combined sewer overflows	x		o				
Address point and non-point sources affecting aquatic nutrient balance	x					o	o
Minimize catastrophic contamination events through reduction of spills, accidents, and	x						

TABLE 9-10 Major Ecosystem Sustainability Enhancement Opportunities							
Opportunities for Enhancing Ecosystem Sustainability	**Without Project**	**Potential Authorities for Implementation[1]**					
		Mitigation related to Specific Navigation Project Authorization	Specific Authorization	Congressional Deauthorization	Specific Congressional Authorization for Ecosystem Projects	Comprehensive Watershed Management Planning	Modified Ohio River Ecosystem Restoration Program[2]
improvement of spill response procedures							
Continue remediation of CERCLA, brownfields, and other contaminated sites	x		o				
Reconnect and restore floodplains on the mainstem and tributaries	x				o		o
Protect or restore riparian habitat diversity, including islands, on the mainstem and tributaries	x	o			o		o
Maintain or restore tributary deltas and connections between rivers and embayments	x	o			o		o
Reforest lower reaches of tributaries to reduce siltation into embayments and mainstem	x					o	o
Restore wetlands in upper ends of tributary embayments to reduce siltation and create fish and wildlife habitat	x					o	o
Conduct economic evaluation of watershed functions and benefits	x					o	

[1] Authorization may exist to address an opportunity at a smaller scale, at certain locations, or with prescribed requirements. Additional authority could be required to address opportunity at a greater scale, in additional areas, or with fewer restrictions

[2] Modifications to the existing Ecosystem Restoration Program may include changes in geographic scope and/or definition of project sponsor. NOTE: The Ohio River Ecosystem Restoration Program has yet to receive Congressional appropriations for implementation and is now a candidate for de-authorization.

9.5 REAL ESTATE CONSIDERATIONS

1. As previously stated, the primary purpose of the SIP is to serve as a guidance document for implementing new management practices, initiating non-structural efficiencies, and establishing budgets for future major rehabilitation and/or feasibility studies. To do this, the SIP will identify where, and approximately when, various improvements should be made along the Ohio River during the time period 2010-2070. **The SIP will not recommend any specific projects for Congressional authorization**; such authorizations would result from future Feasibility studies that focus on site-specific improvements. Because of the nature of this report a Real Estate Plan (REP) as described in ER 405-1-12 Chapter 12 is not included. Any future feasibility reports seeking authority to implement specific projects would contain complete detail in the form of a REP. Additionally, supplemental Real Estate Design Memorandums (REDMs) may need to be prepared in accordance with applicable Corps (ER 405-1-12) and HQ/Division guidance.

2. In all cases in this report, any inclusion of or reference to, real estate costs are based on preliminary venture level cost estimates and/or historical data. All references to real estate issues and cost in this report are tentative in nature and subject to change. Again, any future reports seeking project authorization would contain full documentation of real estate issues including a REP and Baseline Cost Estimate for Real Estate (BCERE).

9.6 SYSTEM INVESTMENT PLAN ALTERNATIVES

9.6.1 Proactive Maintenance Alternatives

Two proactive maintenance alternatives are built up from the reactive maintenance (WOPC) alternative as described below. As with the baseline alternative, routine and cyclical maintenance practices are continued and major components are repaired after failure.

9.6.1.1 Advanced Maintenance Alternative

Under the Advanced Maintenance Alternative (AMA), where economically justified, components are replaced before failure. No more than one component is replaced in any given year (components are not bundled together to share mobilization/de-mobilization costs and/or closures).

9.6.1.2 Major Rehabilitation Alternative

Under the Major Rehabilitation Alternative (MRA), major rehabilitations usually involving replacement of “bundles” of components are allowed where economically justified. This alternative also includes all operations and maintenance measures included in the Advanced Maintenance Alternative.

9.6.2 Lock Modernization Alternative

The Lock Modernization Alternative (LMA) includes all operations and maintenance activities allowed in the Major Rehabilitation Alternative as well as all lock modernization measures carried forward.

9.6.3 Summary of With-Project Condition Alternatives

Table 9-11 summarizes the alternatives and measures involved in each WPC alternative and includes the Reactive Maintenance Alternative (WOPC) for comparison. All appropriate measures are considered for all traffic forecast scenarios.

9.7 DIRECT, INDIRECT, AND CUMULATIVE EFFECTS OF NAVIGATION INVESTMENT ALTERNATIVES

Potential direct and indirect effects on major VECs of the three alternatives (AMA, MRA and LMA) considered under With-Project Conditions are presented in **Table 9-12**. Each of the WPC alternatives is briefly described. The major portion of **Table 9-12** is associated with "cells" containing descriptive information on the effects (impacts) of the 3 WPC alternatives on the six major VECs; namely, water quality, fish, mussels, riparian resources, recreation, and health and safety. These six VECs were designated as major based on inputs from the Interagency Working Group and various publics, recognition of their inherent importance in the environment of the Ohio River Mainstem, and their susceptibility to damage from multiple governmental and private actions in the Mainstem environs. **Table 9-12** also includes codes in the upper parts of cells to denote whether the anticipated effects are detrimental or undesirable (denoted by a "-" sign), beneficial or desirable (denoted by a "+" sign), or a mixture (denoted by a "-/+" sign). This table follows the format utilized for WOPC in **Table 8-9**.

TABLE 9-11

Navigation Measures in Each Investment Alternative

Alternative Includes Measures:	*Reactive Maintenance Alternative (RMA)*	*Advanced Maintenance Alternative (AMA)*	*Major Rehabilitation Alternative (MRA)*	*Lock Modernization Alternative (LMA)*
Routine Maintenance	X	X	X	X
Cyclic Maintenance	X	X	X	X
Unscheduled Component Replacement	X	X	X	X
Scheduled Component Replacement	X		X	X
Major Rehabilitation			X	X
N-up/N-down Lockage	X	X	X	X
Industry Self-Help	X	X	X	X
Adjustments by Industry During Main Chamber Closures	X	X	X	X
Mooring Cells (existing)	X	X	X	X
Tow Haulage (existing)	X	X	X	X
Coordination with Industry	X	X	X	X
Lock Extensions*				X
New Locks**				X

*600’ Lock Extensions of 110’x600’ auxiliaries (resulting in 110’x1200’ chamber) considered at Meldahl, Markland, Cannelton and Newburgh.

**New 110’x600’ or 110’x1200’ locks to replace 56’x360’ auxiliary chambers at Emsworth, Dashields and Montgomery.

TABLE 9-12

POTENTIAL DIRECT AND INDIRECT EFFECTS ON MAJOR OHIO RIVER VECS IN WITH PROJECT CONDITIONS*

WPC Alternatives	Description of Alternatives	Impacts on Major VECS					
		Water Quality	**Fish**	**Mussels**	**Riparian Resources**	**Recreation**	Health & Safety
With Project Conditions not only include the three alternatives described in this table, but also all maintenance, operational and low-cost structural measures for Without Project Reactive Maintenance Conditions, as listed in Tables 8-4 and 8-5__.							
Advanced Maintenance Alternative (AMA)	Includes replacement of specific L & D components as they age, when economically feasible. More proactive than Reactive Main-tenance and should reduce number of unscheduled repairs. Miter gate replacement is the most complicated and costly item under this alternative.	-/+ Impacts to major VECs would be similar to those listed in Table 8.9 for Cyclical Maintenance except impacts would be reduced in proportion to the benefits associated with more proactive maintenance and the resulting reduction in unscheduled repairs. Advanced notification to shipping industry would lead to some reduction in queuing and its associated impacts					
Major Rehabilitation Alternative (MRA)	Involves major component or repair work that exceeds a specified monetary threshold adjusted annually. Where feasible, components may be “bundled” for budgetary and temporal economies of scale. . Long-term, MRA should	-/+ Impacts to water quality, as well as to fish, mussels and riparian resources would be similar to those occurring during AMA. The potentially longer duration of activities under MRA may exacerbate some impacts, but this would be compensated by a reduction in total number of repair activities. As with AMA, operational actions to notify shippers and reduce river traffic would reduce these negative impacts. As with the AMA, seasonal timing is important. For example, an 18-month rehab, may be planned such that only one fish spawning season (or one recreational season) is affected instead of two. MRA involves longer durations and more complicated projects than AMA or reactive maintenance. On the positive side, however, bundling of replacement components would					-/+ Impacts would be similar to AMA. However, the risk of accidents may be increased because major rehabs are often longer in duration and involve more workers and types

	result in fewer repair events and less time under closure conditions than AMA or reactive maintenance.	realize both time and cost efficiencies by reducing the number of projects and the need for future repair closures. Unlike emergency repairs, MRA is planned well in advance and, consequently, could include opportunities to avoid, minimize or mitigate adverse direct or indirect impacts.		of equipment.
Lock Modernization Alternative (LMA)	Involves possible new 110' x 600' and 110 x 1200' locks at Emsworth, Dashields and Montgomery (EDM) and possible auxiliary lock extensions at 14 L & Ds (Meldahl, Markland, Cannelton, and Newburg). Congestion conditions are currently most serious at EDM.	-/+ Short term impacts to water quality would be similar to those for AMA and MRA, but of greater duration. Additionally, this alterative involves major dredging and excavation in the river which may result in long-term changes in sediment transport and flow patterns that may erode river banks and nearby islands. Dredging and excavation during construction would destroy aquatic habitat in the impact area and could cause turbidity and siltation of adjacent habitats that may interfere with feeding and reproduction of aquatic life. Clearing of riparian areas during construction would remove habitat and affect local hydrology. Such areas may require decades to return to pre-disturbance conditions. Prop wash and scour is known to cause some larval fish mortality. Positive aspects of LMA include long-term reduction in tow queuing and its adverse effects on aquatic habitat, as well as providing opportunities to add project design measures (e.g. facilitation of fish passage) to enhance environmental sustainability. -	-/+ Short-term negative impacts associated with construction. Access through dam likely to be restricted to commercial vessels. Long-term impacts would likely be positive as new, extended, or replaced locks would be more efficient & dependable, providing greater capacity to handle recreational boaters. Related long-term negative impacts to fisheries may result from cumulative	-/+ New locks or extensions would provide increased capacity for commercial and recreational vessels that would relieve congestion associated with queuing, particularly when main lock chambers are closed during maintenance. This would facilitate safer, more efficient movement of traffic. Strict enforcement of onsite safety regulations for workers and the public and proper disposal of all construction materials, effluents and other wastes would minimize risks.

			impacts of increased commercial & recreational navigation.	Vessel congestion and conflicts during construction could be alleviated through structural and operational measures.

9.7.1 Impacts to Valued Environmental Components

To parallel the analyses in Section 8 (WOPC), a careful review of the information in **Table 9-10 and Table 9-12** was made. Based upon that review, the following general observations can be made:

- Regarding the Advanced Maintenance Alternative (AMA), the associated component replacements would cause localized and limited effects on the six VECs. Some maintenance actions related to major lock component replacement would be expected to require lock chamber dewatering. Dewatering can cause short-term detrimental effects relative to increased water turbidity, interference with upstream movement of fish, damage to fish habitat in tailwater areas, disruptions in downstream mussel habitat, damage to riparian resources due to the queuing of tows and their bank toe-ins and tie-offs, and disruption of recreational boat lockages. The impacts of a specific replacement action would be related to its duration and the time of year it is performed. For example, if fish spawning was known to occur in an impact area, an action's effects would be expected to be more pronounced if component replacement occurred during the spawning season rather than during other times of year. On the positive side, because AMA is more proactive than Reactive Maintenance, as described in the WOPC, it would result in a long-term reduction in the number of unscheduled repairs and the more detrimental and unpredictable environmental effects associated with them.

- Regarding the Major Rehabilitation Alternative (MRA), the associated actions would have impacts similar to those occurring under the AMA. To attain budgetary and temporal economies of scale, however, several components requiring replacement may be grouped or "bundled" into one large rehabilitation project, thus avoiding smaller repeated repair events. For example, an 18-month rehabilitation project may result in a 40-day closure in contrast to three 9-month events under AMA involving 20-day closures for each event. Although proactive like AMA, the MRA involves more complex actions that are of greater duration; accordingly, some impacts may be exacerbated during MRA. As with AMA or any scheduled repair or replacement, timing is important. It may be possible, for example, to time an 18-month major rehabilitation so it would interfere with only one recreation season instead of two.

- Regarding the Lock Modernization Alternative (LMA), the associated actions would be more complex than the AMA, MRA or actions planned under the WOPC. Although similar in many ways to the AMA and MRA, the LMA would have more pronounced environmental impacts of longer duration than under either AMA or MRA. Further, unlike all previous maintenance alternatives, which involve various degrees of repair & upkeep of existing facilities, LMA constitutes new, in-stream construction. Impacts always associated with LMA include:
  - Permanent loss of aquatic habitat within the 'footprint' of the new construction (about 2 acres for a new 600'x110' lock at EDM)

- Permanent modification of flow patterns downstream of LM area
- Temporary instream construction impacts such as blasting/dredging/removal of substrate and turbidity and sedimentation

Other impacts that may occur with LMA include:
- Permanent loss of aquatic habitat if new approach dredging is required
- Permanent loss of riparian habitat if construction or approach pattern requires bank reconfiguration

Dredging and excavation in the river are particularly important actions during lock modernization and would have localized impacts that would be considerably more extensive both in area affected and in duration than in either the AMA or MRA option.

- In comparing and contrasting impacts of With Project and Without Project Conditions, one must continue to bear in mind that all operational and low-cost structural actions discussed in Section 8 that reduce queuing are applicable to both cases, as appropriate. Most operational and low-cost structural actions have beneficial effects, including reductions in localized water turbidity levels; decreases in disruptions to habitats for fish, mussels, and riparian resources; and lowered accident potentials. Both permanent and temporary mooring cells are expected to cause negative and positive effects on the six VECs. Depending upon their location, negative effects could occur from mooring cells that are located over or near mussel beds, disrupt fish habitat, or are near erodible shorelines. Positive effects related to appropriately sited mooring cells could result from reductions in queuing and the minimization of dispersed damages to habitats.

From the perspective of the potentially impacted VECs, the following can be noted from **Table 9-12**:

- The AMA and MRA have similar short-term, localized effects on the Water and Sediment Quality VEC related to increased turbidity, changes in oxygen levels and release of contaminants from disturbed sediments. Impacts, resulting from lock closures, queuing, and construction activities would be partially attenuated by the 4 operational actions and the 3 low-cost structural actions described in **Table 8-9,** all of which apply to the WPC. The LMA, in contrast, involves more extensive dredging and in-river excavation which would exacerbate water quality and sediment impacts both in extent of area affected and duration. Additionally, alterations in long-term sediment transport may occur in a localized area as a result of new locks. With the water and sediment quality VEC, as well as with the remaining VECs, impacts become increasingly pronounced progressing from AMA to MRA and, finally, LMA. On the positive side, beneficial effects would accrue over the long term by minimizing localized turbidity levels from tow queuing, particularly in tailwater areas below the locks.

- The AMA and MRA have similar short-term, localized effects on the Fish VEC, including sediment resuspension and deposition, disruption of seasonal feeding or spawning patterns, and disruption of fry and larval life stages. Dredging and excavation during the LMA, however, would increase the severity of these impacts with permanent loss of aquatic habitat occurring within the 2+ acre project footprint. Further, placement of fill materials around the foundations of extended lock walls could cause siltation of fish habitat or may permanently eliminate it. Because of its long-term planning horizon, the LMA also may offer opportunities to enhance fish passage through construction of new structures or adaptations of older ones.

- As with the Fish VEC, the AMA and MRA have similar short-term, localized effects on the Mussel VEC, including turbidity, scouring and sediment deposition, that could disrupt feeding and reproduction. The duration of impacts such as sediment deposition and flow alterations could continue beyond the actual periods of disturbance. The effectiveness of operational and low-cost structural practices designed to minimize impacts would be enhanced by carefully documenting the location of mussel populations in proximity to the project and potential queuing areas prior to initiation of such disturbances. In the LMA, placement of fill materials around the foundations of extended lock walls could cause siltation of mussel beds or permanently eliminate them.

- Impacts to the Riparian Resources VEC are localized and are similar for the AMA and MRA options, although the duration of such effects is expected to be longer in the MRA. Among the impacts are potential damage to riparian resources from queuing and toe-ins and tie offs, but operational and low-cost structural measures in place under both WPC and WOPC help to minimize these impacts. Fewer repair events resulting from AMA or MRA, in contrast to reactive maintenance of the WOPC, would be beneficial in sustaining riparian resources. The long-term, extensive nature of LMA, however, could have more lasting impacts on riparian resources. Clearing activities and subsequent changes to local hydrology may take decades to return to previous patterns. Further, temporary or long-term alterations in river flow may cause erosion of riverbanks or nearby islands.

- Impacts to the Recreation VEC under the AMA option would likely be similar to those for Reactive Maintenance. The MRA option may be more restrictive and limit or prohibit passage of recreational vessels through the locks during construction. Wherever recreational lockages are permitted in the WPC, operational and low-cost structural measures will facilitate passage of commercial vessels, in turn, making it more efficient for recreational vessels to pass through. In the LMA option, however, passage of recreational vessels may be prohibited for extended periods repeated over the multi-year construction of the project. These inconveniences may be compensated somewhat by the availability of recreational opportunities elsewhere on the river. Long-term impacts to recreation would be positive, however, as LMA is predicted to increase lock capacity and efficiency.

- Impacts to the Health and Safety VEC under the AMA and MRA would be similar to those under the Reactive Maintenance alternative of the WOPC, although the duration of risk will be longer, especially under the MRA. Concerns will be minimized if workers and others adhere to the Corps' proactive safety procedures. Closure of lock and dam areas to visitors and temporary suspension of recreational lockages are examples of such proactive measures. The operational and low-cost structural measures applicable to the WPC and WOPC also contribute to safety by reducing congestion in the vicinity of construction activity. In contrast to AMA and MRA, the LMA option involves a longer time period of more intensive activity and, therefore, greater risk of accident and injury. Again, strict adherence to proactive safety measures would minimize concerns. In the long-term, alleviating congestion by providing more efficient vessel passage through modernized locks would have beneficial safety effects for both commercial and recreational vessels.

9.7.2 Cumulative Effects

The final consideration related to the direct and indirect effects of the WPC alternative, comprising the Advanced Maintenance Alternative (AMA), Major Rehabilitation Alternative (MRA), and Lock Modernization Alternative (LMA), focuses on two issues – the anticipated relative contributions of the three WPC alternatives to current and future cumulative effects on the six VECs, and the influence of the three WPC alternatives on the current and future environmental sustainability (ES) of the six VECs. These two issues are addressed as follows:

- Under current conditions, negative water quality effects of the AMA and MRA are expected to be similar to Reactive Maintenance; that is localized, short-term, and relatively minor. Bundling of components under the MRA would likely result in fewer repair events than under the AMA, although a major rehabilitation would generally be of longer duration than an AMA event. Continuing through the 60-year planning horizon for ORMSS, the number of lock closures and repair activities associated with AMA and MRA would be expected to decline relative to the proposed aggressiveness and consistency of maintenance as lock components age, as well as to traffic levels at each lock. The rate at which such traffic levels change is illustrated in the 5 traffic scenarios.

- A major cumulative benefit to the water quality, fish, mussels and recreation VECs under the LMA would be the long-term reductions in queuing. Completion of new 600' locks at EDM and improved reliability elsewhere on the river would be expected to significantly reduce queuing by reducing the number of future repair events at these projects.

- In contrast to AMA and MRA, LMA would more profoundly and permanently affect aquatic and riparian resources and result in a net loss of

aquatic habitat and riparian vegetation. Site-specific impacts at LMA sites would be directly related to the pre-construction quality and quantity of these resources. Because of the precariousness of the mussel resource in the Ohio River mainstem and mussels' limited mobility, any loss or damage to large mussel beds near locks would contribute to an overall decline in their Environmental Sustainability (ES). LMA projects may result in permanent modification of flow patterns downstream which may affect sediment transport and necessitate additional maintenance dredging. Riparian resources would be expected to be more resilient, but their ES also would be lowered over the decades required to recover to pre-construction conditions.

- Scheduled, proactive maintenance of locks and dams under AMA and MRA would sustain recreational activities on the river. The effects of closures during L & D maintenance and repair would not only be related to the length of associated closures, but also to the time of year of closures and the boating population of a specific pool. Similar cumulative effects would occur with LMA, but with more enhanced long-term benefits to recreation in terms of lock reliability and capacity. Under all WPC alternatives, advanced notice of lock closures and the availability of alternative launch sites and other recreational facilities would reduce temporary inconveniences to boaters and fisherman.

- Health and safety risk factors would rise in direct proportion to the cumulative increase in the number and duration of repair activities. Because work activities under WPC are planned in advance, however, there should be sufficient time to plan and implement applicable Corps procedures to minimize health and safety concerns.

9.8 FORMULATION OF ECOSYSTEM RESTORATION WITH-PROJECT ALTERNATIVES

9.8.1 Methodology

1. In Section 8.5, **Tables 8-6 and 8-7** identify a spectrum of program authorities by which the Corps, other state or federal agencies, or private organizations, may be able to initiate efforts to improve the environmental sustainability of certain Ohio River resources. **Table 8-6** compares a list of 26 opportunities for enhancing ES with existing authorizations and related programs or responsibilities of the Corps. A category is also included for other agencies and NGOs, which was expanded upon in this Section (see **Table 9-10)** and which addresses ES authorities of other governmental agencies.

2. **Table 8-10** also listed the opportunities for ES enhancement and their potential effects on the major VECs, excluding Health & Safety. These opportunities were organized into 4 groups that reflect progressive levels of implementation complexity. **Table 8-10** is not repeated here because the listed ES measures are not strictly dependent

on Without- or With-Project Conditions, although implementation of some opportunities may be more likely under a WPC that provides authorization and funding.

3. To reiterate information presented with **Table 8-10**, the 26 ES measures are organized as follows:

- Group A: Measures for which authority already exists and which involve minimal costs. These measures would also increase awareness of key VECs, focus on impact prevention, and could be implemented relatively quickly.

- Group B: Measures for which authority already exists, but which would require some costs for planning and/or construction. These measures focus on key VECs and incorporate restoration and enhancement.

- Group C: Measures for which some authority already exists, but new authority may be needed for some opportunities. Planning and construction costs may be relatively high. These measures generally encompass broad descriptions of opportunity that may need refinement and the focus tends toward broader-level environmental needs.

- Group D: Measures which require new authorities or are primarily addressed through authorities of other agencies (e.g., USEPA). Planning and construction costs may be relatively high. These measures generally encompass broad descriptions of opportunity that may need refinement, and the focus tends toward broader-level environmental needs.

4. These measures and their groupings are reconsidered in Section 9.8.2 with regard to the WPC.

9.8.2 Sustainability in the With-Project Condition

1. All authorities and operational measures for implementation of ES opportunities applicable to the WOPC also apply to the WPC. Consequently, the 14 ES measures listed in Groups A and B in Table 8.10 can be implemented under existing authority in both the WOPC and WPC. While some opportunities among the 14 are relatively low-cost and straightforward, others would require additional planning and/or construction.

2. The implementation of the costlier and more broadly focused ES opportunities in Group C would require new authorization and additional funding to become more feasible under the WPC than under the WOPC. For example, potential changes in flow regimes to induce seasonal flooding may be considered in the context of engineering activities included in the WPC. Other activities in Group C, including reconnecting and restoring streams and floodplains may be feasible near locks and dams undergoing major rehabilitation or extension. In areas not closely associated with locks and dams, the likelihood of reconnecting and restoring streams and floodplains would be greatly

enhanced if Congress were to allocate significant funding for implementation of the Ohio River Ecosystem Restoration Program (ERP) or some other means.

3. In some cases, Group D activities, such as reducing bacterial contamination from combined sewer overflows, are clearly beyond the authority of the Corps, but may be encouraged through collaboration with other federal agencies in an overall restoration and adaptive management program for the Ohio mainstem. Other activities – enhancing fish passage around or through dams; dismantling of federal dams along Ohio River tributaries, and conducting economic evaluations of watershed functions and benefit – appear to be within the purview of the Corps. Such Group D activities are more likely to occur with WPC authorization and/or funding than in the WOPC. For example, fish passage enhancements could be designed and budgeted for in future rehabilitations or modernizations of Ohio River mainstem locks and dams, whereas dismantling Federral dams would require specific Congressional authority.

4. Table 8-10 represents a seemingly comprehensive list of ES opportunities, but continuing research in environmental sustainability, changing technologies, and potentially innovative funding sources will ensure the list of opportunities will grow over the long planning horizon of ORMSS.

5. These groups of measures are aggregated into two WPC ecosystem alternatives, Groups A, B and C comprises the "moderate" plan, and all four groups comprise the "maximum plan." These alternatives are evaluated and compared to the "minimum" plan (corresponding to the ES WOPC) in Section 10.

SECTION 10
EVALUATION OF ALTERNATIVE SYSTEM INVESTMENT PLANS

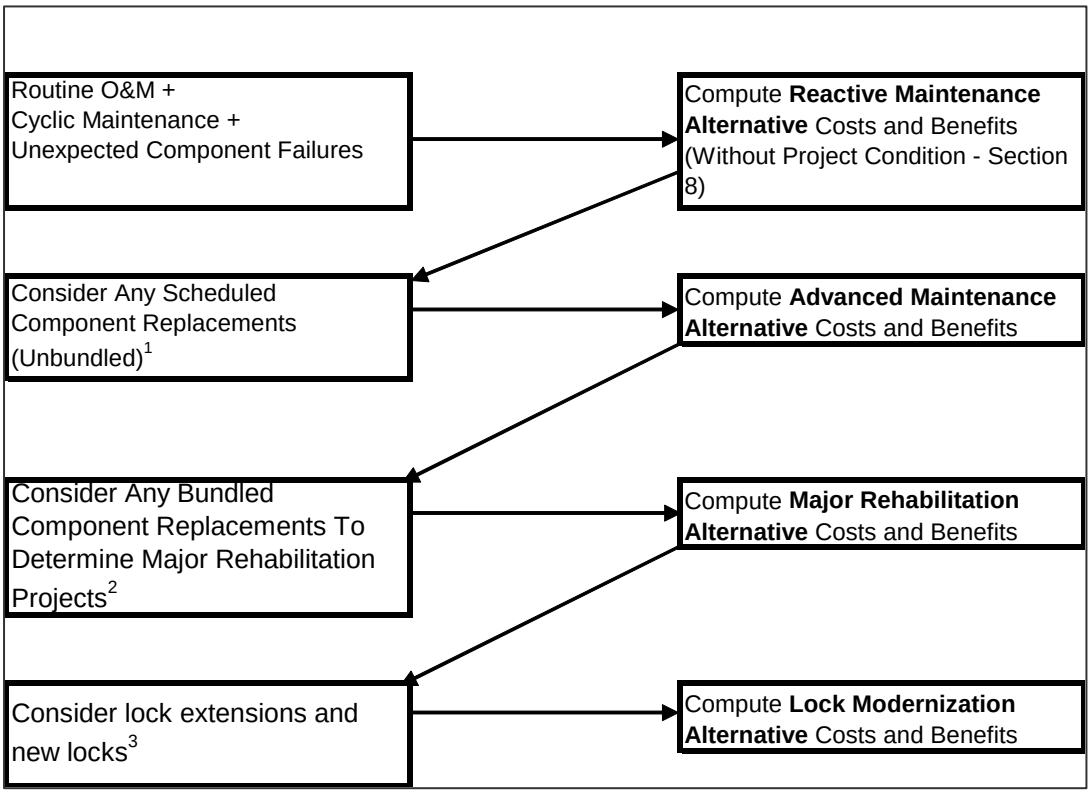
This section describes in detail the economic and environmental aspects for the System Investment Plan determined for each of the traffic scenarios. Economic methodology, results for each of the three With Project Condition (WPC) alternatives and selection of the WPC National Economic Development System Investment Plan are presented in Section 10.1. Environmental assessments of the WOPC and WPC Plan are presented in Section 10.2. Based on the evaluation criteria described in Section 10.3, a schedule of investments combining navigation and environmental sustainability measures is tentatively selected as the Combined National Economic Development/National Ecosystem Restoration Plan. This plan serves as a basis for initiating actions ranging from budget submittals to scheduling future site specific major rehabilitation and feasibility studies. This section completes the fourth, fifth, and sixth step of the plan formulation process (Sections 2.4.4, 2.4.5 and 2.4.6 respectively).

10.1 ECONOMIC SYSTEM ANALYSIS

10.1.1 Methodology

1. The general process (top-down) used to evaluate With-Project Condition alternatives is shown in **Figure 10-1**. The top step shows the evaluation of the Without-Project Condition that was described and evaluated in Section 8 and which forms the baseline from which all WPC alternatives are compared. The WPC alternatives described in Section 9 are evaluated in order of increasing latitude of maintenance or lock improvement options. The first WPC alternative is advanced maintenance that only allows for component replacements. The second is the major rehabilitation alternative that allows for bundling component replacements into larger projects meeting MR requirements, and finally the lock modernization alternative that incorporates all possible proactive maintenance strategies as well as construction of lock extensions or new locks. Costs and benefits are determined for each alternative and compared to the WOPC to determine economic justification.

Figure 10-1
Process To Evaluate Economics of WPC Alternatives



[1]For components for which a scheduled replacement is economically justified, this step would reduce or eliminate repair and navigation delay costs due to unexpected failures obtained in the first step. Costs are not necessarily eliminated unless the component replacement is performed at the beginning of the analysis period since a component could then fail prior to the date established for the replacement.

[2]For components included in a Major Rehabilitation project, his step could reduce repair and navigation delays costs obtained in the prior step for unscheduled or scheduled replacement.

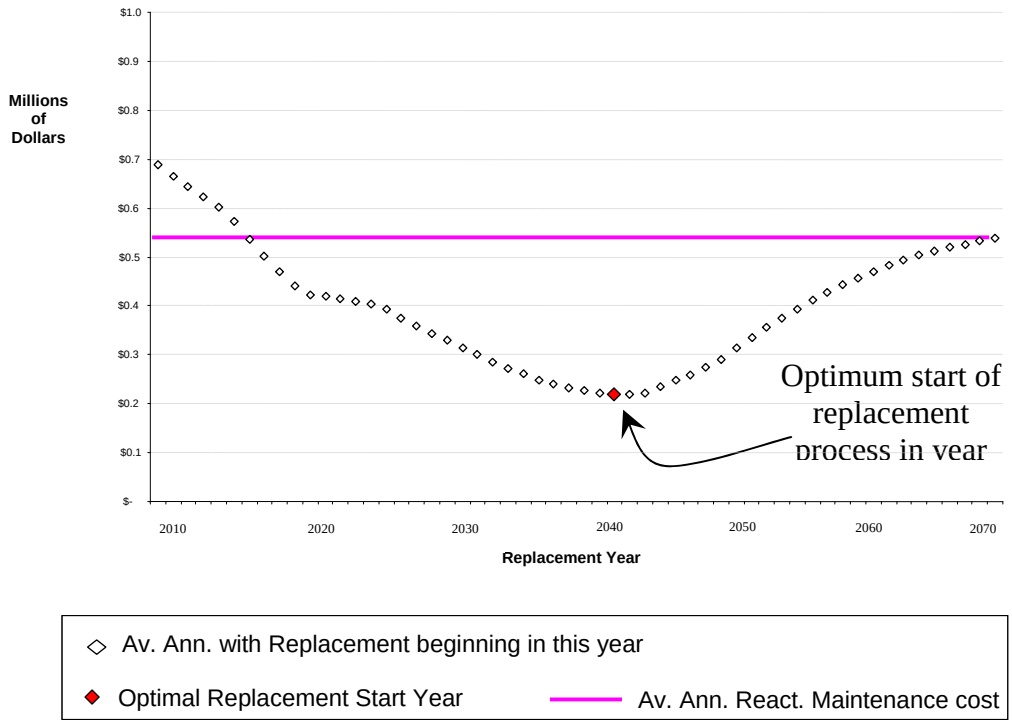
[3]This step could reduce maintenance costs and navigation delays through construction of new locks or lock extensions.

2. The timing of any scheduled component replacements are determined in step four in the following fashion. Through the use of ORNIM, the optimal year to schedule the replacement of a particular component is determined, the associated economic cost is calculated, and that cost is compared to the expected cost obtained in the Reactive Maintenance Alternative. An example is shown in **Figure 10-2.** The points plotted for each year represent the equivalent annual cost of the scheduled replacement, taking into account the potential for failure (and replacement under emergency conditions) prior to that time. For example, to determine the expected cost of a scheduled replacement in 2020, the expected costs

2020, the expected costs to repair this component if it fails before 2020[1] is accumulated, and the probability of survival of the component up to 2020 calculated, and the expected up-front replacement cost is calculated. The year associated with the least cost is the year assigned for the scheduled replacement. As denoted by the horizontal line in **Figure 10-2**, the amortized costs determined in the Reactive Maintenance Alternative are approximately $0.54 million. Scheduling a replacement of this component in any year before 2016 would result in a higher amortized cost than the Reactive Maintenance strategy and therefore such a decision would not be sensible. Between 2016 and 2070 the amortized cost is less than the cost for the reactive maintenance strategy. It is a minimum in 2040, at about $0.21 million. Therefore, the year 2040 would be the scheduled replacement date for this particular component.

FIGURE 10-2

Example Comparison
Reactive Maintenance vs. Scheduled Replacement For Any Component



3. Navigation projects are composed of many components. Determination of optimal replacement timing of each component in the Advanced Maintenance Alternative is a critical step, but it may not indicate the best maintenance alternative for the project.

[1] Replacement of a component due to failure would eliminate the need for the scheduled replacement. A minor repair (for example, repair of the "minor" or "bad" conditions denoted in Figure 8-1) would not impact the scheduled replacement date.

is a critical step, but it may not indicate the best maintenance alternative for the project. Combining individual component replacements in a major rehabilitation might offer additional savings when compared to replacing those components individually in mobilization and de-mobilization costs and result in fewer chamber closures. Also, a large enough bundling of component replacements might eliminate enough collective reactive maintenance costs to be economically justified despite the up-front replacement of the individual components not being justified. This type of condition analysis of individual components and bundled components is useful in formulating possible chamber rehabilitation or replacement needs. This can result in a least-cost maintenance strategy for the Ohio River which could consist of a combination of reactive maintenance, advanced maintenance (component replacement), and chamber rehabilitation alternatives.

4. Lock extensions and new locks are considered in the final step. Such work may obviate the need for component replacements or major rehabilitation activities if the lock construction replaced the respective components prior to any scheduled replacement.

10.1.2 Advanced Maintenance Alternative

1. The advanced maintenance strategy allows for a component to be replaced before it fails. A planned, up-front component replacement can minimize the adverse navigation impacts of an unscheduled, emergency repair. Before advanced maintenance can be fully formulated at a project, optimal individual component replacements must be determined. Optimal individual component replacement represents a piecemeal maintenance strategy which can be more efficient than reactive maintenance. It is considered a viable stand-alone alternative although there might be more efficient "bundles" of component replacements. The bundling of components can lead to a major rehabilitation strategy and this is discussed in Section 10.1.3.

2. For each of these components and/or component systems analyzed at each site with the reliability analysis described in Section 8.7.1.1, ORNIM is used to calculate the expected costs of maintenance and repair and the additional transportation costs associated with the delays from the maintenance and repair closures. The amortized reactive maintenance costs are compared to up-front component replacement scenarios to determine if replacement is economically justified and if so, the optimal timing for the upfront replacement.

3. The resulting economically justified work at each lock and dam and for each traffic scenario is shown below but the emphasis of all discussions of economic performance of those alternatives is on river-wide (or system) benefits and costs, as the merit of alternatives is based on comparing aggregate statistics with those for the WOPC **(Table 8-8**). Additional details for all WPC alternatives analogous to Sections 8.7.1.2 and 8.7.1.3 is provided in the **Economics Appendix**.

10.1.2.1 Advanced Maintenance Strategy for Each Project

1. The advanced maintenance alternative effectively combines reactive maintenance with economically justified component replacement. Components for which there are no economically justified replacement dates are thereby replaced only after failure as in the Reactive Maintenance alternative. **Tables 10-1** through **10-5** show the year for beginning the recommended component replacement schedules and reactive maintenance (RM) strategies for each project and traffic forecast scenario. The gray shaded cells represent components not expected to fail at any point in the analysis period such that there would not be any need for scheduled maintenance. RM represents reactive maintenance which is the same thing as fixing the component after failing, and the number in a cell represents the year which optimizes the start of the up-front component replacement process.

TABLE 10-1
Advanced Maintenance Alternative
Scheduled Component Replacement
Forecast Scenario – Clear Skies

Ohio River Mainstem Project																		
Chamber / Component	**Smithland**	**J.T. Myers ***	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup ****	**R.C. Byrd**	**Racine**	**Belleville**	**Willow Island**	**Hannibal**	**Pike Island**	**New Cumberland**	**Montgomery**	**Dashields**	**Emsworth**
MAIN																		
Gates	RM	**29**	**39**	**24**	-	**10**	**16**	-	**55**	**53**	**32**	**30**	**12**	**17**	-	-	-	-
Gate Machinery	RM	**18**	RM	**15**	RM	RM	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Hydraulic	RM	**16**	**15**	**15**	**30**	**36**	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Culvert Valve	**10**	**10**	**23**	**38**	**10**	**10**	RM	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	**15**	**15**	**15**	RM	**15**	**27**	-	**24**	**10**	**10**	**10**	RM	**15**	RM	RM	RM	RM
Valve Machinery	RM	RM	RM	RM	RM	RM	RM	-	-	RM	RM	-	RM	RM	RM	RM	RM	RM
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**18**	-	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**15**	**13**	**12**
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	**11**
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
AUX																		
Gates	**55**	-	-	-	-	RM	**10**	-	-	-	-	-	RM	RM	**37**	-	-	-
Gate Machinery	RM	-	-	-	-	RM	-	-	-	-	-	RM	-	RM	RM	-	-	-
Hydraulic	RM	-	RM	RM	-	RM	RM	-	-	RM	RM	RM	-	RM	RM	RM	-	RM
Culvert Valve	**10**	-	RM	RM	-	RM	-	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	-	RM	RM	-	RM	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	-	RM	-	-	RM	-	-	-	-	-	-	-	RM	-	-	-	-
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**58**	**38**	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Myers is authorized and scheduled for an auxiliary chamber extension by 2010 (includes replacemane of gates and the electrical system).

** Greenup is authorized and scheduled for an auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).

TABLE 10-2
Advanced Maintenance Alternative
Scheduled Component Replacement
Forecast Scenario – Modified Clear Skies

Ohio River Mainstem Project																		
Chamber Component	**Smithland**	**J.T. Myers ***	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup ****	**R.C. Byrd**	**Racine**	**Belleville**	**Willow Island**	**Hannibal**	**Pike Island**	**New Cumberland**	**Montgomery**	**Dashields**	**Emsworth**
MAIN																		
Gates	**54**	**27**	**37**	**24**	-	**10**	**12**	-	**53**	**38**	**28**	**29**	**10**	**14**	-	-	-	-
Gate Machinery	RM	**10**	**15**	**22**	RM	**28**	**20**	-	RM	RM	**20**	RM	RM	RM	RM	RM	RM	RM
Hydraulic	RM	**10**	**15**	**15**	**30**	**10**	RM	-	RM	RM	**20**	RM	RM	RM	RM	RM	RM	RM
Culvert Valve	**10**	**10**	**22**	**37**	**10**	**10**	RM	-	-	**50**	-	RM	RM	-	-	-	-	-
Electrical	RM	**10**	**15**	**15**	RM	**10**	**10**	-	**10**	**20**	**10**	**23**	RM	**15**	**15**	RM	RM	RM
Valve Machinery	RM	RM	RM	RM	RM	RM	RM	-	-	RM	RM	-	RM	RM	RM	**17**	RM	**38**
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**14**	-	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
AUX																		
Gates	**51**	-	-	-	-	RM	**10**	-	-	-	-	-	**65**	**52**	**34**	-	-	-
Gate Machinery	RM	-	-	-	-	RM	-	-	-	-	-	RM	-	RM	RM	-	-	-
Hydraulic	RM	-	RM	RM	-	RM	RM	-	-	RM	RM	RM	-	RM	RM	RM	-	RM
Culvert Valve	**10**	-	RM	RM	-	RM	-	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	-	RM	RM	-	RM	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	-	RM	-	-	RM	-	-	-	-	-	-	-	RM	-	-	-	-
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**53**	**35**	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Myers is authorized and scheduled for an auxiliary chamber extension by 2010 (includes replacemane of gates and the electrical system).

** Greenup is authorized and scheduled for an auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).

TABLE 10-3
Advanced Maintenance Alternative
Scheduled Component Replacement
Forecast Scenario – NAAQS Growth

Ohio River Mainstem Project																		
Chamber Component	**Smithland**	**J.T. Myers ***	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup ****	**R.C. Byrd**	**Racine**	**Belleville**	**Willow Island**	**Hannibal**	**Pike Island**	**New Cumberland**	**Montgomery**	**Dashields**	**Emsworth**
MAIN																		
Gates	**54**	**27**	**37**	**24**	-	**10**	**12**	-	**52**	**39**	**28**	**29**	**10**	**14**	-	-	-	-
Gate Machinery	RM	**10**	**15**	**15**	RM	**24**	**22**	-	RM	**10**	**10**	RM	RM	**15**	RM	**15**	RM	RM
Hydraulic	RM	**10**	**15**	**15**	**30**	**20**	RM	-	RM	RM	RM	RM	RM	RM	RM	**15**	RM	RM
Culvert Valve	**10**	**10**	**22**	**36**	**10**	**10**	RM	-	-	**54**	-	RM	RM	-	-	-	-	-
Electrical	RM	**10**	**15**	**15**	RM	**10**	**10**	-	**24**	**10**	**10**	**23**	RM	**14**	**15**	RM	RM	RM
Valve Machinery	RM	RM	RM	RM	RM	RM	RM	-	-	RM	RM	-	RM	RM	RM	**15**	**35**	**16**
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**14**	-	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**11**	**10**	**14**
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
AUX																		
Gates	**50**	-	-	-	-	RM	**10**	-	-	-	-	-	RM	**52**	**34**	-	-	-
Gate Machinery	RM	-	-	-	-	RM	-	-	-	-	-	RM	-	RM	RM	-	-	-
Hydraulic	RM	-	RM	RM	-	RM	RM	-	-	RM	RM	RM	-	RM	RM	RM	-	RM
Culvert Valve	**10**	-	RM	RM	-	RM	-	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	-	RM	RM	-	RM	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	-	RM	-	-	RM	-	-	-	-	-	-	-	RM	-	-	-	-
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**53**	**34**	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Myers is authorized and scheduled for an auxiliary chamber extension by 2010 (includes replacemane of gates and the electrical system).

** Greenup is authorized and scheduled for an auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).

TABLE 10-4
Advanced Maintenance Alternative
Scheduled Component Replacement
Forecast Scenario – Utility Based

Ohio River Mainstem Project																		
Chamber / Component	**Smithland**	**J.T. Myers ***	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup ****	**R.C. Byrd**	**Racine**	**Belleville**	**Willow Island**	**Hannibal**	**Pike Island**	**New Cumberland**	**Montgomery**	**Dashields**	**Emsworth**
MAIN																		
Gates	**54**	**28**	**37**	**24**	-	**10**	**10**	-	**48**	**52**	**31**	**29**	**12**	**18**	-	-	-	-
Gate Machinery	RM	**15**	**27**	**20**	RM	**15**	**15**	-	RM	**15**	RM	RM	RM	RM	RM	RM	RM	RM
Hydraulic	RM	**15**	**21**	**17**	**30**	**15**	**15**	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Culvert Valve	**10**	**10**	**23**	**36**	**10**	**10**	RM	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	**10**	**17**	**15**	RM	**10**	**14**	-	**19**	**15**	**15**	**15**	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	RM	RM	RM	RM	RM	RM	-	-	RM	RM	-	RM	RM	RM	**51**	RM	RM
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**19**	-	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
AUX																		
Gates	**51**	-	-	-	-	RM	**12**	-	-	-	-	-	RM	**57**	**37**	-	-	-
Gate Machinery	RM	-	-	-	-	RM	-	-	-	-	-	RM	-	RM	RM	-	-	-
Hydraulic	RM	-	RM	RM	-	RM	RM	-	-	RM	RM	RM	-	RM	RM	RM	-	RM
Culvert Valve	**10**	-	RM	RM	-	**45**	-	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	-	RM	RM	-	RM	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	-	RM	-	-	RM	-	-	-	-	-	-	-	RM	-	-	-	-
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**58**	**38**	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Myers is authorized and scheduled for an auxiliary chamber extension by 2010 (includes replacemane of gates and the electrical system).

** Greenup is authorized and scheduled for an auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).

TABLE 10-5
Advanced Maintenance Alternative
Scheduled Component Replacement
Forecast Scenario – Utility Based High

Ohio River Mainstem Project																		
Chamber / Component	**Smithland**	**J.T. Myers ***	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup ****	**R.C. Byrd**	**Racine**	**Belleville**	**Willow Island**	**Hannibal**	**Pike Island**	**New Cumberland**	**Montgomery**	**Dashields**	**Emsworth**
MAIN																		
Gates	**51**	**27**	**37**	**24**	-	**10**	**10**	-	**45**	**52**	**30**	**29**	**12**	**16**	-	-	-	-
Gate Machinery	RM	**10**	**25**	**19**	RM	**15**	**14**	-	RM	**15**	**18**	RM	RM	RM	RM	RM	RM	RM
Hydraulic	RM	**10**	**19**	**16**	**28**	**15**	**14**	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Culvert Valve	**10**	**10**	**23**	**35**	**10**	**10**	**56**	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	**10**	**16**	**15**	RM	**10**	**10**	-	**14**	**15**	**15**	**15**	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	**33**	RM	RM	RM	RM	RM	-	-	RM	RM	-	RM	RM	RM	**35**	RM	**50**
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**17**	-	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
AUX																		
Gates	**50**	-	-	-	-	RM	**10**	-	-	-	-	-	RM	**56**	**37**	-	-	-
Gate Machinery	RM	-	-	-	-	RM	-	-	-	-	-	RM	-	RM	RM	-	-	-
Hydraulic	RM	-	RM	RM	-	RM	RM	-	-	RM	RM	RM	-	RM	RM	RM	-	RM
Culvert Valve	**10**	-	RM	RM	-	**41**	-	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	-	RM	RM	-	RM	**58**	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	-	RM	-	-	RM	-	-	-	-	-	-	-	RM	-	-	-	-
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**56**	**38**	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Myers is authorized and scheduled for an auxiliary chamber extension by 2010 (includes replacemane of gates and the electrical system).

** Greenup is authorized and scheduled for an auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).

10.1.2.2 Summary of Advanced Maintenance Alternative Economic Statistics

1. **Table 10-6** summarizes average annual system benefits and costs from an advanced maintenance strategy at each mainstem project over the five traffic forecast scenarios analogous to **Table 8.8** for the WOPC (reactive maintenance). The actual dates of component replacement evaluated for each traffic scenario reflect the rule that not more than one component be replaced in any given year and therefore may vary slightly from the years shown in tables **10-1 through 10-5**. Scheduled improvement costs include component replacements and the remaining costs to complete the authorized Greenup and Myers projects. This level of proactive maintenance improves total system benefits from $95 to $124 million annually compared to the WOPC due almost solely to decreases in reduced or eroded savings (delays incurred at the locks). These decreases in eroded savings represent lower transit costs to the navigation industry. The total system benefits representing transportation cost savings range from $2.37 to $2.58 billion annually.

TABLE 10-6
Advanced Maintenance Alternative*
Average Annual Costs and Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Advanced Maintenance Benefits					
Equilibrium Waterway Savings	$2,383.4	$2,543.2	$2,563.0	$2,590.8	$2,645.6
Reduced Savings from Unscheduled Repair	($17.6)	($74.4)	($37.0)	($56.3)	($61.2)
Total System Benefits	**$2,365.8**	**$2,468.8**	**$2,526.0**	**$2,534.5**	**$2,584.4**
Advanced Maintenance Costs					
Scheduled Lock Maintenance	$ 20.7	$ 20.9	$ 20.4	$ 21.1	$ 20.9
Scheduled Dam Maintenance	$ 6.9	$ 6.9	$ 6.9	$ 6.9	$ 6.9
Scheduled Lock Improvements**	$ 19.7	$ 15.0	$ 20.2	$ 15.2	$ 15.6
Unscheduled Lock Repair	$ 4.3	$ 8.4	$ 5.0	$ 7.6	$ 7.7
Normal O&M	$46.7	$46.7	$46.7	$46.7	$46.7
Random Minor	$2.4	$2.4	$2.4	$2.4	$2.4
Total System Costs	**$100.7**	**$100.4**	**$101.7**	**$100.0**	**$100.3**
Net Benefits	**$2,265.0**	**$2,368.4**	**$2,424.2**	**$2,434.5**	**$2,484.1**
BCR	**23.5**	**24.6**	**24.8**	**25.3**	**25.8**

**Note: Sums and differences may reflect rounding error.*

*** Scheduled Lock Improvements are 50% cost shared with the Trust Fund for the authorized 600' extension of the auxiliary chamber at Myers in 2010 and rehabilitation of the Greenup main chamber in 2010-11, plus any justified component replacements.*

2. The total system Federal plus Trust Fund costs for the AMA go up very slightly compared to reactive maintenance. Cost categories that differ from the WOPC costs in **Table 8.8** are shaded in gray in **Table 10-6**. Scheduled lock improvement costs increase ranging from $9.2 million to $14.4 million annually reflecting the justified component replacements. These increased costs are countered by reductions in scheduled lock maintenance and unscheduled lock repair costs across all forecast scenarios (less frequent cyclic maintenance and component failures), the former costs decease from $2.0 to $2.7 million, and the latter from $6.7 to $10.0 million annually. The total system costs for all alternatives is about $100-101 million annually for all forecast scenarios, representing very small increases of about $0.2 to $2.8 million annually over reactive maintenance. Taking all costs and benefits into account, the average annual net benefits to the nation range from $2.27 to $2.48 billion annually, generally a 2.5-3.0% increase over reactive maintenance.

3. **Table 10-7** displays incremental benefits and costs of advanced maintenance compared to reactive maintenance plans. There is a positive net benefit for all forecast scenarios indicating that in the long run, it is more economic to pursue an up-front component replacement strategy rather than a reactive maintenance strategy. The table shows incremental net benefits of a planned component replacement ranging from $94.8 to $172.4 million annually. These positive benefits indicate that the advance maintenance alternative is preferable to the WOPC (reactive maintenance) for all forecast scenarios

TABLE 10-7
Advanced Maintenance Alternative*
Average Annual Incremental Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Incremental Benefits over Reactive Maintenance	$113.0	$95.1	$174.1	$105.8	$124.3
Incremental Costs over Reactive Maintenance	$2.8	$0.3	$1.7	$0.3	$0.2
Net Benefit	**$111.3**	**$94.8**	**$172.4**	**$105.5**	**$124.1**

*Differences subject to rounding error.

10.1.3 Major Rehabilitation Alternative

1. The major rehabilitation alternative (MRA) takes the advanced maintenance alternative one step further by allowing for major rehabilitation (MR) projects that effectively bundle individual component replacements into projects qualifying for the Corps MR program (described in Section 6.1.3). Since less mobilization and demobilization is required, rehabilitation costs and closures are usually improved over individual component replacements. If the bundled components did not exceed the rehabilitation threshold, then they were left as individual component replacements.

2. Recall that the only major rehabilitation option considered practical at Emsworth, Dashields, and Montgomery at this stage of study was reconstruction of the lock chambers and was screened out of the analysis at all three sites based on economic rationale.

10.1.3.1 Major Rehabilitation Strategy By Project

The MRA combines reactive maintenance with justified component replacements and chamber rehabilitations. **Table 10-8** summarizes recommended chamber rehabilitations for each traffic forecast scenario over the 2010-2070 timeframe. The gray shaded cells represent chambers where there was no group of components identified for a potential MR project due to a varied timing of individual component replacements. Cells with a "-" represent chambers where one or more bundles were identified as potential MR projects but were not determined to be economically justified. The year represents the start of the chamber rehabilitation process which is modeled with one year for a general investigation study and two years for the actual rehabilitation. The Greenup MR project is based on the authorized project and not due to any evaluations conducted through this study.

TABLE 10-8
Recommended Major Rehabilitations By Lock Chamber

Project / Chamber	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Olmsted					
Main					
Auxiliary					
Smithland					
Main	-	-	-	-	-
Auxiliary	-	-	-	-	-
Myers					
Main	2014	2011	2013	2013	2013
Auxiliary					
Newburgh					
Main	2025	2016	2016	2016	2016
Auxiliary					
Cannelton					
Main	2017	2017	2016	2017	2017
Auxiliary					
McAlpine					
Main					
Auxiliary					
Markland					
Main	-	-	2010	2010	2010
Auxiliary	-	-	-	-	2052
Meldahl					
Main	2013	2010	2010	2010	2010
Auxiliary	-	-	-	-	-
Greenup*					
Main					
Auxiliary					
R. C. Byrd					
Main	-	2044	2045	2030	2033
Auxiliary					
Racine					
Main	2020	2019	2020	2019	2019
Auxiliary					
Belleville					
Main	-	2017	2017	2017	2028
Auxiliary					
Willow Island					
Main	2027	2027	2027	2027	2028
Auxiliary					
Hannibal					
Main	2012	2011	2011	2012	2011
Auxiliary					
Pike Island					
Main	2016	2015	2015	2016	2015
Auxiliary	-	-	-	-	-
New Cumberland					
Main	-	-	-	-	-
Auxiliary	-	-	-	-	-

*The major rehabilitation of the Greenup main chamber recommended along with the lock extension project is assumed to begin in 2010.

10.1.3.2 Summary of Major Rehabilitation Alternative Economic Statistics

1. **Table 10-9** summarizes average annual system benefits and Federal plus Trust Fund costs for the MRA for each of the five traffic forecast scenarios. Scheduled improvement costs include MR projects according to **Table 10-8**, remaining costs to complete the authorized Greenup and Myers projects, and any remaining up-front component replacements is economically justified. Adding MR as a maintenance option has the effect of decreasing eroded savings (navigation delays due to unscheduled component repairs) by about $0.5 million to $2.0 million annually (compared to advanced maintenance). Compared to reactive maintenance, total system benefits are increased from $116 to $182 million annually, about the same incremental impact as for advanced maintenance. The total system benefits range from $2.37 to $2.60 billion annually.

TABLE 10-9
Major Rehabilitation Alternative*
Average Annual Costs and Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Rehabilitation Maintenance Benefits					
Equilibrium Waterway Savings	$2,386.2	$2,565.1	$2,570.7	$2,602.1	$2,659.1
Reduced Savings from Unscheduled Repair	($17.6)	($62.7)	($36.9)	($56.1)	($61.5)
Total System Benefits	**$2,368.6**	**$2,502.4**	**$2,533.8**	**$2,546.1**	**$2,597.7**
Rehabilitation Maintenance Costs					
Scheduled Lock Maintenance	$18.3	$17.4	$17.0	$17.6	$17.5
Scheduled Dam Maintenance	$6.9	$6.9	$6.9	$6.9	$6.9
Scheduled Lock Improvements**	$20.4	$16.7	$20.9	$16.7	$16.6
Unscheduled Lock Repair	$4.2	$7.4	$4.8	$7.3	$7.3
Normal O&M	$46.7	$46.7	$46.7	$46.7	$46.7
Random Minor	$2.4	$2.4	$2.4	$2.4	$2.4
Total System Costs	**$99.0**	**$97.6**	**$98.8**	**$97.7**	**$97.4**
Net Benefits	**$2,269.5**	**$2,404.8**	**$2,435.0**	**$2,448.4**	**$2,500.2**
BCR	**23.9**	**25.6**	**25.7**	**26.1**	**26.7**

**Sums and differences may reflect rounding error.*

*** Scheduled Lock Improvements are 50% cost shared with the Trust Fund and include authorized 600' extension of the auxiliary chamber at Myers in 2010 and rehabilitation of the Greenup main chamber in 2010-11, justified component replacements plus justified rehabilitations.*

2. Costs and benefits that differ from the WOPC are shaded in gray in **Table 10-9**. Scheduled lock improvement costs for the MRA are increased over the corresponding WOPC expenditures by the cost of the MR projects and any remaining component

replacements, increases ranging from $10.8 to $14.6 million annually. These cost increases are counterbalanced by decreases in scheduled lock maintenance and unscheduled lock repair costs across all forecast scenarios, decreases ranging from $4.8 to $6.1 million annually for the former and from $7.4 to $10.2 million annually for the latter. The total system costs decrease from the WOPC in four of the forecasts, decreases ranging from $1.2 to $2.7 million and remaining the same in the fifth (Clear Skies). Taking all costs and benefits into account, the average annual benefits to the nation, representing total transportation savings to the navigation industry, range from $2.27 to $2.50 billion.

3. **Table 10-10** displays incremental benefits and costs of the major rehabilitation alternative compared to reactive maintenance. The table shows positive incremental net benefits of a planned component replacement ranging from $116 million to $183 million annually. These positive benefits indicate that the major rehabilitation alternative is preferable to the WOPC (reactive maintenance) for all forecast scenarios.

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TABLE 10-10
Major Rehabilitation Alternative*
Average Annual Incremental Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Incremental Benefits over Reactive Maintenance	$115.7	$128.7	$181.9	$117.4	$137.5
Incremental Costs over Reactive Maintenance	($0.0)	($2.5)	($1.3)	($2.1)	($2.6)
Net Benefit	**$115.7**	**$131.2**	**$183.2**	**$119.5**	**$140.2**

*Differences subject to rounding error.

10.1.4 Lock Modernization Alternative

The final alternative analyzed was the Lock Modernization, where 600' extensions of any 110'x600' auxiliary chamber and new 110'x600' and 110'x1200' locks to replace any of the small auxiliary chambers at EDM were considered. Lock extension plans were evaluated at Meldahl, Markland, Cannelton and Newburgh. In addition, the full complement of proactive maintenance measures were allowed as for the major rehabilitation alternative

10.1.4.1 Lock Modernization Strategy for Each Project

1. Lock extensions and new locks at EDM were systematically analyzed as described in the **Economics Appendix**. The first observation was that no auxiliary lock extensions were justified compared to major rehabilitation at any of the site. This suggests that a reliable main chamber negates the need for additional auxiliary capacity under the traffic forecast scenarios used in this analysis. Auxiliary lock extensions are

dropped from further analysis. However, replacements of the auxiliary lock chambers at EDM were justified up front in all five scenarios. The optimum sizes and timing for new locks are shown in **Table 10-11**.

2. For all other locks, the maintenance strategy is the same as for the Major Rehabilitation alternative.

TABLE 10-11
Economically Justified New 1200' or 600' Locks
At Emsworth, Dashields and Montgomery

Project / Chamber	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Emsworth					
Main	-	-	-	-	-
New 600' Lock	2010	2010	2010	2010	2010
Dashields					
Main	-	-	-	-	-
New 600' Lock	2011	2010	2010	2010	2010
Montgomery					
Main	-	-	-	-	-
New 600' Lock	2010	2010	-	2010	2010
New 1200' Lock	-	-	2010	-	-

10.1.4.2 Summary of Lock Modernization Alternative Economic Statistics

1. **Table 10-12** summarizes average annual system benefits and Federal plus Trust Fund costs of the lock modernization alternative for each of the five traffic scenarios. Scheduled improvement costs include new locks at EDM according to **Table 10-11**, remaining costs to complete the authorized Greenup and Myers projects, and any remaining up-front component replacements and major rehabilitation work that is economically justified. Adding lock modernization to the full complement of proactive maintenance measures in the major rehabilitation alternative significantly reduces eroded navigation savings over the major rehabilitation alternative by $5 to $38 million annually ($63 to $105 annually compared to reactive maintenance). Further, the full complement of proactive maintenance and new locks adds the greatest increment of total system benefits over the reactive maintenance, increases ranging from $148 to $260 million annually. The total average annual benefits range from $2.40 to $2.69 billion annually.

2. Scheduled lock improvement costs for this alternative are increased over the corresponding WOPC expenditures by the cost of the lock modernization projects and any remaining MR projects and component replacements, increases ranging from $37.2 to $41.8 million annually. These cost increases are counterbalanced by decreases in scheduled lock maintenance and unscheduled lock repair costs across all forecast

scenarios, decreases ranging from $7.9 to $9.2 million annually for the former and from $10.0 to $10.8 million annually for the latter. The total system maintenance and improvement costs increase from the WOPC, increases ranging from $18.4 to $21.5 million. Taking all costs and benefits into account, the average annual benefits to the nation, representing total transportation savings to the navigation industry, range from $2.28 to $2.57 billion annually.

TABLE 10-12

Lock Modernization Alternative*
Average Annual Costs and Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Optimum Lock Size at EDM Benefits					
Equilibrium Waterway Savings	$2,413.5	$2,631.5	$2,631.0	$2,656.5	$2,717.0
Reduced Savings from Unscheduled Repair	($12.9)	($20.7)	($19.4)	($20.8)	($23.6)
Total System Benefits	**$2,400.6**	**$2,610.7**	**$2,611.7**	**$2,635.7**	**$2,693.4**
Optimum Lock Size at EDM Costs					
Scheduled Lock Maintenance	$15.2	$14.0	$13.9	$14.0	$14.0
Scheduled Dam Maintenance	$6.9	$6.9	$6.9	$6.9	$6.9
Scheduled Lock Improvements**	$43.0	$44.6	$47.6	$44.7	$44.5
Unscheduled Lock Repair	$4.0	$4.3	$4.2	$4.2	$4.2
Normal O&M	$46.7	$46.7	$46.7	$46.7	$46.7
Random Minor	$2.2	$2.2	$2.2	$2.2	$2.2
Total System Costs	**$118.0**	**$118.7**	**$121.5**	**$118.7**	**$118.5**
Net Benefits	**$2,282.6**	**$2,492.0**	**$2,490.1**	**$2,517.0**	**$2,574.9**
BCR	**20.3**	**22.0**	**21.5**	**22.2**	**22.7**

**Sums and differences may reflect rounding error.*

*** Scheduled Lock Improvements are 50% cost shared with the Trust Fund and include authorized 600' extension of the auxiliary chamber at Myers in 2010 and rehabilitation of the Greenup main chamber in 2010-11, justified component replacements, justified rehabilitations plus optimum construction of 1200'- 600' locks at EDM.*

3. **Table 10-13** displays incremental benefits and costs of the lock modernization alternative compared to reactive maintenance plans. The table shows positive incremental net benefits for lock modernization ranging from $128.8 to $238.3 million annually. These positive benefits indicate that the lock modernization alternative is preferable to the WOPC (reactive maintenance) for all forecast scenarios. As with the two proactive maintenance alternatives, the lock modernization alternative is economically better than reactive maintenance.

TABLE 10-13
Lock Modernization Alternative
Average Annual Incremental Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Incremental Benefits over Reactive Maintenance	$147.8	$237.0	$259.8	$207.0	$233.3
Incremental Costs over Reactive Maintenance	$19.0	$18.6	$21.5	$18.9	$18.4
Incremental Net Benefit	**$128.8**	**$218.4**	**$238.3**	**$188.1**	**$214.9**
Incremental BCR	**7.8**	**12.7**	**12.1**	**10.9**	**12.7**

*Differences subject to rounding error.

10.1.5 Identification of the With-Project Condition (National Economic Development System Investment Plan) for Navigation

1. All three with-project alternatives are carried forward since they are preferable to the WOPC. **Table 10-14** shows the average annual net benefits for the WOPC and all With Project investment alternatives. The lock modernization alternative maximizes net benefits across all traffic forecast scenarios and is thus selected as the with-project condition. The new lock chamber needs along with a more aggressive maintenance strategy will, in the long run, reduce the National Economic Development (NED) costs associated with the operation and maintenance of the heavily vested and economically mature Ohio River mainstem navigation system. The system statistics for the WPC are as shown in **Tables 10-12 and 10-13**.

TABLE 10-14
Average Annual Net Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Alternative	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
WOPC	$2,145	$2,274	$2,252	$2,329	$2,360
AMA	$2,265	$2,368	$2,424	$2,435	$2484
RMA	$2,270	$2,405	$2,435	$2,448	$2,500
LMA	**$2,283**	**$2,492**	**$2,490**	**$2,517**	**$2,575**

2. The system WPC is a mixture of structural improvements (new lock chambers), operational measures (helper boats and N-up/N-down lockage policy during closures), and maintenance alternatives (reactive, advanced and rehabilitation). The optimum lock size at EDM is a 600' chamber for four of five traffic forecast scenarios. Only in the NAQQS traffic forecast scenario is a 1200' new chamber recommended at Montgomery.

3. As expected, delays at individual locks and diverted tonnages are less than in the WOPC (discussed in Section 8.7.1.4). At EDM, the results are dramatic. At Montgomery, the average annual delay times fall to between 1.5 and 2.0 hours per tow after a new main lock chamber is constructed, compared to average annual delays of over 10 hours per tow throughout the planning horizon in the WOPC. Furrther, with a new main chamber and larger auxiliary chamber, the average delays are about constant throughout the analysis period (i.e. there are no spikes due to chamber closures). Diverted traffic is reduced to near zero for most years of the planning period in the WPC, compared to 0.5 – 2.0 million tons diverted annually in the WOPC after 2020. At Racine, delays are comparable to the WOPC in the early years of the planning period, but significant reductions in delays are seen beyond 2050. The average annual delays are held to an hour or less on average per tow throughout the entire analysis period in the WPC, typically about 0.5 – 1.0 hours less per tow per year than in the WOPC until 2050, when the reductions in delays increase to 10 hours or more. However, as in the WOPC, annual delays reach about 4 or 5 hours per tow during years of scheduled component replacements or major rehabilitations. Diverted tonnaged is reduced to about 0.1 – 0.2 million tons for all years of the analysis period in the WPC, compared to about 0.2 – 1.0 million tons annually in the WOPC. See Section 10.2.3.3 for additional discussion of diverted traffic from a system perspective.

4. The findings in this draft report make clear the need for future maintenance and investment in the Ohio River. The recommended investments presented here encourage directing scarce resources to optimize maintenance at existing Ohio River projects and conducting timely feasibility level analysis on the upper Ohio.

5. Specific maintenance and lock construction at each lock and dam and the optimum timings in the WPC are described below.

10.1.5.1 With-Project Strategy By Project

1. **Tables 10-15 – 10-31** show the project-level investments included in the Navigation SIP. All years represent the start of the investment process; a process that can take several years, depending on the investment. Advanced component replacement can take 1-3 years, chamber rehabilitation 3 years, 600' lock replacement 7 years and 1200' lock replacement 8 years. Each of the recommended investments will require additional up-front time for the required analysis leading to an action or authorization.

2. Significant findings include: new lock chambers are recommended at Emsworth, Dashields and Montgomery to replace the existing auxiliary chambers. Main chamber rehabilitations are recommended at all other mainstem projects except McAlpine and New Cumberland where auxiliary chamber rehabilitation is recommended. A reliable main chamber displaces the need for auxiliary lock extension under the current traffic forecast scenarios. Reactive maintenance or component replacement strategies complement the Navigation SIP.

3. **Table 10-15** shows a new 600’ x 110’ lock chamber to replace the existing 360’ x 56’ auxiliary chamber at Emsworth is economically justified immediately in the study period (2010). The table also shows main chamber component replacements to be traffic forecast sensitive. The draft ORMSS SIP recommends immediate feasibility level analysis for auxiliary lock chamber replacement at Emsworth and continued monitoring of traffic forecasts and main chamber component reliability to optimize future investments.

TABLE 10-15
Emsworth Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber *					
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	**2038**	**2016**	RM	**2050**
Land Wall	**2012**	RM	**2014**	RM	RM
Middle Wall	**2011**	RM	RM	RM	RM
Upper Guide Wall	RM	RM	RM	RM	RM
Lower Guide Wall	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	**2010**	**2010**	**2010**	**2010**	**2010**
Electrical Systems	New	New	New	New	New
	110 x 600	110 x 600	110 x 600	110 x 600	110 x 600

* Main Chamber is only used when the new 600' Aux is closed for maintenance. This is the reason for leaving the chamber in the reactive maintenance mode. If repairs are needed they will be made while the new lock is open.

4. **Table 10-16** shows a new 600' x 110' lock chamber to replace the existing 360' x 56' auxiliary chamber at Dashields is economically justified immediately in the study period (2010). The table also shows main chamber component replacements to be traffic forecast sensitive. The draft ORMSS SIP recommends immediate feasibility level analysis for auxiliary lock chamber replacement at Dashields and continued monitoring of traffic forecasts and main chamber component reliability to optimize future investments.

TABLE 10-16
Dashields Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber *					
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	**2035**	RM	RM
Land Wall	**2013**	RM	**2010**	RM	RM
Middle Wall	RM	RM	RM	RM	RM
Upper Guide Wall	RM	RM	RM	RM	RM
Lower Guide Wall	RM	RM	RM	RM	RM
Auxiliary Chamber					
Electrical Systems	**2011**	**2010**	**2010**	**2010**	**2010**
Upper Guard Wall	New	New	New	New	New
Lower Guard Wall	110 x 600	110 x 600	110 x 600	110 x 600	110 x 600

5. **Table 10-17** shows a new 600’ x 110’ lock chamber to replace the existing 360’ x 56’ auxiliary chamber at Montgomery is economically justified immediately in the study period (2010) in four of the five forecast scenarios. In the NAAQS growth forecast scenario, a 1200’ x 110’ replacement of the auxiliary chamber is optimum. The table also shows main chamber component replacements to be traffic forecast sensitive. The draft ORMSS SIP recommends immediate feasibility level analysis for auxiliary lock chamber replacement at Montgomery and continued monitoring of traffic forecasts and main chamber component reliability to optimize future investments.

TABLE 10-17
Montgomery Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber *					
Miter Gate Machinery (Upper and Lower)	RM	RM	**2015**	RM	RM
Hydraulic Systems	RM	RM	**2015**	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	**2017**	**2015**	**2051**	**2035**
Land Wall	**2015**	RM	**2011**	RM	RM
Middle Wall	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	**2010**	**2010**	**2010**	**2010**	**2010**
Electrical Systems	New	New	New	New	New
River Wall	110 x 600	110 x 600	110 x 1200	110 x 600	110 x 600

* Main Chamber is only used when the new 600' Aux is closed for maintenance. This is the reason for leaving the chamber in the reactive maintenance mode. If repairs are needed they will be made while the new lock is open.

6. **Table 10-18** shows the need to replace auxiliary miter gates at New Cumberland ranges from 2034 to 2039 depending on the traffic forecast scenario. Since the cost of replacing both sets of miter gates exceeds the $10.6 million threshold when considering fabrication, delivery, assembly, painting, and installation, it is listed as a major rehab. The table also shows economically justified proactive component replacement of the electrical systems in two forecast scenarios. Due to the longer term need of auxiliary gate replacement at New Cumberland, the draft ORMSS SIP recommends continued monitoring of traffic forecasts and component reliability to optimize future investments.

TABLE 10-18
New Cumberland Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	**2015**	**2015**	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gate Upper	**2037**	**2034**	**2034**	**2037**	**2037**
Miter Gate Lower	**2038**	**2035**	**2034**	**2038**	**2038**
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

7. **Table 10-19** suggests the need at Pike Island to rehab the main chamber miter gates and electrical systems in the 2015-2016 timeframe. Other component replacements show traffic forecast sensitivity. The draft ORMSS SIP recommends a near-term major rehabilitation study of the main chamber miter gates and electrical systems at Pike Island and continued monitoring of traffic forecasts and other component reliability to optimize future investments.

TABLE 10-19
Pike Island Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates Upper	**2016** Rehab	**2015** Rehab	**2015** Rehab	**2016** Rehab	**2015** Rehab
Miter Gates Lower					
Electrical Systems					
Miter Gate Machinery (Upper and Lower)	RM	RM	**2014**	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gate Upper	RM	**2052**	**2052**	**2057**	**2056**
Miter Gate Lower	**2058**	**2053**	**2053**	**2058**	**2056**
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

8. **Table 10-20** shows the need to rehabilitate the main chamber miter gates and miter gate machinery at Hannibal ranges from 2011 to 2012 depending on the traffic forecast scenario at this stage of study. The table also shows economically justified proactive auxiliary miter gate replacement way out in 2065 in one forecast scenario. Due to the immediate need of main chamber rehabilitation at Hannibal, immediate action to begin a major rehabilitation study is recommnended along with continued monitoring of traffic forecasts and component reliability to optimize future investments.

TABLE 10-20
Hannibal Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2012**	**2011**	**2011**	**2012**	**2011**
Miter Gate Machinery (Upper and Lower)	Rehab	Rehab	Rehab	Rehab	Rehab
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gate (Upper and Lower)	RM	**2065**	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

9. **Table 10-21** shows the need to rehab the main chamber miter gates and electrical systems at Willow Island ranges from 2027 to 2028 depending on the traffic forecast. Such timing suggests a more intermediate need. The finding at Willow Island leads the draft ORMSS SIP to recommend continued monitoring of traffic forecasts and component reliability at Willow Island to optimize future investments.

TABLE 10-21
Willow Island Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2027**	**2027**	**2027**	**2027**	**2028**
Electrical Systems	Rehab	Rehab	Rehab	Rehab	Rehab
Hydraulic Systems	RM	RM	RM	RM	RM
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

10. **Table 10-22** shows the need to rehab the main chamber miter gates, miter gate machinery, and electrical systems at Belleville in four of five traffic forecasts. The findings at Belleville lead to a draft ORMSS SIP recommendation of preparation for main chamber major rehabilitation project to begin study within the next 7 years and continued monitoring of traffic forecasts and component reliability to optimize future investments.

TABLE 10-22
Belleville Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2032**	**2017** Rehab	**2017** Rehab	**2017** Rehab	**2028** Rehab
Miter Gate Machinery (Upper and Lower)	RM				
Electrical Systems	**2010**				
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

11. **Table 10-23** shows the need at Racine to rehab the main chamber miter gates, miter gate machinery, and electrical systems in 2019 -2020. The relatively robust finding at Racine leads to a draft ORMSS SIP recommendation of continued monitoring of traffic forecasts and component reliabilities at Racine, in the near term with the intent of starting a major rehabilitation analysis in the medium term to optimize investments.

TABLE 10-23
Racine Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2020** Rehab	**2019** Rehab	**2020** Rehab	**2019** Rehab	**2019** Rehab
Miter Gate Machinery (Upper and Lower)					
Electrical Systems					
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	**2050**	**2054**	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

12. **Table 10-24** shows the need to rehabilitate the main chamber miter gates and electrical systems at Byrd ranges from 2030 to 2045 depending on the traffic forecast scenario. Such a broad range of timing suggests more uncertainty and because of the less robust finding at Byrd Locks continued monitoring of traffic forecasts and component reliability at Byrd to optimize future investments is recommended.

TABLE 10-24
Byrd Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2055**	**2044**	**2045**	**2030**	**2033**
Electrical Systems	**2024**	Rehab	Rehab	Rehab	Rehab
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Auxiliary Chamber					
Electrical Systems	RM	RM	RM	RM	RM

12. **Table 10-25** shows the need at Meldahl to rehab the main chamber miter gates, miter gate machinery, and electrical systems ranges from 2010 to 2013 depending on the traffic forecast scenario. Also, main chamber hydraulic systems shows economic justification in two traffic scenarios. The auxiliary chamber gates show economic justification for proactive replacement in all traffic scenarios. Since the cost of replacing both sets of miter gates would exceed $10.6 million when fabrication, delivery, assembly, painting, and installation is considered, this also qualifies as a major rehab. Given the relatively robust findings at Meldahl, the draft ORMSS SIP recommends starting both a main chamber and auxiliary major rehabilitation analysis at Meldahl while continuing to monitor traffic forecasts and component reliability of the main hydraulic systems order to optimize future investments.

TABLE 10-25
Meldahl Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2013** Rehab	**2010** Rehab	**2010** Rehab	**2010** Rehab	**2010** Rehab
Miter Gate Machinery (Upper and Lower)					
Electrical Systems					
Hydraulic Systems	RM	RM	RM	**2020**	**2015**
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gates (Upper and Lower)	**2010**	**2010**	**2010**	**2012**	**2010**
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	**2058**

13. **Table 10-26** shows immediate need at Markland to rehab the main chamber miter gates and culvert valves in three of the five traffic forecast scenarios. The table also shows a long term need (2052) to do similar rehab work on the auxiliary chamber in one forecast scenario. Markland findings also show justification for proactive component replacement to be traffic forecast sensitive. Given the relatively robust findings at Markland, the draft ORMSS SIP recommends an immediate main chamber major rehabilitation analysis at Markland that includes the economically justified main chamber component replacements while continuing to monitor traffic forecasts and component reliability of the auxiliary lock components to optimize future investments.

TABLE 10-26
Markland Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Base High
Main Chamber					
Miter Gates (Upper and Lower)	**2010**	**2010**	**2010**	**2010**	**2010**
Culvert Valves	**2013**	**2013**	Rehab	Rehab	Rehab
Miter Gate Machinery (Upper and Lower)	RM	**2023**	**2024**	**2015**	**2015**
Electrical Systems	**2016**	**2016**	**2013**	**2013**	**2013**
Hydraulic Systems	**2036**	**2022**	**2020**	**2016**	**2016**
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gates (Upper and Lower)	RM	RM	RM	RM	**2052**
Culvert Valves	RM	RM	RM	**2045**	Rehab
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

14. **Table 10-27** shows economic justification at McAlpine for proactive replacement of main chamber culvert valves in 2010 and hydraulic systems in 2028-2030. Given this finding, close monitoring of main chamber culvert valve performance at McAlpine and continued monitoring of traffic forecasts and main chamber component reliability to optimize future investments is recommended.

TABLE 10-27
McAlpine Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Hydraulic Systems	**2030**	**2030**	**2030**	**2030**	**2028**
Culvert Valves	**2010**	**2010**	**2010**	**2010**	**2010**
Culvert Valve Machinery	RM	RM	RM	RM	RM

15. **Table 10-28** shows the need at Cannelton to rehab the main chamber miter gates, miter gate machinery, electrical and hydraulic systems, and culvert valves ranges from 2016 to 2017. Based on this finding at Cannelton, the draft ORMSS SIP recommends continued monitoring of traffic forecasts and component reliability of the main chamber until such time a main chamber major rehabilitation analysis is warranted.

TABLE 10-28
Cannelton Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2017** Rehab	**2017** Rehab	**2016** Rehab	**2017** Rehab	**2017** Rehab
Miter Gate Machinery (Upper and Lower)					
Electrical Systems					
Hydraulic Systems					
Culvert Valves					
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

16. **Table 10-29** shows the need at Newburgh to rehab the main chamber miter gates, miter gate machinery, electrical and hydraulic systems, and culvert valves ranges from 2016 to 2025 depending on the traffic forecast scenario. Based on this finding at Newburgh, the draft ORMSS SIP recommends continued monitoring of traffic forecasts and component reliability of the main chamber until such time a main chamber major rehabilitation analysis is warranted.

TABLE 10-29
Newburgh Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2025** Rehab	**2016** Rehab	**2016** Rehab	**2016** Rehab	**2016** Rehab
Miter Gate Machinery (Upper and Lower)					
Electrical Systems					
Hydraulic Systems					
Culvert Valves					
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

17. **Table 10-30** shows the need at Myers to rehabilitate the main chamber miter gates, miter gate machinery, electrical and hydraulic systems, culvert valves and culvert valve machinery ranges from 2011 to 2014 depending on the traffic forecast scenario. Based on this finding at Myers, near term preparation of a main chamber major rehabilitate analysis while continuing to monitor traffic forecasts and component reliability of the main chamber to ensure optimal investment timing is recommended.

TABLE 10-30
Myers Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2014** Rehab	**2011** Rehab	**2013** Rehab	**2013** Rehab	**2013** Rehab
Miter Gate Machinery (Upper and Lower)					
Electrical Systems					
Culvert Valves					
Culvert Valve Machinery					
Hydraulic Systems					

18. **Table 10-31** suggests the need to replace or totally rehabilitate the culvert valves of both chambers at Smithland in the near term. The table also suggests a long term need to replace miter gates. The finding at Smithland means the draft ORMSS SIP will recommend continued monitoring of component reliability in the short run at Smithland until such time the need for a component replacement becomes clearer.

TABLE 10-31
Smithland Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	RM	**2054**	**2052**	**2054**	**2048**
Culvert Valves	**2013**	**2013**	**2013**	**2013**	**2013**
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gates (Upper and Lower)	**2055**	**2050**	**2049**	**2050**	**2051**
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	**2010**	**2010**	**2010**	**2010**	**2010**
Culvert Valve Machinery	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

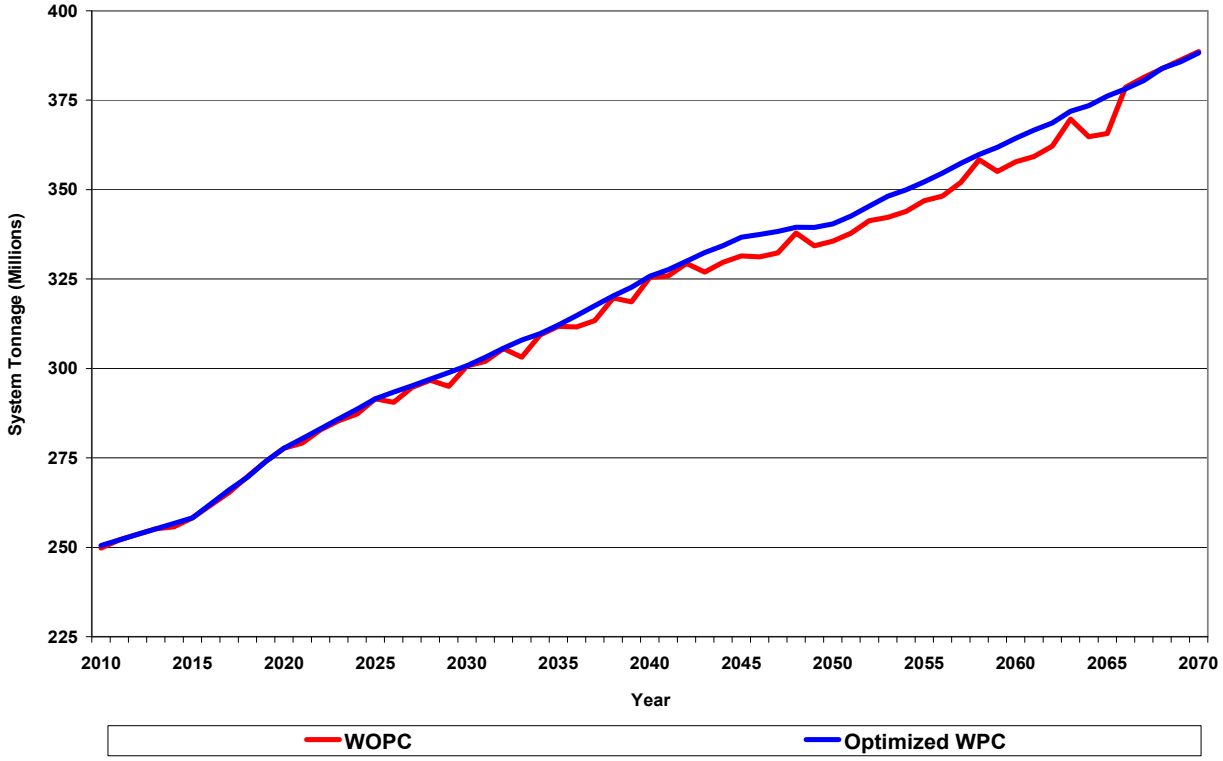
10.1.6 With-Project Condition System Statistics

The with-project condition (WPC) contains a combination of structural improvements and operational and maintenance strategies to optimize Ohio River mainstem navigation for the next 60 years. This sub-section compares WPC system statistics to WOPC system statistics.

10.1.6.1 Equilibrium System Tonnage

Figure 10-3 displays equilibrium system traffic accommodated in the WOPC and WPC. The gap represents incremental diverted traffic between the WOPC and WPC. Over the period of analysis, an average of 2.9 million tons of additional commercial traffic is diverted each year in the WOPC. This additional diverted traffic would challenge overland carrying capacity and increase congestion, traffic accidents, and pollutant emissions.

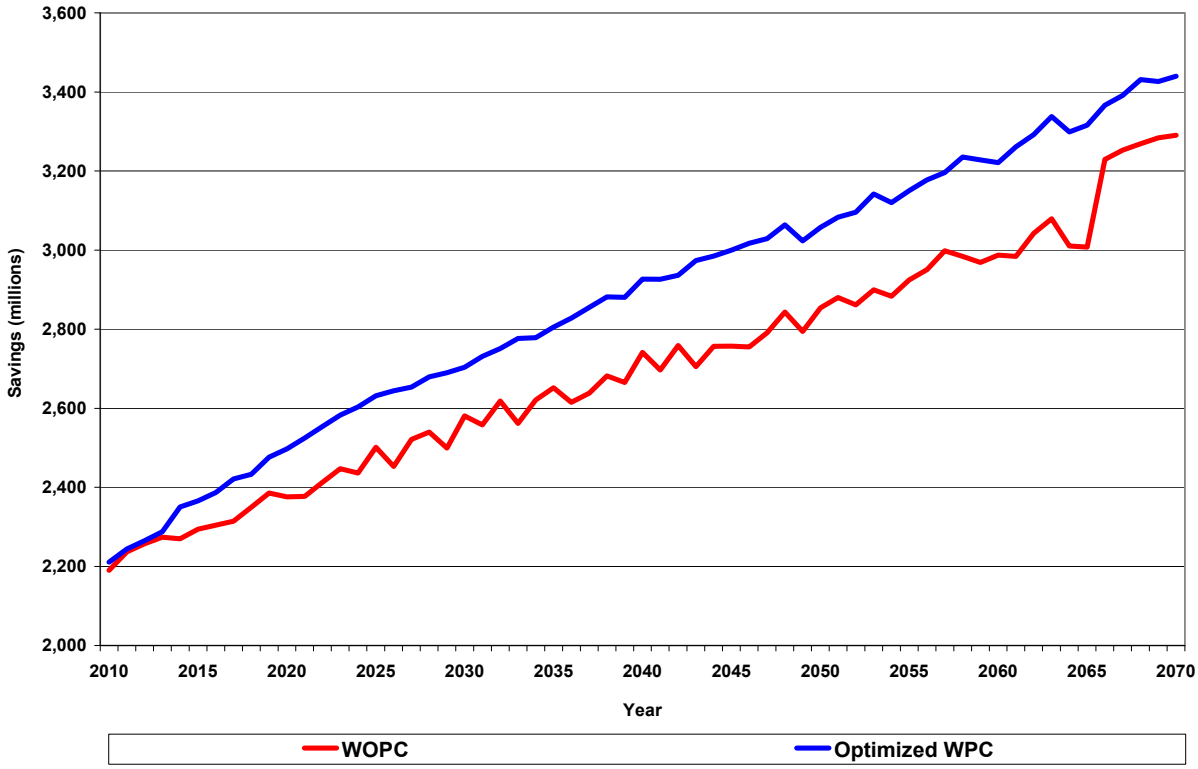
FIGURE 10-3
Equilibrium System Traffic
Average of 5 Forecasts
(Million Tons)



10.1.6.2 System Savings

Figure 10-4 displays system transportation savings averaged over all 5 traffic forecast scenarios for the optimized WPC and WOPC. Equilibrium transportation savings represent system benefits in accordance with ER 1105-2-100. The gap represents incremental system benefits attributable to the more aggressive maintenance and new construction associated with the optimized WPC.

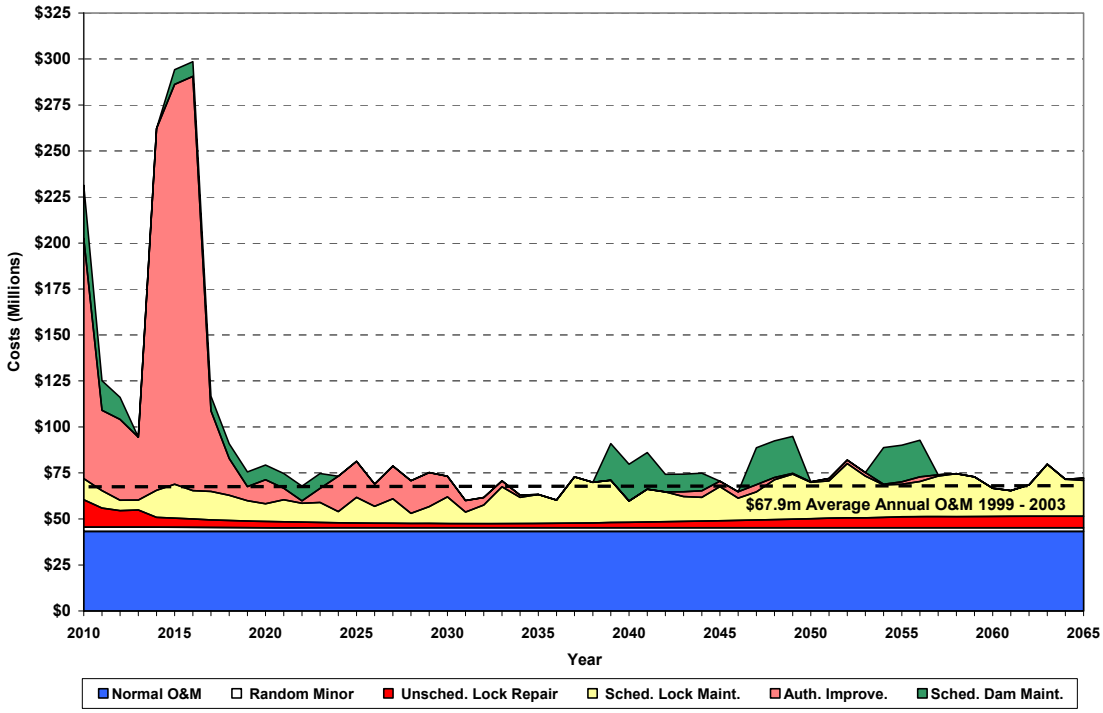
FIGURE 10-4
Equilibrium System Savings
Average of 5 Forecasts
(Million Dollars)



10.1.6.3 System Costs

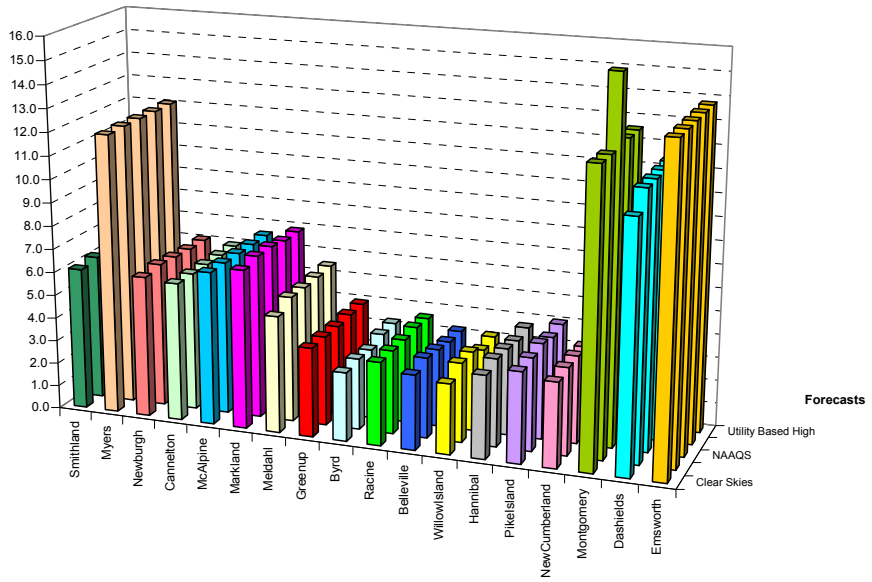
1. **Figure 10.5** shows forecast Federal funding needs over time for the WPC that includes construction of optimum sized locks at EDM and expected unscheduled repair/replacement costs, component replacement, and major rehabilitation costs.

FIGURE 10-5
Total Annual Federal Costs for Ohio River Locks and Dams
With-Project Condition
Average of 5 Forecasts



2. **Figure 10-6** displays the average annual Federal costs for the WPC by project and traffic forecast, including all Federal costs. This large bumps at EDM reflects new construction costs, with the authorized Myers improvement standing out as well and the rehabilitation and maintenance needs at Markland, Meldahl, Hannibal, Willow Island, Pike Island, Newburgh, and Cannelton.

FIGURE 10-6
ORMSS Forecast of Annual Federal Costs
at Ohio River Locks and Dams
With-Project Condition

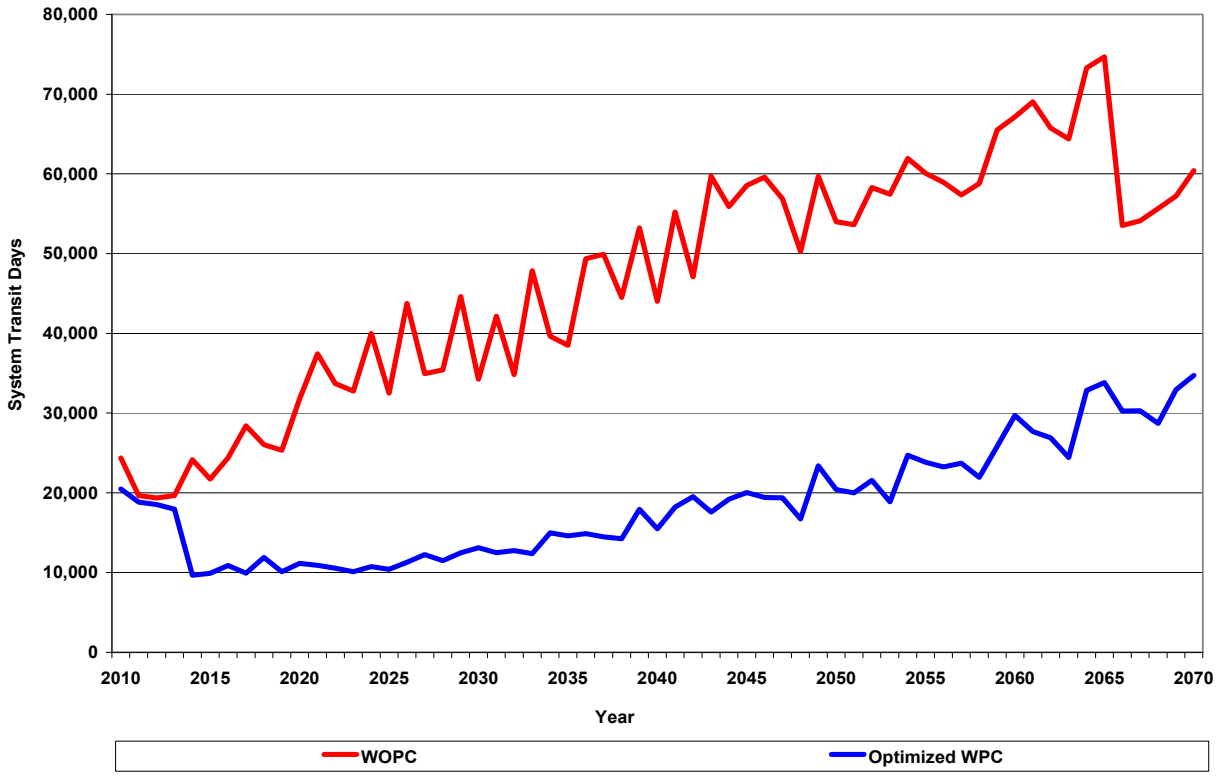


10.1.6.4 System Transit Days

1. **Figure 10-7** compares system equilibrium traffic transit time (averaged over all five traffic scenarios) between the WOPC and WPC alternatives. With-project benefits are derived from a more efficient transportation system because of improved reliability and increased capacity. Capacity increases with fewer closures and the newer, larger chambers. System downtime also decreases. The lower-river rehabilitations and upper-river new lock chambers reduce total system transit days relative to the WOPC.

2. The drop in transit days from 2013-2014 in the WPC is due to the new locks at EDM and the main chamber rehabilitations at Markland, Hannibal, Meldahl, Myers, and Pike Island all coming on-line. The volatility in transit days seen in the WOPC curve results from the unreliability and more frequent scheduled closures found with the reactive maintenance strategy.

FIGURE 10-7
Transit Days to Accommodate Equilibrium Traffic
(WOPC vs. WPC)
Average Of 5 Forecasts



10.2 ENVIRONMENTAL CONSEQUENCES

This is a programmatic EIS and the environmental consequences discussed in this section are discussed from a system-wide perspective. Future NEPA documents for site specific actions would be tiered from this programmatic EIS.

10.2.1 Impacts of WOPC and WPC Alternatives on Major VECS

1. The six major VECs identified during the ORMSS scoping process and emphasized in the CEA Appendix are: water and sediment quality, fish, mussels, riparian resources, recreation, and health and safety. This section summarizes impacts on the VECs under both the WOPC and WPC. Additional details on impacts are presented in **Tables 8-9** and **9-12** and in the accompanying text in subsections 8.7.2 and 9.7.1, respectively. Also, specific traffic and construction related issues identified that have potential environmental impacts are discussed in 10.2.3.

2. Under the WOPC alternative and its three maintenance options (routine, cyclical and unscheduled repairs), general short-term detrimental effects would include increased water turbidity, interference with upstream movement of fish, disruptions in downstream mussel habitat, damage to riparian resources due to the queuing of tows and their bank toe-ins and tie-offs, and disruption of recreational boat lockages. Of the three maintenance actions, unscheduled repairs are potentially the most disruptive and detrimental to all major VECs. Emergency repairs under extraordinary conditions, including the failure of major lock components, preclude opportunities to avoid or minimize environmental impacts while increasing impacts from queuing and construction site activities. In such cases, any mitigation or restoration of environmental damages would occur after-the-fact. The duration of emergency conditions and the time of the year they occur would influence the extent of the impacts.

3. Two of the three options under the WPC alternative – the advanced maintenance alternative (AMA) and major rehabilitation alternative (MRA) – have short-term, localized impacts that are similar to those in routine or cyclical maintenance under WOPC. However, more pronounced impacts would occur in the lock modernization alternative (LMA), primarily because of extensive dredging and excavation impacts and the permanent loss of aquatic habitat within the project footprint. Further, placement of fill materials around the foundations of lock walls and alternations in flow patterns could cause siltation of fish and mussel habitat. Clearing of riparian areas would reduce habitat and also may alter local hydrological patterns; revegetation and restoration of function in such areas may take decades. A positive aspect of LMA is that its long-term planning horizon may offer opportunities to enhance environmental sustainability (ES) during construction of new structures or adaptations of older ones. Enhancement could include incorporation of desired ES outcomes into the design of new or modified infrastructure. Examples could include fish passage or facilities to increase dissolved oxygen.

4. The long-term perspective of the ORMSS process requires consideration of impacts beyond those caused by the individual maintenance, repair or modernization activity. While short term impacts of less aggressive WOPC maintenance are localized and relatively brief, especially under routine and cyclical maintenance, WOPC maintenance approaches do not address the long-term, negative effects of barge queuing. In fact, as navigation infrastructure ages and traffic increases throughout the ORMSS planning horizon, more unscheduled repairs would be expected to occur, compounding the impacts of queuing on aquatic and riparian resources.

5. In contrast, more aggressive maintenance, including the three projects associated with the LMA, incurs more pronounced environmental impacts during implementation. However, these improvements would provide for long term reductions of such impacts as a result of more efficient and reliable handling of both commercial and recreational river traffic accompanied by reductions in queuing and its detrimental impacts.

6. Impacts to the Health and Safety VEC under the AMA and MRA would be similar to those under the Reactive Maintenance alternative of the WOPC. The duration of risks during individual projects will be longer, especially under the MRA, but the

frequency of such events would be reduced. In contrast to AMA and MRA, the LMA option involves a longer time period of more intensive activity and, therefore, greater risk of accident and injury during the lock construction projects. The need to conduct emergency repairs, sometimes under intensive and higher-risk conditions, may occur under any of the alternatives, but is likely to be experienced most frequently in the WOPC. Under any alternative, strict adherence to proactive safety measures is essential to minimize worker accidents and injuries. In the long-term, alleviating congestion by providing more efficient vessel passage through modernized locks would have beneficial safety effects for both commercial and recreational vessels.

10.2.2 Cumulative Effects

10.2.2.1 Approach To Analyzing Cumulative Effects

1. Environmental issues are addressed in a Cumulative Effects Assessment (CEA) study of the entire mainstem navigation system (see **Environmental Appendix**). This strategic-level impact study provides a holistic review of the past, current, and anticipated environmental impacts from multiple actions and programs of the Corps of Engineers; other Federal, state, and local governmental agencies; and private industries and agricultural activities. The CEA study forms the technical basis for this programmatic environmental impact statement (PEIS). This section provides an overview of the CEA findings. For a detailed discussion of the CEA methodology and findings, see Cumulative Effects Assessment in the Environmental Appendix.

2. Cumulative effects (CEs) are an emerging issue, in general, in impact studies; the definition that follows is in the Council on Environmental Quality (CEQ) National Environmental Policy Act (NEPA) Regulations (Council on Environmental Quality, 1978):

> "Cumulative impact" is the impact on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

3. This CEA study is in consonance with the above definition and with the policy of the U.S. Army Corps of Engineers relative to addressing the cumulative effects of water resources plans such as the SIP. This policy is (U.S. Army Corps of Engineers, 1999):

> The cumulative effects of the plan and other similar activities should be analyzed. Each proposed water resource development activity is but a piece of a large-scale program. The combined beneficial and adverse economic, environmental and social impacts of individual projects, each of which may be

relatively minor, can have a significant regional or national impact. At each level of the evaluation and review process it is necessary to assess the cumulative beneficial and adverse effects of individual project impacts. Significant effects should guide the decisions.

4. Within the CEA, the use of Environmental Sustainability (ES) as an "ultimate test" for determining the significance of cumulative effects was used. ES is identified in the Corps' recently published Environmental Operating Principles (EOPs) as "a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations" (U.S. Army Corps of Engineers, 2002).

5. The ES categories of the various environmental resources or Valued Environmental Components (VECs) included in the CEA are derived by combining the best professional judgment of the Corps Project Delivery Team and Interagency Working Group (IWG) members with the cumulative effects of multiple actions as manifested through information available on indicators selected for each VEC. Although ES categories are somewhat qualitative, they are based on thorough analyses of past and present conditions as well as future conditions related to trends, plans, laws, regulatory programs and other sources of information that are beyond mere speculation.

6. Categories of ES were determined for the past, present, and future of each VEC. Specific ES categories were developed for each VEC and are found in the corresponding CEA chapters. The general template for the ES categories follows:

- Not sustainable (NS) – The composite conditions of the selected indicators do not reflect conditions that can sustain the resource long-term.

- Marginally sustainable (MS) – The composite conditions for the selected indicators are such that the resource can be sustained for the majority of river miles in or along the Ohio mainstem, but conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences.

- Sustainable (S) – The composite conditions of the selected indicators reflect sustainability for essentially all the river miles in or along the Ohio mainstem. Further, conditions of the indicators exceed regulatory thresholds and pertinent governmental programs are in place to support the resource.

10.2.2.2 Environmental Sustainability Conclusions By Valued Environmental Component

1. Applying this methodology to each Valued Environmental Component (VEC) in the CEA resulted in past, present, and future characterizations of ES that were included in bar graphs accompanied by synopses of conditions. Because of implementation of

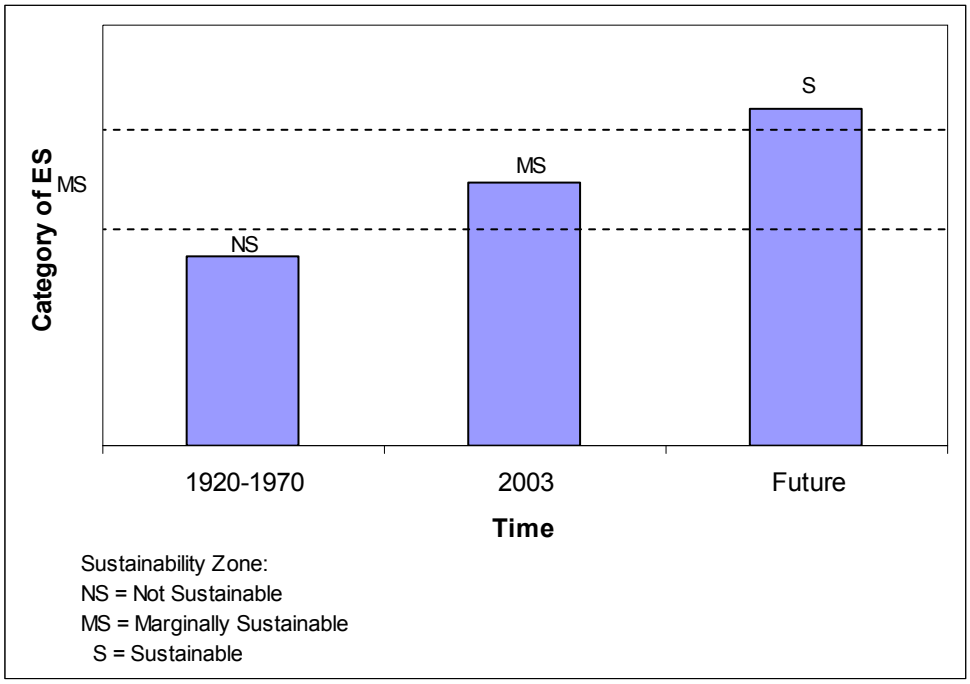
important legislation or the quality of information available, more than one ES category may be used to categorize past conditions.

2. The following sections present the ES graphs (**Figures 10-8 through 10-18)** and their respective synopses which form the basis for additional conclusions related to interactions among VECs, overall cumulative effects, and sustainability of the Ohio River mainstem.

A. Water Quality and Sediment Quality

1. Prior to 1920, and continuing up to about 1950, the water quality of the mainstem was in a degraded state characterized by low DO concentrations, low pH levels in the upper river, high bacterial contamination, high nitrogen concentrations, and remobilization of potentially toxic chemicals that had become associated with river sediments. Essentially no pollution reductions or controls programs, or regulatory programs, were in place during this period. Further, declines in the diversity and health of fish communities in the mainstem had occurred. Accordingly, the ES of water quality was classified as "not sustainable". Primary contributors to these conditions were the largely untreated and uncontrolled point and non-point pollutant discharges from growing municipalities and various types of industries and land uses along the river.

FIGURE 10-8
ES of Water Quality



2. Due to the programs of ORSANCO, and requirements of the Federal Water Pollution Control Act (and the amended Clean Water Act), the water quality of the Ohio River has shown a steady improvement in recent decades. For example, DO concentrations are typically above the 5.0 mg/L standard, pH levels are between the 6.0 to 9.0 standard, and nitrogen concentrations meet current water quality criteria. However, continuing concerns include bacterial contamination primarily associated with non-point source pollution downstream from major urban areas, legacy "contaminated sediments" in the upper Ohio River, and fish consumption advisories throughout the mainstem. In contrast, the results of algae (plankton) and aquatic macroinvertebrate surveys in recent decades have demonstrated steady improvements in these resources, which parallel water quality improvements. As of 2003, 779 of 981 miles (~80%) of the mainstem are "fully supporting" aquatic life, and 949 miles (~97%) are "fully supporting" public water supply use. None of the mainstem was "fully supporting" fish consumption due to consumption advisories along its total length. For contact recreation, 269 miles (~27%) are "fully supporting", with major impairment continuing from combined sewer systems in urban areas. Overall, the implementation of the National Pollutant Discharge Elimination System (NPDES) permit programs by USEPA under the Clean Water Act for municipalities, industries, and stormwater has led to the reduction of discharges into the mainstem. Initiatives for increasing the use of "Best Management Practices" (BMP) have also been established. Further, the diversity and health of fish communities along the mainstem has considerably improved. Accordingly, at this time, although there are many positive signs, the ES of the water quality VEC is classified as "marginally sustainable".

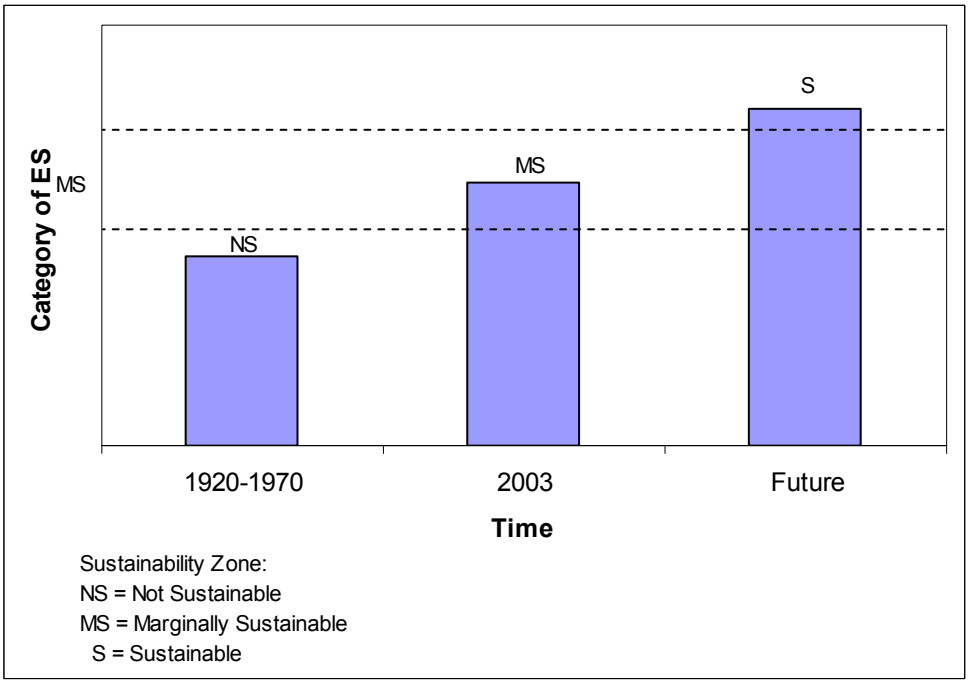
3. Regarding the future, it is expected that water quality of the Ohio River mainstem will further improve with continuation of source control and other pollution reduction programs, and implementation of the Ohio River Ecosystem Restoration Program and other remediation efforts. NOTE: The Ohio River Ecosystem Restoration Program has yet to receive Congressional Appropriations and is now a candidate for de-authorization. However, it is anticipated that the ES of water quality will achieve a "sustainable" condition. Vigilant efforts are still needed to continue effective water quality and aquatic ecological monitoring and management efforts. In this regard, it may be desirable to plan and implement source monitoring programs for selected actions considered of high importance relative to cumulative effects. Further, special surveys for legacy-contaminated sediments are needed along with site-targeted efforts to reduce bacterial pollution from combined sewer overflows (CSOs). Reasonably foreseeable future actions expected to be beneficial to water quality in the future include implementation of nonstructural navigation improvements and technological improvements related to communications and more environmentally-advanced barge design. Activities that support commercial navigation (e.g., port development and maintenance dredging) will continue to be scrutinized by regulatory agencies and Non-Governmental Organizations and may be more strictly regulated. Some redevelopment activity may revive underused urban space or industrial brownfield areas, with possible long-term water quality benefits related to clean up. Much development activity, however, will involve conversion of existing floodplain lands that now afford habitat protection, open space and ecosystems values. Once converted, such lands are unlikely to revert to their former more natural states. Increasing emphasis on pollution prevention, erosion control BMPs, and implementation of the Phase 1 and 2 NPDES storm water programs could counteract some adverse impacts, particularly in more urban areas. In general, several regulatory initiatives in recent years should measurably improve water and sediment quality, but it is not possible to predict the magnitudes of their beneficial effects.

B. Fish Resources

1. Prior to1920 and continuing well into the mid-20th century, fish communities became degraded, as reflected in the decline of many native species and the increase in pollution tolerant species. This decline was particularly pronounced in the upper and middle river, where human populations grew rapidly during the first half of the 20th century, leading to increased inputs of domestic sewage, industrial effluent, and acid mine drainage. Numerous other actions contributed to the degradation of fish communities, including land clearing and sedimentation beginning in the 19th century; impoundment of the river by navigation dams that disrupted migrations of several important river fishes; in-stream sand and gravel dredging; development of new ports, terminals and marinas; introduction of the common carp, and increasing quantities of stormwater runoff from urbanizing areas. Because these actions contributed to habitat loss, changes in species composition and abundance, and serious declines in necessary water quality conditions, the ES for this period is classified as "not sustainable". Further, until 1948, when a limited precursor of the Clean Water Act was passed and the ORSANCO interstate compact was signed, pertinent laws were limited. Accordingly,

based on scientific data indicating changes in fish communities as well as the recognition of multiple actions and factors causing such changes, it was concluded that the composite conditions for the selected indicators of ES for fish communities did not reflect conditions that would sustain diverse, healthy fish populations throughout the river.

FIGURE 10-9
ES of Fish Communities



2. From the mid-20th century until the present time, improvements in sustainability of fish resources have been observed throughout the mainstem. Such improvements have resulted primarily from initiatives by ORSANCO, efforts of the six Ohio River states, and the requirements of the Federal Water Pollution Control Act and the amended Clean Water Act. As municipal wastewater and industrial effluents to the river have improved, and other pollution control measures have increased pH and oxygen while reducing toxins, fish communities of the Ohio River have shown steady improvement, marked by the recovery of many native species. The common carp is no longer as dominant as in the past. Concurrent with improvements in water quality, however, has been the continued inundation of fish habitat not only from navigation structures constructed before 1950, but also from the continued construction and operation of additional high-lift dams. The modern navigation system, combined with land use and flood control practices in the watershed, has caused the inundation and siltation of extensive areas of gravel substrate, preferred by many migratory fishes. Various studies on human impacts on Ohio River fishes, including studies on winter habitat and fish passage, underscore the need for additional research and development of resource management practices to gain a more comprehensive understanding of ES of the mainstem fish. Accordingly, the ES of the fish resource at present is classified as "marginally sustainable." Two major uncertainties emerged during the last decade that may affect the fish resource into the

future: 1) the invasion of Asian carps and 2) the invasion and unknown population dynamics of zebra mussels.

3. Regarding the long-term future, the CEA has identified 60 reasonably foreseeable future actions ranked as having high or medium importance to fish. These include actions that change habitat, change disturbance regimes, change hydrological patterns, affect ecological services, and are related to population changes. During recent decades, regulatory requirements and pollution control programs have been implemented that will benefit the fish resource, if continued into the future. Additional tools and studies that also should increase understanding of the ES of fish in the mainstem include the NAVPAT habitat assessment model, the new Ohio River Fish Index (ORFIn), and supplemental fish studies related to §316(a and b) of the Clean Water Act. It is also expected that the Ohio River Fish Management Team, comprised of state agencies along the river, and USFWS' Ohio River Valley Ecosystem Team will continue to be involved in fish resource monitoring and management. Given recent improvements in the resource, the development of new assessment tools, and the level of stakeholder interest, it is expected that fish communities of the Ohio River mainstem will attain a "sustainable" condition and may further improve with long-term elimination of combined sewer overflows and better non-point pollution control. The habitat effects of impoundment of the river are expected to persist into the future, but implementation of ES improvement measures may produce responses that counteract such effects and benefit habitat and enhance interpool connectivity. A possible threat to the resource is the invasion of Asian carps moving upriver. Vigilance by ORSANCO and other resource agencies will be required to assess populations while potential measures to control these species are evaluated for the Ohio and other major river systems in the U.S.

C. Mussels

1. Mussels are part of the river's natural filter system, and they play an important role in the breakdown/compartmentalization of organic matter as well as provide habitat for other invertebrates. To summarize the historical and current status of mussel populations in the Ohio River mainstem, the following observations can be made:

2. Over the last century the number of mussel species has declined from about 80 to the currently reported 54 species. Evidence suggests that the number reached a low in the vicinity of about 25 to 35 species in the 1950s and 1960s. Numerous factors contributed to the decline, including, but not limited to, water pollution from municipalities, industries, and acid mine drainage; instream extractions of sand and gravel; construction and operation of high-lift locks and dams; and disruptions to mussel beds due to barge fleeting areas, queuing, and disposal of dredged materials. Recent increases in the numbers of species can be attributed to water quality improvements, protection efforts related to mussel beds, and natural reintroductions from tributary and/or downstream populations. However, despite these advances, research continues on the unique characteristics of the life cycles of numerous mussel species, and their susceptibility or resiliency regarding natural stresses from dynamic river flows and water quality, and from human-induced stresses associated with economic development

activities. The greatest factor affecting mussels in the mainstem Ohio River is habitat alteration resulting from impoundment by the high lift dams. Maintenance of the navigation pools creates year round slackwater habitat which has had and continues to have the most significant adverse affect on mussel resources.

3. The lower portion of the river was not as severely affected by historical water quality degradation as the upper river. As a result, the lower river typically had and continues to support more diverse mussel populations and generally higher densities than the upper river. However, concerns currently exist relative to fluctuating populations of invasive zebra mussels and continued re-introduction of zebra mussels attached to barges. Also, recent invasions by asian carps, especially black carp, is a cause for further concern. Thus there is a need for additional research on the interactive relationships between the invasive species and native mussels and their associated life cycle, including fish hosts.

4. As more information is assembled on the locations and characteristics of mussel beds in the mainstem, the planning and implementation of targeted and long-term mussel monitoring programs can be more effectively accomplished. Further, the results can be used in an ecosystem restoration program focused on enhancing and maintaining the ES of the mussel resource.

5. Based upon the above-described affected environment conditions, and consideration of multiple actions and their effects, the ES of mussels of the mainstem of the Ohio River can be characterized and depicted as follows:

6. In the time period from 1920, and continuing up to the mid-point of the last half of the 20th century, the ES of freshwater mussels in the mainstem was in a continuing decline and thus classified as "not sustainable". The decline in mussel species and densities, and the areal extent of mussel beds, was particularly noted in the upper and middle river segments, with the lower river concurrently experiencing a lesser, but similar decline. Numerous actions contributed to the decline, including, but not limited to, acid mine drainage in the upper river, high-lift locks and dams disrupting mussel and fish-host migration, numerous discharges of untreated to partially treated municipal and industrial wastewaters, in-stream sand and gravel mining, dredging for new ports and terminals, periodic maintenance dredging for the navigation system, mussel harvesting for button manufacturing and the cultured pearl industry, and multiple land use changes resulting in increased non-point source pollution. These actions and others contributed to losses in quality mussel habitat throughout the river, declines in necessary water quality conditions, and disruptions in various components of the mussel life cycle. Additional contributing factors to this decline included the limited information on the life cycle requirements of several mussel species and poor understanding of the influence of timing of interpool movement of fish on mussel reproduction. Further, there was limited recognition of the biological importance of mussels, and limited existence of environmental and resource protection laws up to 1948 (when a limited precursor to the current Clean Water Act, the Federal Water Pollution Control Act, was passed) and 1973 (when the Endangered Species Act was passed). Accordingly, as a result of the scientific

data indicating declines in various mussel populations in the mainstem, as well as the recognition of multiple actions and factors causing such declines, it was concluded that the composite conditions for the selected indicators of ES for mussels did not reflect conditions that would sustain diverse, healthy populations of freshwater mussels throughout the river.

7. In the time period from 1975 up to 2003, some improvements in sustainability of the mussel resource in the mainstem have been noted, although improvements are typically localized and exhibit frequent fluctuations. Conversely, there has also been a general reduction in number and aerial extent of previously known mussel beds since about 1975. Improvements that have occurred resulted from 1) reduced acid mine drainage in the upper river, 2) enhanced treatment requirements for municipal and industrial wastewater treatment plant discharges, 3) consideration of mussel bed locations in river-related permitting programs (e.g., Section 404 and Section 10 permits) and navigation system operational features (location of queuing and barge fleeting/storage areas, and placement of dredged material), and 4) protection provided through designation of several mussel species as threatened or endangered under the ESA and similar state protective mechanisms.

8. Recent fish migration research indicates evidence of some inter-pool movement (see fish resources chapter); however, it is not clear if sufficient host fish are able to move successfully from a mussel assemblage in one pool to another mussel assemblage in another pool or that such movement coincides with seasons when host fish would be carrying mussel glochidia. The designation of "marginally sustainable" is appropriate considering that composite conditions for the selected Ecological Sustainability indicators are such that diverse mussel populations are occurring only along some segments and in some pools of the river and that conditions of the indicators are somewhat tenuous both in location and likelihood of occurrence. The conditions also reflect a continuing level of uncertainty regarding appropriate quantitative measures of the Ecological Sustainability of freshwater mussels.

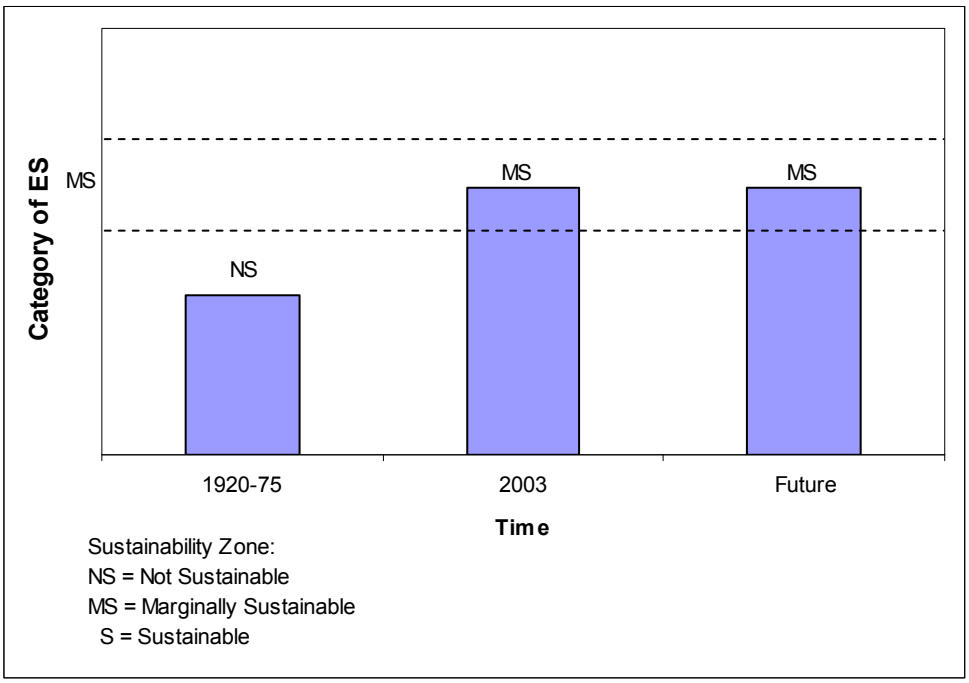
9. Six previously designated endangered species have not been recently found in the mainstem; however, five others have been recorded in the mainstem during this period, but mainly as very old individuals or single individuals. This trend of apparent loss and/or diminishment of listed mussel species during this time period does not bode well for sustainability of mussels in the future. Three additional mussel species (spectacle case, rayed bean, and sheepnose) are currently candidate species in line to be added to this list. The spectacle case is already generally considered extirpated from the mainstem. In addition, the rabbitsfoot mussel has undergone a status review and is now listed as endangered.

10. In contrast to the improvements, concerns still exist regarding the occurrence of non-indigenous species such as zebra mussels and asian carps, especially black carp. The most recent decade has been characterized by expanding databases to include results of scientific studies of freshwater mussels in the Ohio River. These databases, although incomplete, have been used in recent environmental planning and permit programs and

are providing the basis for on-going research efforts into the life cycle of various mussel species. As a result of relatively recent scientific data (since 1990) indicating recruitment and general improvement in some mussel populations in navigation pools in the lower, middle, and some upper portions of the river; the recognition of improvements in water quality and general habitat conditions resulting from various features of the Clean Water Act and Endangered Species Act, and recent fish migration research which indicates evidence of limited inter-pool movement (see Fish Resources), it is concluded that the current ES classification is "marginally sustainable,"

11. Regarding the future, this study has identified 56 types of reasonably foreseeable future actions ranked as having high importance relative to CEs on native mussels, and 14 additional types ranked as having medium importance. These 70 actions include ones that directly or indirectly contribute to mussel habitat degradation and instability, that affect reproductive success and community connectivity, or that are beneficial to mussels (numerous regulatory and educational actions are included in this latter group). As additional regulatory requirements and pollution control programs are implemented, the habitat conditions should be more conducive to reproductive success and community connectivity than at present. Of particular importance is the need to integrate considerations of mussel beds and the life cycle features of mussels into permitting and other locational decisions within or along the mainstem. As further mussel monitoring and research is conducted, these data should be added to databases to provide further information for both protecting and promoting mussels. Further, consideration should be given to implementation of an ecosystem restoration program for Ohio River freshwater mussels. While these actions collectively will not reverse the habitat loss that has occurred, they should aid in recolonization and at least partial restoration of mussel populations in the remaining suitable habitat.

FIGURE 10-10
ES of Mussel Resources



12. This assessment of future marginal sustainability acknowledges that many unknowns remain and that recovery of the Ohio River mainstem native mussel populations will be a long-term process involving many years of collaborative efforts and monitoring. Evidence of recruitment and population stability will be necessary to validate viability. To illustrate the many uncertainties, the following tasks to effect recovery have been selected from a more extensive list from Watters (1994) and supplemented by the ORMSS Interagency Working Group:

- Identify other resource values associated with mussel populations, including fish hosts, key food organisms and habitat elements.
- Protect and manage mussel populations and their habitat on a site-specific basis to avoid future net loss of available habitat or populations.
- Characterize the habitat that best supports species of concern, including historically important sites.
- Restore habitats and reintroduce mussel species to suitable areas.
- Conduct searches for additional populations.
- Enforce all laws and regulations pertaining to collection of specimens and protection of habitat.
- Enhance knowledge of life histories for species of concern, including life histories of host fishes.
- Identify the potential effects and responses to zebra mussel and Asian carps (especially black carp) invasions and their control measures.
- One particular mitigation measure that needs to be evaluated would be the efficacy of removing zebra mussels from vessels to prevent re-infesting areas.

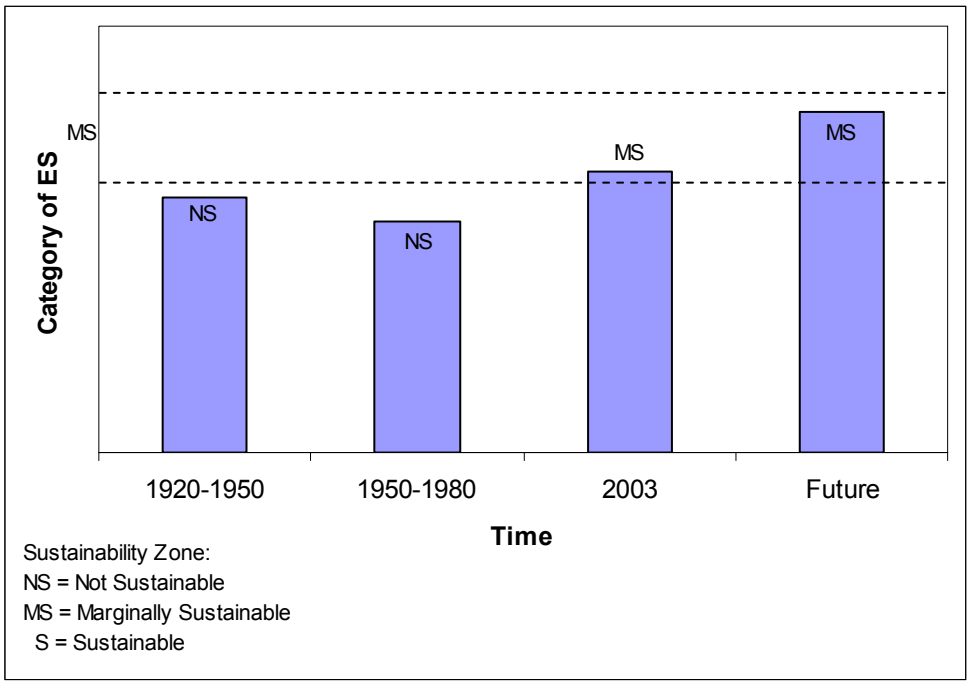
- Increase public and agency awareness of existing laws that protect mussels.
- Use media opportunities to reach the general public and encourage involvement in the recovery process.
- Restore and protect direct connections to tributary populations.
- Restore mobility of fish hosts through dams at appropriate times of the year needed for mussel reproduction.

D. Riparian/Floodplain Resources

1. In the time period prior to 1920, and continuing up to about 1950, the riparian/floodplain resource (RFR) can be classified as "not sustainable" due to relatively rapid losses of riparian habitats and their functions, the lack of knowledge of the importance of these resources to both terrestrial and aquatic ecosystems, and the essential absence of any institutional programs to manage or control riparian areas. Further, the lack of awareness of environmental services performed by RFR, coupled with ongoing floodplain development, especially in the upper and middle river, led to loss and fragmentation of valuable RFR along the Ohio mainstem before such resources could be well-documented.

2. In the time period from 1950 to 1980, worsened "not sustainable" conditions occurred in the first several decades as a result of still more disruptions and losses of riparian areas. However, recent decades have included an increasing awareness of riparian services, including regulation of wetlands, a highly productive riparian component. The establishment of the Ohio River Islands National Wildlife Refuge has focused attention on the disappearance of another riparian habitat type, islands, and has heightened visibility of the riparian resources of the Ohio mainstem embayments. These initiatives suggest the current status of RFR may be moving toward "marginally sustainable". Accompanying these initiatives is an increasing recognition that institutional programs must be established to protect RFR.

FIGURE 10-11
ES of Riparian/Floodplain Resources



3. Regarding RFFAs for these resources, the growing awareness of environmental services performed by RFR, as well as increasing demand for river corridor enhancement and protection for passive recreation may help move RFR toward a more sustainable future. However, it is less certain if environmental regulations and institutional programs will be in place to support RFR sustainability and stem fragmentation and loss of RFR from development along the Ohio River mainstem. Accordingly, the future ES of RFR is classified as "marginally sustainable."

4. An important issue is the need for institutional programs for riparian area management. Examples of such program features include, but are not limited to:

- requiring impact identification and mitigation via the NEPA process..
- designation of special management areas on public lands.
- regulation or other means to discourage activities that further fragment or degrade functional values on privately-owned riparian areas.
- utilization of incentives such as cost-sharing, low-cost loans, or tax reductions to encourage the use of BMPs on riparian areas.
- the purchase of privately owned riparian lands, either in fee or by easement, for public management.

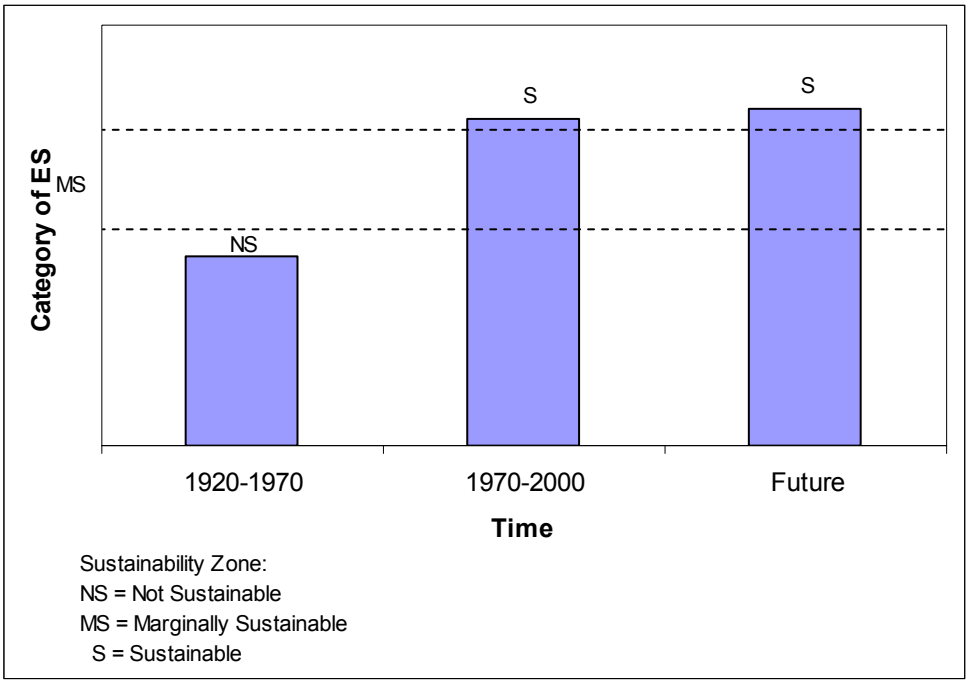
E. Air Quality

1. In the time period prior to 1920, and continuing up to about 1970, air quality of the Ohio River Valley was in a degraded state and thus classified as "not sustainable" due to largely untreated and uncontrolled point and non-point pollutant discharges from coal fired power plants, other types of industries, and vehicular sources.

2. Due to the requirements of the Federal Clean Air Act of 1970 and subsequent amendments, the air quality in the region has shown a steady improvement in recent decades; thus it is currently in a "sustainable" category.

3. Regarding RFFAs for these resources, it is expected that air quality in the Ohio River Valley will further improve as a result of continuation of source control and other pollution reduction programs; thus, it will be maintained in a "sustainable" condition. However, this characterization should not bring complacency; rather, vigilant efforts are still needed to continue effective air quality monitoring and management efforts. Such efforts are reflected in the recent implementation of more stringent standards for ozone and particulate matter and ongoing efforts to establish effective limits for mercury and to continue analysis of the need to control other types of emissions.

Figure 10-12
ES of Air Quality



F. Health and Safety

1. In the time period prior to 1920 and continuing into the 1960-70s, health and safety issues on the Ohio River represented a broad spectrum of risk factors.

Construction and workplace conditions were generally more dangerous than at present; spills and discharges from commercial navigation, river oriented industries, and untreated municipal effluents contributed to a variety of public health risks; and little or no information was available to advise the public of ambient risk levels associated with river oriented activity.

2. While individual risk factors no doubt varied significantly from time to time, most H&S related issues for the period are categorized in **Figure 10-13** as 'marginally sustainable.' However, activities that involved more direct exposure to water quality risk factors are categorized as 'not sustainable' in **Figure 10-14**.

3. Improvements to water quality, reduced risks of spills and faster response, improved workplace safety standards, and effective safety standards for recreational boating have all combined to make the Ohio River a safer place to work, live, and play. These improved present day conditions result in a 'sustainable' classification in **Figure 10-13.** Improved conditions have also contributed to reduce risk factors associated with contact recreation and fish consumption. However, problems associated with continued exceedances of biological standards, the persistence of some contaminants associated with fish consumption, and mixed signals regarding fish consumption standards result in a present time classification of 'marginally sustainable' for these activities.

FIGURE 10-13
Health & Safety for Workplace and Boating Accidents

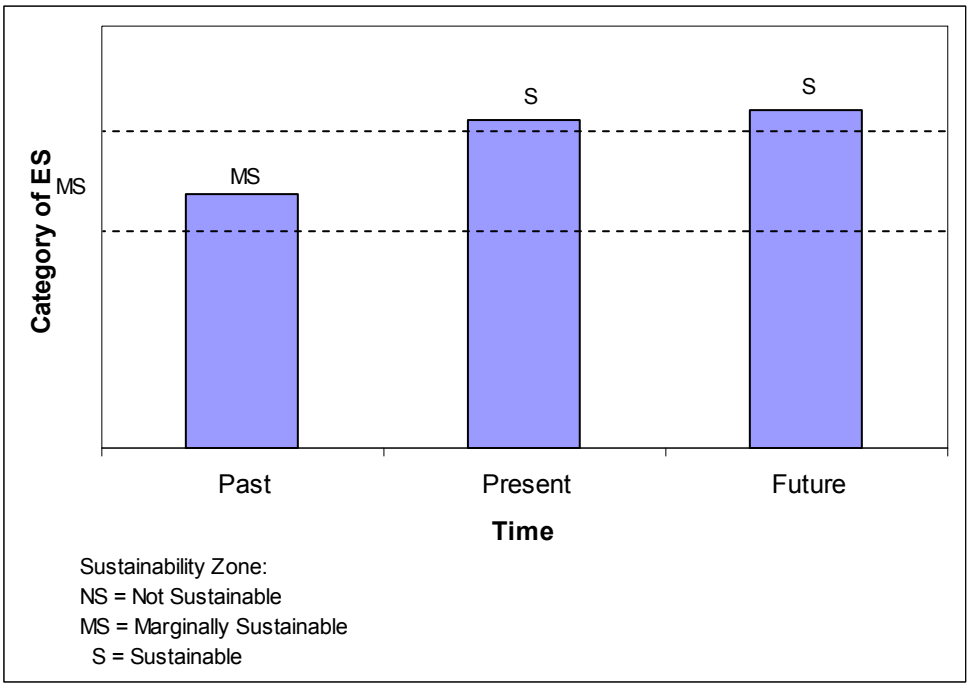
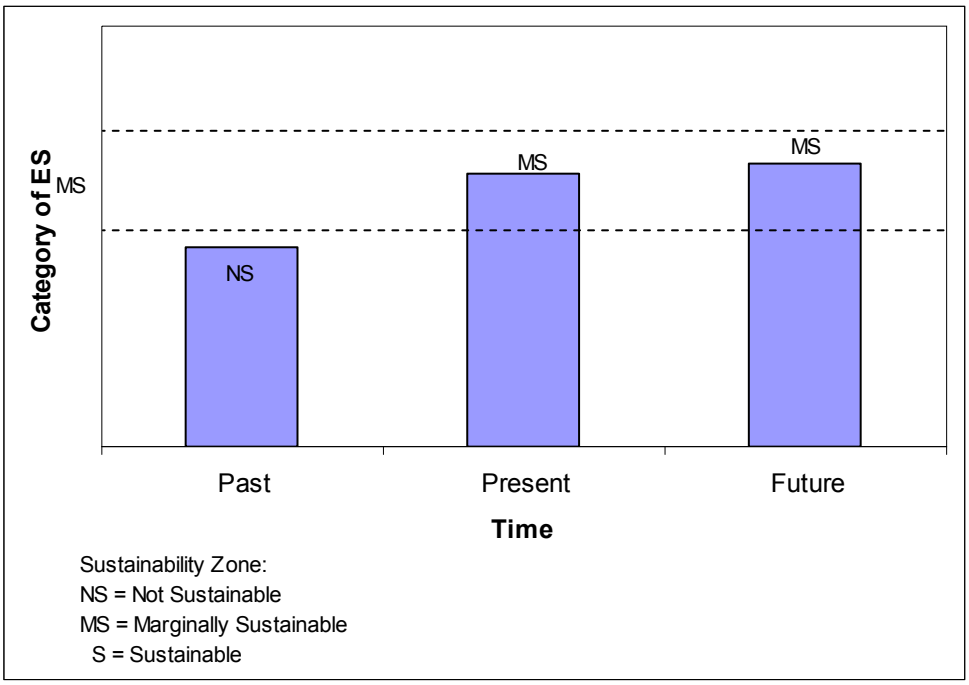


FIGURE 10-14
Health & Safety for Contact Recreation and Fish Consumption



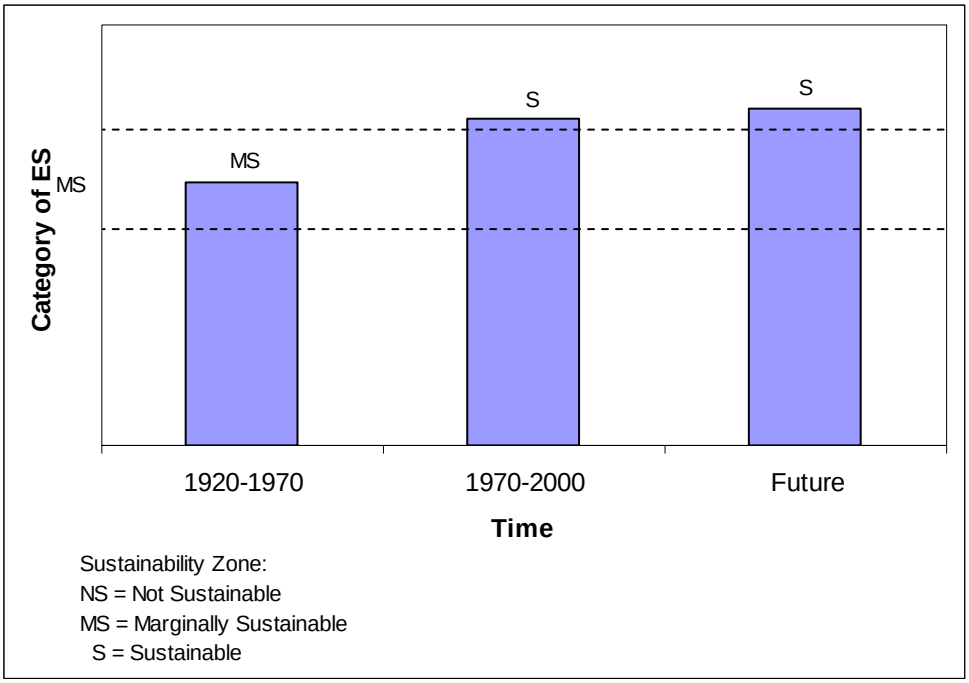
4. With respect to RFFAs, most H&S issues are expected to remain in the 'sustainable' rankings. It is important to note, however, that continued growth of commercial navigation, recreational activity, river oriented industries, and other uses of the river will require continued improvements in management and regulation of H&S issues just to maintain the status quo.

5. While improvement of risk factors associated with contact recreation and fish consumption is expected to continue, these factors are kept in the 'marginally sustainable' category as a conservative estimate of potential trends. Some efforts required for continued improvement, such as rehabilitation of sanitary sewer systems to eliminate CSOs and SSOs or reduction of mercury emissions from coal combustion, will require significant investments and long periods of time to achieve results.

G. Recreation

1. In the time period prior to 1920, and continuing up to about 1950, recreation on the Ohio River occurred in a degraded environment due to largely untreated and uncontrolled pollution discharges from growing municipalities, mining activity, and various types of industries and land uses along the river. Although the river continued to be used for recreation during this period, the overall ES was "marginally sustainable" and may have been "not sustainable" for the worst years of pollution. However, recreation information from the worst decades of pollution is limited as that time period coincided with the Great Depression, World War II, and the post-war period shortly thereafter, when leisure time and financial resources were limited.

Figure 10-15
ES of Recreational Resources



2. At the present time, recreation on the Ohio River is currently in a "sustainable" condition due in large measure to water quality improvements related to ORSANCO programs and requirements of the Federal Water Pollution Control Act (and the amended Clean Water Act). Water quality improvements, combined with increased economic prosperity, have increased the demand for and stimulated the development of marinas, ramps, and other recreation facilities along the river. The recent era of more integrated riverfront planning also has addressed recreation needs and has increased opportunities for an expanded spectrum of recreational choices.

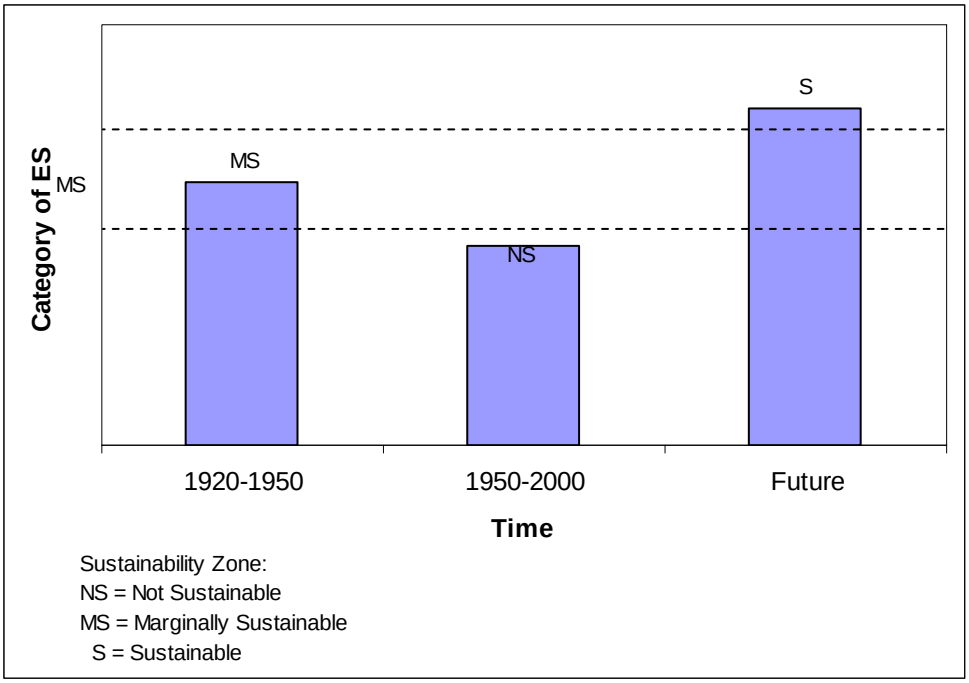
3. Regarding RFFAs for these resources, it is expected that community planning and development of recreation facilities, further water quality improvements, especially in stormwater and CSO management, and habitat protection and restoration efforts will continue to enhance recreation experiences. Socioeconomic projections for a stable or slowly growing population and continued improvement in standard of living would be expected to result in continued growth of demand for recreational opportunity. Consequently, the future ES is classified as "sustainable." Although the perception exists that increased participation could lead to overcrowding and competition for limited resources, it does not currently seem to be an overriding influence affecting people's decisions to participate in river-related activities.

H. Transportation and Traffic

1. In the time period prior to 1920, and continuing up to about 1950, the waterway transportation and traffic system can be classified as "marginally sustainable". This classification is a result of system capacities that tended to exceed demands; however, the system was not particularly cost-effective or efficient, nor was it focused on minimizing externalities.

2. In the time period from 1950 to 2000, "non-sustainable" conditions were often experienced as a result of the construction of new infrastructure, demands that exceeded system capacities at numerous locations, and the use of auxiliary locks during repair and maintenance periods. In fact, due to the aging infrastructure, it can be anticipated that the "non-sustainable" conditions will continue into the future, and even further decline, in the absence of the system investment plan and its implementation. Regarding RFFAs, it is anticipated that the sustainability of the transportation and traffic system will improve as a result of navigation investment actions identified in this report.

FIGURE 10-16
ES of Transportation and Traffic System



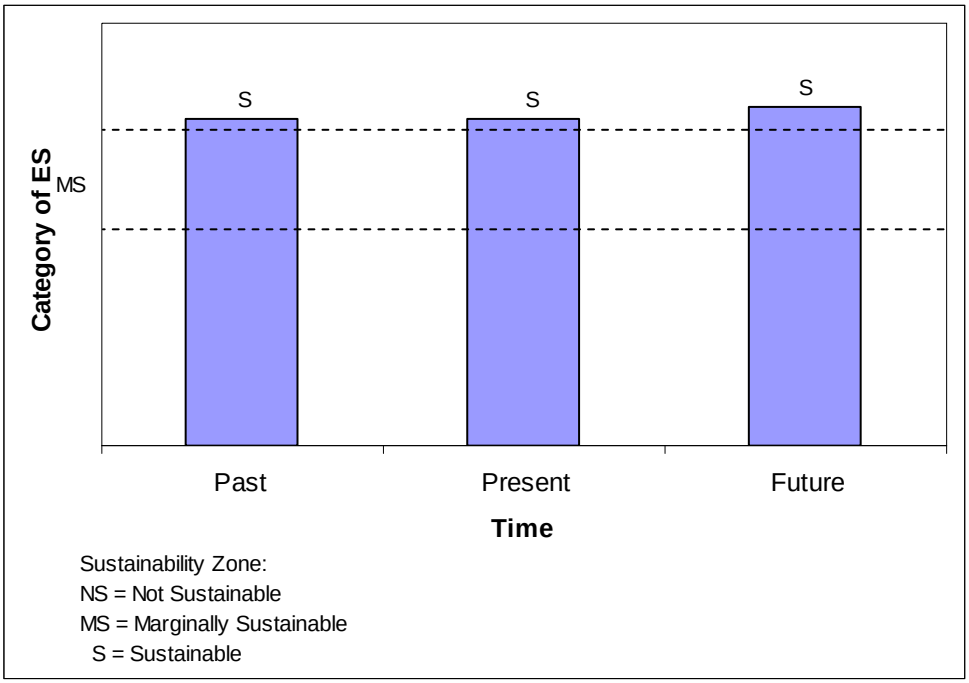
I. Socioeconomic Resources

1. Historic, present and future trends for socioeconomic resources in the Ohio River study area illustrate a pattern of increasing sustainability, related to population growth and conversion of natural resources and landscapes.

2. The past was characterized by rapid conversion of natural resources and landscapes to meet the industry and infrastructure demands of a rapidly expanding population. Although socioeconomic resources were generally sustainable, volatile patterns of explosive growth and recession cycles occurred such that the ES was somewhat less stable than in recent decades.

3. At present, the region offers a reasonably healthy mix of agriculture, varied industries, and commercial, financial, education, and health care services and is supported by a fully developed economic infrastructure. This economic infrastructure includes rail, highway, river and air transportation, modern communication capabilities, and affordable and reliable utilities, including coal fired electricity generation that depends directly on the river navigation system. The social system is equally well established, with a generally healthy, educated, and technically skilled population supported by an established network of urban, suburban, and rural communities.

Figure 10-17
ES of Socioeconomic Resources



4. In recent decades, improved water quality has contributed to increased redevelopment interest for many riverfront neighborhoods. Growing interest in environmental amenities within residential/commercial settings contributes to the design of community oriented restoration projects that combine floodplain functionality, aquatic and riparian habitat enhancement, open space, recreational activities, stormwater detention, and related functions within multi-purpose or integrated aquatic restoration projects.

5. Regarding RFFAs, the projected slow population growth and attendant slow growth of the economy allows for a gradual expansion from the existing infrastructure and an opportunity for relative economic stability in contrast to the 'boom and bust' patterns of the past century. The projected growth patterns may present opportunities to proceed with gradual and better planned processes of development and redevelopment serving the needs and interests of a stable and established population. This steady pattern for development should score higher for sustainability than the more volatile pattern of the past.

6. Further, ongoing investments in social and economic infrastructure should have a generally positive impact on socioeconomic resource values. For the Ohio River valley, most primary infrastructure investments have already been accomplished, including a complete system of interstate and other primary highway networks, railroads, river bridges, airports, locks and dams, levees and floodwalls. Expansion plans for infrastructure continue on the basis of projected demand or existing capacity expansion needs, but a relatively stable population for the foreseeable future should contribute to reduced demand for additional primary infrastructure. Future improvements to this system would focus primarily on maintenance, refinement, rehabilitation, improvement, or replacement of the existing inventory.

7. Lock extension/replacement, major rehabilitation, and ongoing maintenance/repair of existing locks would contribute to positive socioeconomics impacts for all segments of the population. Environmental Justice concerns were examined and it was determined that benefits would accrue to minority and low income populations in proportion to the overall population. Further, no minority or low income populations would be disproportionately impacted by system investments in navigation or environmental sustainability. Within the context of the larger economy of the Ohio River valley, these actions would contribute fairly small, but cumulative impacts. Long term growth of navigation traffic will require more tugs and barges in operation, more terminals and related port facilities, more maintenance dredging for expanded terminals, and expanded areas of fleeting operations. These expansions would convert existing floodplain lands (e.g., farmland, riparian woods, and wetlands) that now afford habitat protection, open space, and ecosystems values. Once converted, such lands are unlikely to revert to their former more natural states. Expansion of navigation infrastructure would also compete for space with expansion of riverfront industries, coal fired utilities, mining, and other commercial operations. Mixed-use urban waterfront developments, marinas, and other recreation-oriented developments would also compete for waterfront space. Waterfront development policies that support the conversion of brownfields, unused or underdeveloped terminals, or other underutilized industrial sites could help to minimize conversion impacts to existing agricultural uses or riparian habitats.

J. Cultural Resources

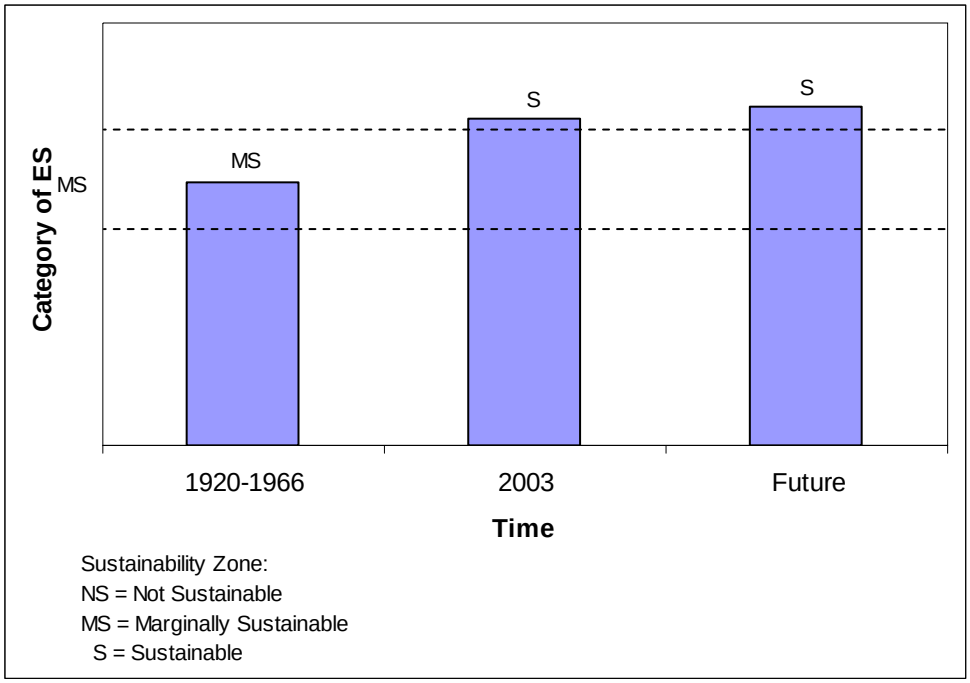
1. In the period from 1920 and continuing until passage of the National Historic Preservation Act of 1966 and other preservation acts later in the 20th century, limited measures were in place to preserve and protect cultural resources; most resources

remained unsurveyed. Widespread razing of potentially historic structures during this time is viewed by some State Historic Preservation Office (SHPO) professionals as having contributed to a decline such that cultural resources may overall have been at the "marginally sustainable" level.

2. The implementation of cultural resources legislation, including creation of the National Register of Historic Places (NRHP) and establishment of SHPOs, has heightened awareness of the need to preserve historic structures in communities along the Ohio River. Simultaneously, National Historic Preservation Act provisions that require consideration of cultural resources where federal involvement occurs have led to the discovery and preservation of previously unknown cultural resources. Accordingly, the ES classification for the current time is "sustainable."

3. Regarding RFFAs, federal and state regulations concerning cultural resources are expected to remain in place and help maintain a "sustainable" condition. The Corps has executed Memoranda of Agreements with all six SHPO offices that will direct cultural resource compliance for all work recommended in this report (See **Environmental Appendix**). Also, during each year of this study, additional resources have become eligible for possible placement on the NRHP, although some SHPO professionals have observed that numbers of NRHP candidate properties may be limited due to societal trends toward disposability, tear down, and sprawl. Additional riverfront development, including recreational areas may result in covering or damage to cultural resources near the land surface.

Figure 10-18
ES of Cultural Resources



Positive trends related to cultural resources include:

- the development of predictive models to determine probability for cultural resources occurrences.
- recent emphasis on context integration of historic districts.
- an increasing number of river festivals and other events through which residents of the Ohio River valley are rediscovering the rich cultural heritage of the river.

10.2.2.3. Interactions With Other Valued Environmental Components

1. Cumulative effects assessment not only considers past, present, and future conditions and trends for individual VECs, but also the interactions which may occur among VECs. Assessment of VEC interactions is prescribed in Step 8 of the CEQ Guidelines: Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities.

2. VEC interactions for the Ohio River mainstem were visualized by constructing a crosswalk of all potential interactions which were then ranked as high, medium, or low/no interactions, as shown in **Table 10-32.** Interactions rankings were based on information presented in individual VEC chapters of the CEA, as well as on best professional judgment of the project team members.

TABLE 10-32
Interactions Among VECS in the ORMSS CEA

VEC Interactions*	WQ & SQ	Fish	Mussels	Riparian/Floodplain Resources	Air	Health & Safety	Recreation	Transportation	Socioeconomics
Cultural Resources									H
Socioeconomics									
Transportation									
Recreation									
Health & Safety									
Air									
Riparian/Floodplain Resources									
Mussels									
Fish									

***Key to shading:**

High

Medium

Low or no interaction

10.2.2.4. ES OVERVIEW OF ALL VECS

1. Of 45 VEC interactions cross-referenced in the **Table 10-32**, 23 display a high level of interaction, 14 display medium interaction, and 8 potential interactions either have no or low interaction. The four VECS with the highest interaction levels are water & sediment quality (6 highs), recreation (7 highs), transportation (6 highs), and socioeconomics (6 highs). Other important VECs have fewer interactions in part because they are confined to only one environmental medium. Fish and mussels, for example, are confined to water and, accordingly, have very limited interaction with VECs such as air and cultural resources.

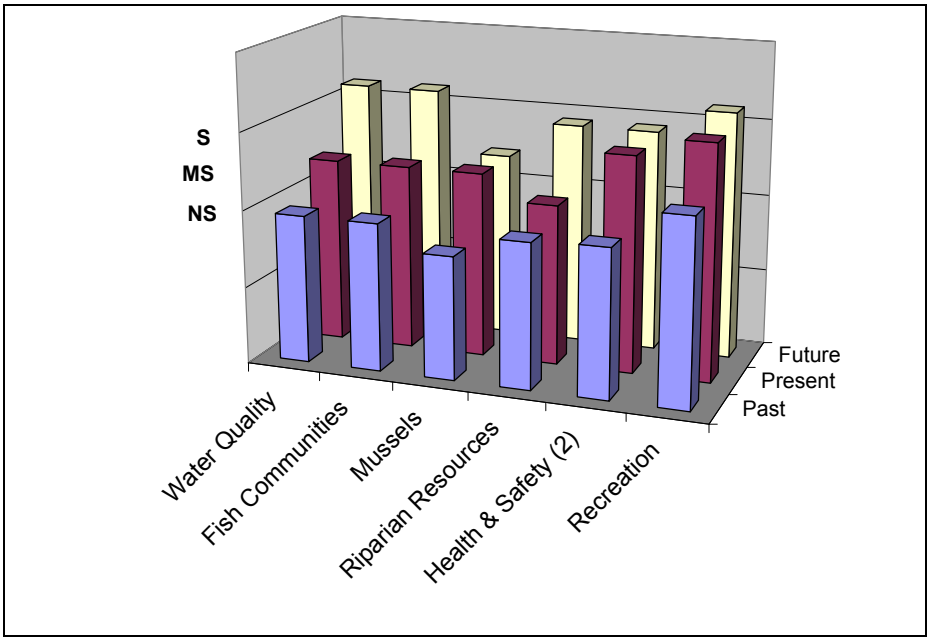
2. Combining ES classifications for individual VECs with interactions among VECs reveals an overview for all ten VECS discussed in the ORMSS CEA. In this context, ES values of certain VECs become important “drivers” that influence ES values

of other VECs in the overall system. Most notably, dramatic improvements in ES of the Water Quality VEC, subsequent to implementation of ORSANCO programs and the Clean Water Act, have driven the other components of the aquatic ecosystem of the Ohio River toward increased ES. The ES of fish has measurably improved, while ES of riparian resources and mussels have benefited to a lesser extent. Cleaner water and improved aquatic resources in turn have enhanced recreational boating and fishing on the mainstem and stimulated growth of related support facilities such as marinas. Cleaner water nationwide also has contributed to a trend toward increased development and use of trails, greenways and other recreational facilities along rivers, including the Ohio mainstem. Such recreation facilities often stimulate riverfront development, including restaurants and entertainment districts, which add to local economic growth, but concomitantly contribute to loss of riparian/floodplain resources and cultural resources.

3. Health & Safety represents a VEC with improved ES in recent decades (due to improved water quality and more stringent workplace regulations), but with the potential for its ES to be driven downward by complex interactions with other VECs. Possible growth of commercial navigation, recreational activity, river-oriented industries, and other river users will require vigilance in management and regulation of H&S issues just to maintain the status quo.

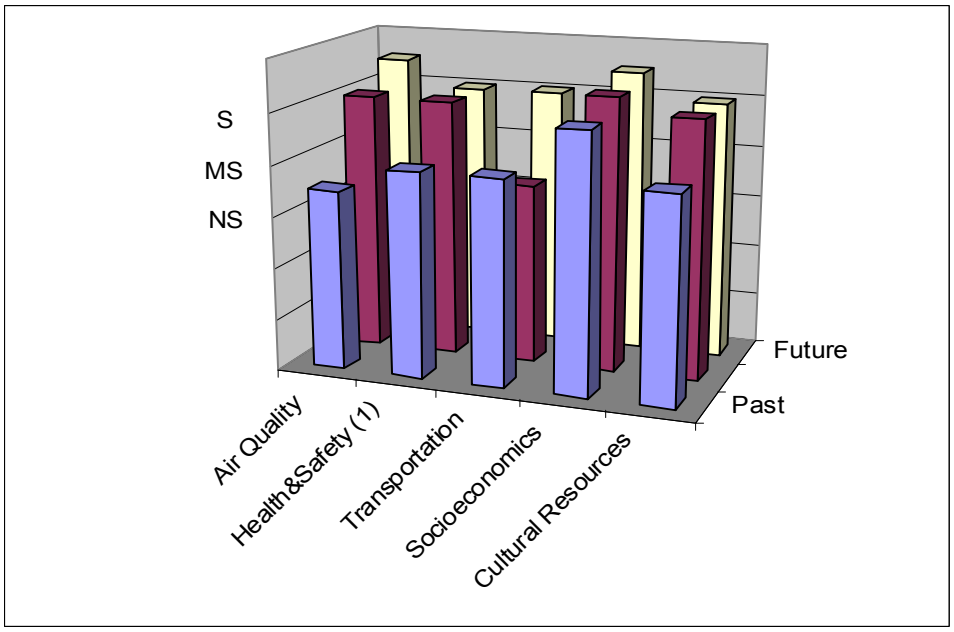
4. ES values of riparian/floodplain resources (RFR) and mussels are particularly confounding in part because of somewhat limited knowledge of these VECs. Regarding RFR, lack of knowledge until recently was correlated with the relatively low value assigned to these resources. Although interest in RFR has increased, these resources present a challenging complex of biogeochemical, hydrological, and ecological processes. Similarly, Ohio River mussels are challenging to study, despite the fact that information on Ohio River mussels has been collected since the 1800s. Scientists studying mussels are hampered not only by lack of knowledge of reproductive cycles and habitats needs, but also by increased water depths due to impoundment of the river and the lack of systematic monitoring of mussel resources. **Figures 10-19 and 10-20** depict past, present and future ES levels for all VECs.

FIGURE 10-19
ES Trends for VEC Group 1



Sustainability Scale: NS, values in the "not sustainable" range; MS, values in the "marginally sustainable" range; S, values in the "sustainable" range

FIGURE 10-20
ES Trends for VEC Group 2



Sustainability Scale: NS, values in the "not sustainable" range; MS, values in the "marginally sustainable" range; S, values in the "sustainable" range

10.2.3 Discussion of Direct and Secondary Influences

10.2.3.1 Eroded Savings

1. As noted in **Section 8** (WOPC) and earlier in this section (WPC), an economic metric, that also infers environmental consequences, is "eroded savings". This metric refers to reductions in system economic benefits resulting from unscheduled repairs at existing locks. Such repairs are expected to result in more queuing of on-river navigation traffic in the immediate downstream areas of locks subjected to such repairs. Navigation-related consequences of unscheduled repairs include increases in the number of transit days associated with the movement of goods within and through the system, and general reductions in the efficiency of the system. Environmental-related consequences of unscheduled repairs include local habitat reductions from queuing in the immediate downstream areas, and general environmental disruptions due to the specific activities associated with the repairs. The extent of queuing as well as the associated environmental consequences will be a function of the types and complexities of the unscheduled repairs.

2. **Table 10-33** summarizes the eroded savings metrics as contained in **Tables 8-8** (RMA), **10-6** (AMA), **10-9** (MRA), and **10-12** (LMA). These metrics are in millions of FY03 dollars, at a 5 1/8% discount rate, expressed on an average basis over the 2010-2070 study period. The data are displayed for each of the four navigation-related plans and each of the five navigation traffic scenarios. The table also includes summary information on unscheduled lock repair costs over the same study period. The following comments are relevant to the eroded savings data summarized in **Table 10.33**:

- For each of the traffic scenarios, the eroded savings decline as a function of the comprehensiveness of the navigation-related plan. For example, the least comprehensive plan (WOPC-RMA) has the highest eroded savings for each scenario, as well as the highest cost for unscheduled lock repairs. In contrast, the most comprehensive plan (WPC-LMA) includes all the measures in the RMA, AMA, and MRA alternatives. Thus, for every scenario, the LMA yields the lowest eroded savings and lowest cost for unscheduled lock repairs. Further, in relation to the other plans, the LMA minimizes the negative environmental effects of queuing and the activities related to unscheduled repairs.

- For each navigation-related plan, the eroded savings increase as a function of the traffic scenario. The scenarios are listed by increasing navigation traffic; e.g., the lowest traffic is for the Clear Skies scenario, while the highest traffic is for the Utility-Based High scenario. In general, the lowest cost for unscheduled repairs is associated with the Clear Skies scenario, while the highest is for one or more of the other scenarios.

- If eroded savings were the only factor to consider in identifying the "best" navigation-related plan, the LMA could be clearly identified as this best system investment plan.

TABLE 10-33
Summary of Eroded Savings and Direct Costs Resulting from Unscheduled Repairs[a]

Traffic Scenario	Navigation-Related Plan			
	WOPC (RMA)	WPC (AMA)	WPA (RMA)	WPC (LMA)
Clear Skies	75.8 (14.0)	17.6 (4.3)	17.6 (4.2)	12.9 (4.0)
Modified Clear Skies	119.8 (15.1)	74.4 (8.4)	62.7 (7.4)	20.7 (4.3)
NAAQS Growth	124.1 (15.0)	37.1 (5.0)	36.9 (4.8)	19.4 (4.2)
Utility Based	107.7 (14.7)	56.3 (7.6)	56.1 (7.3)	20.8 (4.2)
Utility Based High	120.3 (15.0)	61.2 (7.7)	61.5 (7.3)	23.6 (4.2)

[a] for each plan and scenario, the first number is eroded savings, the number in parenthesis is the cost for unscheduled lock repairs (average annual basis, 2010-2070, 5 1/8%, Million FY03 $)

10.2.3.2 Transit Time

1. A metric that can be used to reflect the efficiency of the navigation system relative to the movement of goods is average transit time expressed in days. **Figure 10-7** (see **Section 10.1.5.4**) displays transit days within the system versus the study time period from 2010 to 2070, averaged over all five traffic scenarios. The displayed transit days are the total days that all tows are expected to spend in transit on the river in a given year. These days are associated with the total annual tonnage on the river (**Figure 10-6**) and the associated equilibrium traffic relative to numbers of tows. The term "equilibrium traffic" reflects all the traffic that is moving on the system with a positive rate savings given the physical and hydrodynamics conditions. For a given time period (year), the physical conditions can be altered by conducting routine maintenance, advanced maintenance, major rehabilitation, and/or lock modernization projects at various locks within the system. When such projects require lock closures, they would tend to cause more queuing and thus increase annual transit days while they are occurring. Further, annual transit days could be influenced by naturally occurring hydrodynamic conditions (e.g., flooding). Flooding conditions would cause disruptions in routine lock operations, and thus local queuing in lock approach zones would be expected.

2. The top curve in **Figure 10-7** reflects the WOPC (RMA) navigation plan averaged over the five traffic scenarios. The overall increase over the study period is primarily reflective of both the increased tonnage moved on the river (**Figure 10-6**) and a greater number of reactive maintenance activities at all the locks on the system. The zigzag nature of the WOPC plan is indicative of both scheduled closures as well as unscheduled repair activities.

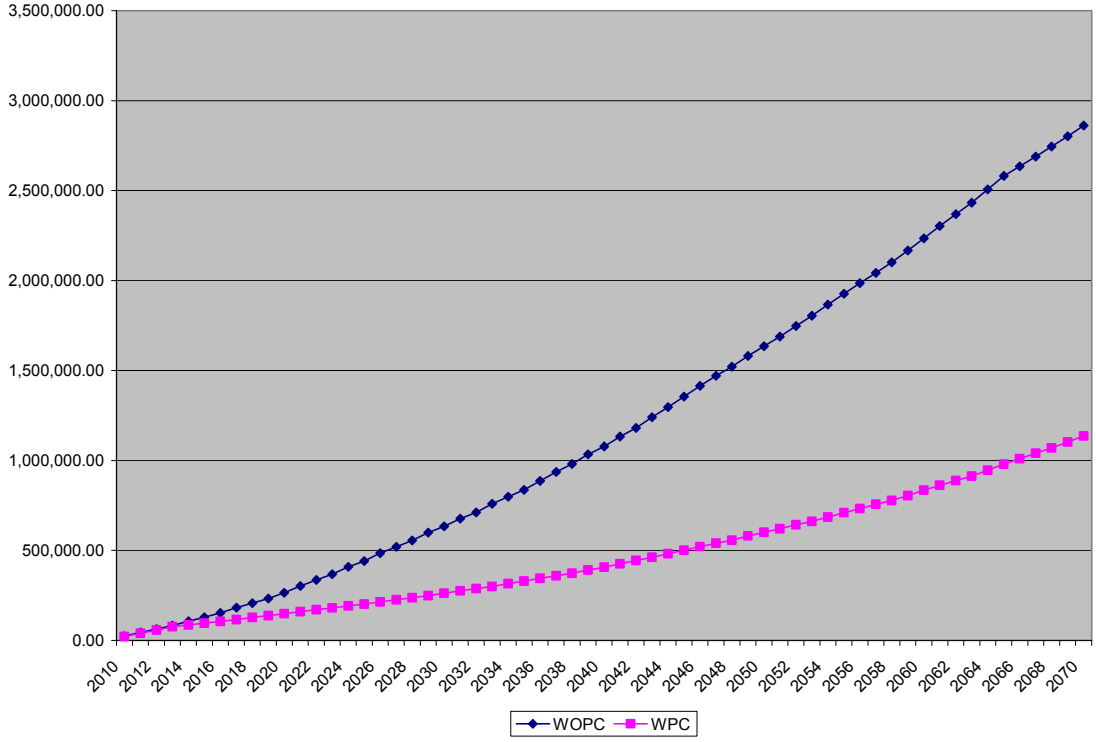
3. The bottom curve in **Figure 10-7** represents the most comprehensive of the WPC plans; namely, the LMA plan averaged over the five traffic scenarios. Further, it should be noted that this plan includes the measures from the RMA, advanced maintenance measures from the AMA, major rehabilitation projects from the MRA, and the lock extensions at EDM from the LMA. As can be seen, the annual cumulative system transit days for the WPC are considerably less than for the WOPC from about 2013 through 2070. The divergence in the WOPC and WPC data in 2013 is based on assumptions that the lock projects at EDM will be completed along with major rehabilitation projects at the Markland, Hannibal, Meldahl, and Myers locks. Because the scheduled improvement projects associated with the WPC increase reliability and, therefore, reduce closure, the zigzag pattern of the WOPC is not present.

4. The differences in the WOPC and WPC curves in **Figure 10-7** indicate that the WPC plan (LMA) will yield both a more efficient navigation system, as well as a system subject to lesser queuing and thus reduced negative effects in lock approach zones. In fact, the differences in annual cumulative transit days are not uniformly dispersed across the system; rather, they are exclusively due to queuing in the approach zones above and below the current lock and dam projects. Finally, the differences in annual system transit days range from about 15,500 in the 2015 to 2020 time period, to about 33,500 in the 2030 to 2070 time period.

5. **Figure 10-21** displays the year-to-year cumulative transit days for the WOPC (RMA) plan and the WPC (LMA) plan averaged over all five traffic scenarios. By progressively cumulating the annual system transit days across the study period, the zigzag pattern for the WOPC (RMA) plan, as shown in **Figure 10-7**, is essentially eliminated. As **Figure 10-21** illustrates, the differences in the WOPC and WPC cumulative transit days are about 116,000 by 2020; 372,000 by 2030; 671,000 by 2040; 1,034,000 by 2050; 1,400,000 by 2060; and 1,725,000 by 2070.

6. Accordingly, the progressive increase in transit days clearly illustrates important benefits of the WPC (LMA) plan relative to improvements in system navigation efficiency and reductions in queuing in important habitat areas in the approach zones of individual lock projects.

FIGURE 10-21
Cumulative Transit Days – WOPC vs. WPC

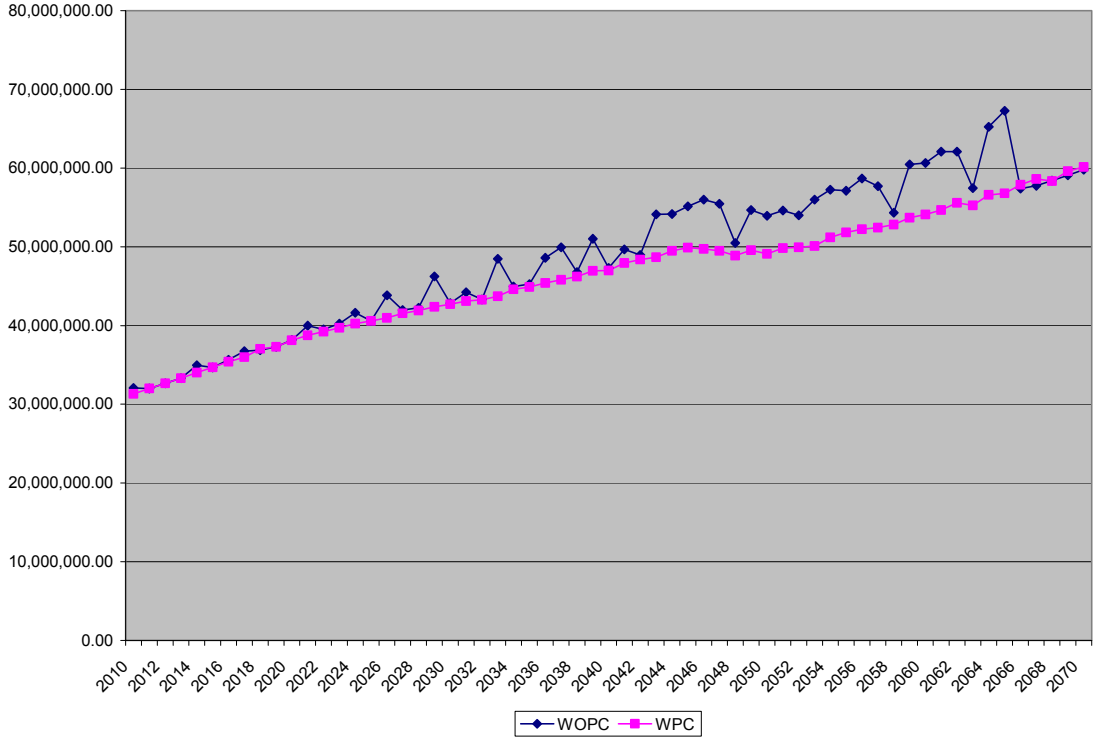


10.2.3.3 Diverted Traffic

1. An additional metric that can be used to reflect the efficiency of the navigation system relative to the movement of goods is illustrated by the concept of diverted traffic. This concept addresses freight that might have been moved on the Ohio River, but is diverted to rail or highway transportation. Calculations of diverted traffic over the study time period from 2010 to 2070 and averaged for all five traffic scenarios are presented in **Figure 10-22.**

2. **Figure 10-22** indicates that similar rates of diversion are estimated for both the WOPC and the WPC. Over the 60 year span of the study period, diverted tonnage under WOPC represents 15.35% of all traffic moved, while the WPC results in 14.41%. The improvements under WPC are attributable to greater transportation efficiencies that result from proactive maintenance, major rehabilitations, and new lock chambers at EDM. The cumulative benefit for the study period totals about 160 million tons of freight not diverted due to improved WPC efficiencies. This represents an annual average of 2.67 million tons, although as indicated in the figure, the model predicts diversions to occur as concentrated events reflecting intermittent periods of congestion and delay under the WOPC. Diverted tonnage attributed to WOPC represents about 5.4% of all diverted traffic or about 0.8% of total traffic moved on the river.

FIGURE 10-22
Tonnage Diverted from Ohio River



3. The environmental impacts of diverted traffic can be talked about in two contexts. One context focuses on impacts of moving the diverted freight by rail and highway modes. The other context looks at impacts to Ohio River VECs associated with traffic leaving the river.

4. With respect to traffic diverted to alternative modes, quantitative impacts would occur with increased fuel consumption, air emissions, deterioration of roads, increases in traffic-related injury, and corresponding increases in the delivery price of diverted materials. The cyclical nature of diverted traffic may contribute to temporary increases in highway congestion or slight delays in deliveries by rail. Since the WOPC predicts that reactive repairs will eventually restore functionality to the river transportation system, it seems unlikely that infrastructure expansions would occur in the rail or highway systems. However, electric utilities and other customers of river traffic may implement marginal expansions of storage yard capacities to compensate for periodic delivery disruptions.

5. Impacts to Ohio River VECs could include reduced impacts to aquatic and riparian resources attributable to reduced levels of construction induced queuing. Reduced air emissions and improved safety conditions in the lock approach areas would also result. Due to the cyclical nature of such diversions, permanent improvements to environmental sustainability factors would not be expected.

10.2.3.4 Construction Impacts Of WPC Alternatives

All WOPC and WPC alternatives will have some degree of construction impacts, including repairs that necessitate closure of main chambers and generate queuing impacts. On a comparative basis, all four alternatives are similar with respect to cyclical, reactive and/or advanced maintenance impacts. Two alternatives under the WPC additionally involve extensive construction activities that would have impacts on terrestrial and aquatic habitats. These alternatives are major lock rehabilitation (MRA) and lock modernization (LMA).

Impacts of Major Lock Rehabilitation

Major rehabilitations of locks would be projected to continue for about four years with the following anticipated impacts:

- Alteration of approximately 10 acres of terrestrial habitat to be used as a lay-down area during the rehabilitation. Clearing of vegetation will be required to prepare the lay-down area consisting of two esplanades, each approximately 150' by 1400' long. The actual size of the work area may vary somewhat based on the amount of land within a contractor's work limits, as well as the amount of government owned land available at the site.

- Approximately 1 acre of the above 10-acre site would permanently be impacted by the building of a construction office and assembly piers and the possible storage of materials removed during the rehabilitation. The remaining acreage not permanently affected could require decades to return to pre-disturbance conditions, unless revegetation to achieve a desired outcome is promptly implemented.

- Assuming the contractor needs an area to load and unload materials onto barges and to float in materials, approximately 400 ft. of bank would be disturbed during the four-year process.

- Dewatering of 600' x 110" lock chambers would affect approximately 3 acres of aquatic habitat for 5 months while dewatering of 1200' x 110' lock chambers would affect approximately 5 acres of aquatic habitat for 5 months.

Impacts of Lock Modernization

Lock modernization would last longer (up to 7 years) and involve larger impact areas than MRA, with impacts varying by site depending upon the quality and quantity of terrestrial and aquatic habitats present. The following discussion focuses on impacts anticipated during lock construction at Emsworth, Dashields and Montgomery (EDM) Locks in the upper Ohio River. Modernization of each of these three locks would involve creation of a new 600' x110' chamber where a 56' x 360' chamber presently exists.

Impacts of the EDM modernizations would be as follows:

- Terrestrial impacts could occur within a 100-acre work area. Although impacts may temporarily occur throughout the work area, approximately 11 acres would be directly affected temporarily for a lay-down area, batch plant, and material stockpiles. Another 20 acres would be expected to be permanently altered to serve as an excavation spoils area. Although such an area would be permanently affected, it could be revegetated to eventually restore terrestrial habitat.

- Approximately 100 linear feet of riverbank would be disturbed at each of the EDM sites. To remediate the site upon project completion, the bank may be riprapped beyond its present extent.

- The structural footprint of each new modernized lock, including the guide walls and fill, would permanently impact 2 1/2 acres of aquatic habitat – a net increase of about 1 acre from the 360' x 56' chamber. The 1 acre represents aquatic habitat lost because the area may be paved or cleaned to bedrock and will be subject to boat traffic, dredging, and constant fill and empty cycles.

- New locks will create 2 ½ acres of embayment area at each site. Aquatic habitat in these areas, between the guard wall and the riverbank, will be permanently impacted by altered flow, concentrated boat traffic, and regular dredging.

- During lock construction, a 4 to 4 ½ acre area is expected to be temporarily dewatered at each site, effectively removing the area as aquatic habitat during that time.

Lock Closures

Both major rehabilitation and lock modernization projects would require some degree of main chamber closure during the construction period. The total length of closure is a very site specific variable. A number of measures are employed to minimize the economic and environmental impacts of such closures. Before construction begins, the auxiliary chamber is inspected and repaired as necessary to ensure reliable operability for the duration of the construction effort. To the extent feasible, shorter closures are distributed throughout the construction period to avoid overlong or too frequent closures. Detailed estimates of the length and timing of such closures are developed during the site-specific feasibility studies. The schedule of closures is published and distributed to the transportation industry well ahead of time to facilitate planning on their part. Impacts associated with these closures would be more specifically addressed in site specific feasibility studies.

10.2.3.5 Expansion of Terminals and Fleeting Areas

10.2.3.5.1 Impacts of Intermodal Facilities

1. Intermodal facilities provide linkages between water and rail or ground transportation that extends commerce on the Ohio River far beyond the Ohio River Basin. The Corps' Inland Navigation Center surveyed intermodal facilities within the region to determine if any facilities would require expansion under various scenarios that could affect terrestrial or aquatic habitats.

2. Only one major facility responded to the survey; therefore, potential future impacts need to be interpolated from these data. Intermodal facilities would distribute large quantities of Powder River Basin coal to utility plants along the Ohio River if western coal is used in the future. Response to the Inland Navigation Center's survey indicates that during the ORMSS planning period additional ground capacity (in acres) for coal storage and additional fleeting area (in acres) capacity may be required. As **Tables 10-34 and 10-35** indicate, the amounts of additional storage and fleeting capacities vary by year and traffic scenario. The NAAQS scenario is predicted to require the largest cumulative increase in storage and fleeting capacities, while the Clear Skies scenario is predicted to require the smallest increase.

Table 10-34

Needed Additional Ground Capacity (Acres) from Current (2005) at One Facility					
	Utility-Based			Clear	Modified
Year	High	Utility-Based	NAAQS	Skies	Clear Skies
2010 0		0	10	0	10
2015 4		1	20	0	17
2020 7		4	27	5	24
2025 12		7	26	5	21
2030 16		10	28	5	23
2035 19		12	31	5	26
2040 24		15	35	5	29
2045 28		18	38	5	32
2050 26		16	38	5	32
2055 31		18	42	5	35
2060 36		21	45	5	38
Note:	Quantities were calculated assuming current use of 29 acres for ground storage.				

Table 10-35

Needed Additional Fleeting Capacity from Current (2005) at One Facility					
Year	Utility-Based High	Utility-Based	NAAQS	Clear Skies	Modified Clear Skies
2010	0	0 14		0	15
2015	6	2 30		0	26
2020	11	6 41		8	36
2025	18	11 39		8	32
2030	24	14 42		8	35
2035	29	18 47		8	39
2040	36	22 52		8	44
2045	42	26 57		8	49
2050	40	24 57		8	49
2055	46	28 62		8	53
2060	53	31 67		8	58
	Note:	Quantities were calculated assuming current use of 30 acres for fleeting area.			

3. The current Terminal ground storage capacity for coal is constrained, with expanded ground capacity needed now. **Table 10-35** also shows the need for additional fleeting capacity soon. Expansion of ground capacity would functionally remove any terrestrial habitat in the area affected. Expansion of fleeting areas would impair aquatic habitat with impacts varying relative to pre-existing habitat quality.

4. It is important to note the speculative nature of reporting the predictions of only one industrial facility. Growth projections based solely on that facility's mix of commodity shipping services are limited to a fairly short time horizon (approximately 20 years).

5. The survey also noted the presence of 2 or 3 additional multi-modal ports within the navigation systems whose operations would be influenced by freight demands on the Ohio River. As mentioned above, these ports did not respond to the survey.

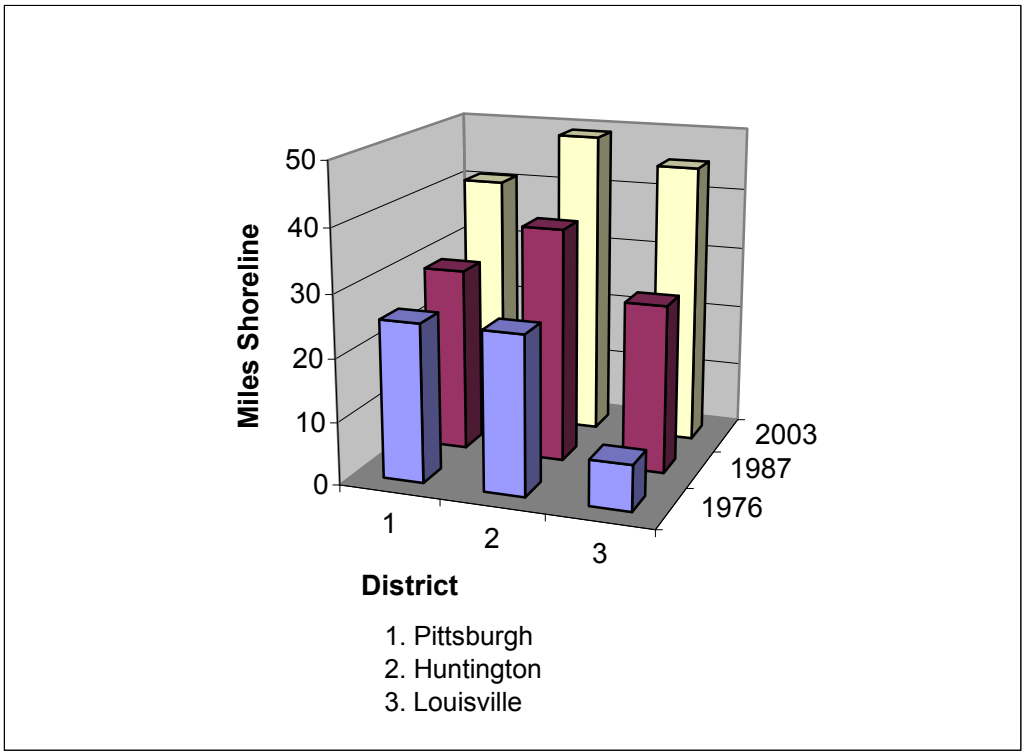
10.2.3.5.2 Fleeting Areas and Competing Uses of Ohio River Resources

1. Efforts to characterize historic trends on the Ohio River were carried out as part of the CEA and are summarized in the following section. By correlating past fleeting/terminals data with historic traffic, one can project future demand for fleeting/terminal space based on traffic projections.

2. The CEA study also considered the use of Corps issued permits (Sections 10 and 404) to track growth, distribution, and cumulative impacts of terminals and fleeting areas. Unfortunately, long term records of issued permits are not maintained, preventing use of this approach to establish historic trends. In the future, appropriate data from permits could be assimilated in a central database for all inland navigation activities. This would greatly improve the Corps' ability to monitor the cumulative impacts of navigation.

3. In addition to the size and number of barges and towboats on the river, the industry requires space for terminals and fleeting activities. Barge and tow activity is reflected in records of net tonnage of commerce shipped on the river (see Section 4). These records provide a detailed history of the growth and distribution of commercial navigation, and an indirect indicator of the growth of shipping infrastructure needed to sustain commercial expansion. Areas devoted to fleeting and terminal activity can also be calculated from Ohio River Navigation Charts. These records are displayed in **Figure 10-23**.

FIGURE 10-23
Mapped Fleeting Areas on the Ohio River



Source: U.S. Army Corps of Engineers, Navigation Charts

4. For the total river, areas devoted to fleeting have increased by 233 per cent from 1976 to 2003. As of 2003, 135 miles of shoreline were used for fleeting activities,

representing 6.9% of the Ohio River's total shoreline (981 miles x 2). The rate of increase has been steepest on the lower half of the river; fleeting areas have increased by over 600% in the Louisville District. Shoreline mileage utilized for fleeting activities on the Ohio River is summarized below in **Table 10-36.** It should also be noted that if expansion of these facilities become cost prohibitive in the future, the infrastructure currently in place is probably adequate to handle most future demand through increased efficiencies.

TABLE 10-36
Miles of Fleeting Activity on the Ohio River

Year	Pittsburgh District	Huntington District	Louisville District	Total
1976	25.3	25.3	7.3	57.9
1987	29.4	37.4	26.8	93.6
2003	40.7	49.1	45.1	134.9

Source: U.S. Army Corps of Engineers Navigation Charts

10.2.3.6 SUMMARY OF NAVPAT ANALYSES

1. The Corps has conducted substantial research on the potential for commercial tows to disturb bottom substrates and interfere with fish reproduction, recruitment, and feeding. To address these potential incremental biological effects of various navigation planning scenarios, more than 20 years ago the Louisville District developed the Navigation Predictive Analysis Technique (NAVPAT). Since its inception, many refinements have been made to the NAVPAT model in efforts to yield the most useful and accurate information. The 2005 version of NAVPAT was used in the ORMSS. Details related to the NAVPAT study and findings are in the **Environmental Appendix** under the title "NAVPAT Application to the Ohio River Mainstem Systems Study and the Evaluation of NAVPAT Relationships".

2. The goal of NAVPAT is to provide quantitative results, which can be used to assess positive or negative effects of tow movement on available aquatic habitat quality for a river reach or a specific area of a river cross-section (called a "cell"). Although NAVPAT focuses on certain fish species and their life stages, NAVPAT does not provide specifics on the response of any particular species. Instead NAVPAT generally links tow movements to possible habitat effects. The habitat relationships in NAVPAT were developed by an interdisciplinary team, comprised primarily of biologists from the US Fish & Wildlife Service (USFWS) and state natural resource agencies. NAVPAT outputs provide quantitative values of projected environmental effects of various navigation proposals at one or more time intervals in units that are habitat-based and essentially "habitat units".

10.2.3.6.1 Input Considerations

1. **Table 10-37** presents the fish life stages used in the ORMSS study, the identifying number each stage is assigned in NAVPAT, the rationale for species selection, and the potential impacts of concern.

TABLE 10-37
Fish Life Stages Selected for Ohio River NAVPAT Model

Fish Species	Life Stages of Concern (NAVPAT number)	Rationale for Species Selection	Potential Impacts of Concern
Emerald Shiner	Spawning (1) ES(s) Fry (2) ES(f)	Represents open water spawners in areas of lower ambient current velocity and fry with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of non-adhesive eggs as water velocity increases with tow passage 2) Destruction of fry caused by entrainment through propellers or associated pressure and turbulence
Paddlefish	Spawning (3) P(s) Larval stage (4) P(l)	Represents open water spawners in areas of moderate ambient current velocity and fry with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of adhesive eggs as water velocity increases with tow passage 2) Destruction of fry caused by entrainment through propellers or associated pressure and turbulence
Freshwater Drum	Egg/larval stages (6) FD(l)	Represents open water spawners in almost any portion of a river and adults that feed on organisms found in bottom sediments	1) Destruction of egg/larval stages caused by entrainment through propellers or associated pressure and turbulence 2) Dislodgment of substrates caused by water velocity from tow passage
Sauger	Spawning (7) S(s) Larval stage (8) S(l)	Represent spawners in relatively high ambient current in areas with coarse substrate and larvae that move to areas of lower ambient current velocity with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of adhesive eggs as water velocity increases with tow passage and/or abrasion of eggs due to substrate scouring 2) Destruction of larvae caused by entrainment through propellers or associated pressure and turbulence
Spotted Bass	Spawning (14) SB(s)	Represents nest spawners in moderate depth water with coarse substrates and juveniles that feed significantly on small	1) Dislodgment of eggs from nests because of water velocity increases with tow passage and vulnerability of eggs to predation 2) Disturbance of substrate

		benthic invertebrates	that could reduce the availability of aquatic insects on which these fish feed
SOURCE: U.S. Army Corps of Engineers, Environmental Effects of Commercial Navigation Traffic – McAlpine Lock and Dam Project, NAVPAT and QUEPAT (not dated).			

2. The NAVPAT traffic scenarios were based on five detailed lock-level traffic demand forecasts the Corps has developed for the Ohio River. These scenarios include potential impacts of concern. The developed habitat relationships for each species/life stage were inputs to the NAVPAT study. The three other primary NAVPAT inputs were:

- river reach characteristics – including information describing multiple reaches of a river which share basic aquatic habitat conditions; i.e., reaches with similar bathymetry, substrate, depth, and velocity profiles

- economic scenarios – including data on various navigation forecasts, as well as data simulating various tows by length, width, speed, travel direction, horsepower, propeller dimensions, and other measurable characteristics, and utility coal forecasts that reflect the effects of coal source switching by electric utilities to comply with existing or proposed environmental regulations.

- physical forces – including information about several types of hydraulic forces generated by tows moving through a waterway. NAVPAT is best used in primary navigation channels as flows in side channels are significantly more complex and not within the scope of the present model.

3. The actual input files for the NAVPAT model included river cross-section data files, river tow traffic files corresponding to the given traffic scenarios, tow position frequency files, and river stage and discharge data files. Section IV of the above-mentioned NAVPAT appendix describes the specific methods used for collection of substrate, bathymetry, and shoreline structure data. Further, detailed information is included on the creation of bathymetry/cell files, traffic files, sailing lines and tow positions, and stage and discharge files.

10.2.3.6.2 Output Features

The habitat relationships for the five species and eight life stages listed in **Table 10-37** yield a qualitative index of the "suitability" of each cell for providing the needed habitat for the species/life stages. These HSIs (habitat suitability indices) range from 0 (no quality) to 1 (optimum quality). When the cell's HSI for a species/life stage is multiplied by the area of the cell (in acres), the product is termed Habitat Units (HUs). Accordingly, HUs can be considered as acres of habitat of some level of suitability for the species/life stage. Such HUs have been displayed by species/life stages for pools upstream of each of the 20 current locks and dams, for three river reaches (upper, middle, and lower), and for the entire Ohio River mainstem.

10.2.3.6.3 Discussion of Results

1. The composited river reach HUs for the five species and eight life stages are displayed in **Figure 10-24** and **Table 10-38**. The displayed HUs are for the navigation traffic associated with the Without Project Conditions (WOPC) in 2010. The WOPC, also known as the Reactive Maintenance Alternative (RMA), is described in Section 8. Accordingly, the WOPC in 2010 reflects the "baseline condition" for comparing the HUs for future WOPC and With Project Conditions (WPC). The WPC is described in Section 9. The Upper River segment extends from the Emsworth pool at RM 0 to the Greenup Lock and Dam at RM 341. The Middle River segment continues from the Greenup Lock and Dam to the McAlpine Lock and Dam at RM 607. The Lower River segment extends from RM 607 to the confluence with the Mississippi River at RM 981. The following observations can be made in relation to **Figure 10-24**:

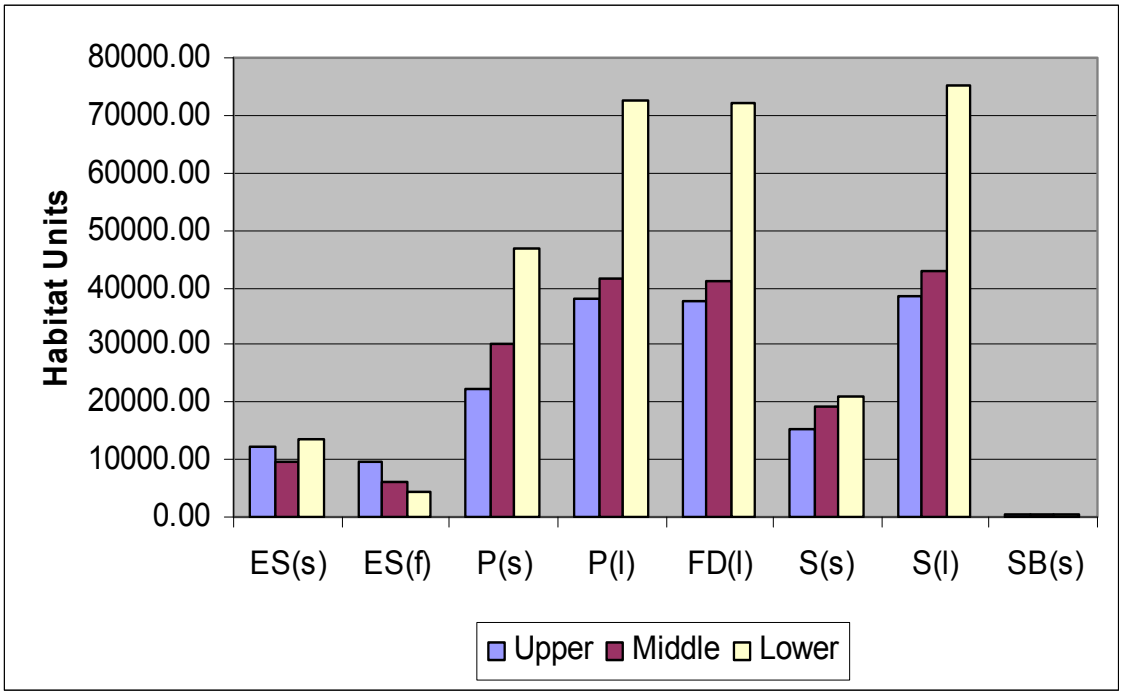
- The HUs for Paddlefish-Larval, Freshwater Drum-Larval, and Sauger-Larval demonstrate similar levels (about 38,000 to 42,000) for the Upper and Middle segments, as well as similar levels (about 72,000 to 75,000) for the Lower segment. Although at different HU levels, these patterns are also seen for Paddlefish-Spawning and Sauger-Spawning.

- The HUs for Emerald Shiner-Spawning are at similar levels (about 10,000 to 13,000) for all three segments. For Emerald Shiner-Fry, the HUs decrease from the Upper segment (about 10,000 HUs) to the Lower segment (about 4,000 HUs).

- The HUs for Spotted Bass-Spawning are considerably less than 1000 for all three segments (about 560, 290, and 290 for the Upper, Middle, And Lower segments, respectively).

- In general, **Figure 10-24** illustrates that HUs vary relative to both species and life stages for individual species. Further, the HUs increase from the Upper to Middle to Lower segments of the River. One possible explanation is related to the more narrow width and higher water velocities in the Upper segment in comparison to the other two segments.

FIGURE 10-24
Distribution of Without Project Habitat



See Table 10-37 for definition of species/life stages.

TABLE 10-38
Total HUs for Ohio River Mainstem (2010, WOPC, eight species/life stages)

Fish Species/ Life Stage	HUs			Total HUs
	Upper	Middle	Lower	
ES(s)	12,144	9,424	13,728	35,296
Emerald Shiner (spawning)				
ES(f)	9,624	5,877	4,255	19,756
Emerald Shiner (fry)				
P(s)	22,323	30,322	46,882	99,527
Paddlefish (spawning)				
P(l)	38,637	40,863	72,384	151,884
Paddlefish (larval)				
FD(l)	38,287	40,892	72,280	151,459
Freshwater Drum (larval)				
S(s)	15,330	19,164	21,089	55,583
Sauger (spawning)				
S(l)	39,099	42,399	75,312	156,810
Sauger (larval)				
SB(s)	559	289	291	1,139
Spotted Bass (spawning)				

- The HUs for Emerald Shiner-Spawning are at similar levels (about 10,000 to 13,000) for all three segments. For Emerald Shiner-Fry, the HUs decrease from the Upper segment (about 10,000 HUs) to the Lower segment (about 4,000 HUs).

- The HUs for Spotted Bass-Spawning are considerably less than 1000 for all three segments (about 560, 290, and 290 for the Upper, Middle, And Lower segments, respectively).

- In general, **Figure 10-24** illustrates that HUs vary relative to both species and life stages for individual species. Further, the HUs increase from the Upper to Middle to Lower segments of the River. One possible explanation is related to the more narrow width and higher water velocities in the Upper segment in comparison to the other two segments.

- Finally, it should be noted that the HUs in **Figure 10-24** are not reflective of the pre-navigation conditions of the Ohio River. Rather, they represent a river navigation condition at a point in time (2010). Nevertheless, these conditions can be used as "benchmarks" to examine the differences in HUs of WOPC and WPC at common points in time, and the differences of each condition over time.

2. As mentioned earlier, the focus of the NAVPAT study was the differences in HUs between the WOPC and the WPC. Such differences can be reflected in both HUs (delta) and the percentage change from the WOPC HUs (% delta). **Tables 10-39** through **10-41** contain the consolidated results for the Upper, Middle, and Lower river segments

under the five traffic scenarios and three selected years (2010, 2040, and 2070). The included results for the species/life stages are composites of the findings for all the pools in the respective segments. Detailed tabular and graphical information for each pool is contained in the above-mentioned Environmental Appendix.

3. To provide a basis for the examination of the delta values in **Tables 10-39** through **10-41**, the values can be considered in relation to the "2010- WOPC" total HUs for the individual species/life stage for all three reaches. These totals are summarized in **Table 10-38**; and they are also shown in **Figure 10-24**. The % delta numbers can be considered in two groups – those indicating less than a 3% change, either negative or positive; and those indicating a 3% or greater change.

4. The 3% threshold was selected based on a 2005 NAVPAT study of the Winfield Pool on the Kanawha River, and on the professional experience of Engineer Research and Development Center (ERDC) scientists and ORMSS biologists familiar with both the species habitat models and the assumptions and uncertainties associated with NAVPAT. Essentially, changes less than 3% are considered to be within the "statistical noise and variability" of the model results; thus, based on the current NAVPAT model, the forecasted changes do not represent actual anticipated changes that would be of concern. In contrast, changes of 3% or greater can be indicative of potential changes that should be considered in current decision making.

TABLE 10-39
NAVPAT Traffic Impacts Upper Ohio River

Fish Species/ Life Stage[1]	Traffic Forecast Scenario	2010				2040				2070				2010-2070			2010-2070		
		Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
ES(s)	Clear Sky w/Hg	12272.56	12240.45	-32.1	-0.26%	12076.2	12111.11	34.9	0.29%	11977.06	11958.25	-18.8	-0.16%	12272.56	11977.06	-2.41%	12240.45	11958.25	-2.31%
1	Clear Sky wo/Hg	11979.55	12076.59	97.0	0.81%	11828.6	11860.23	31.6	0.27%	11721.05	11715.82	-5.2	-0.04%	11979.55	11721.05	-2.16%	12076.59	11715.82	-2.99%
	NAAQS	12078.60	12057.58	-21.0	-0.17%	11760.9	11784.29	23.4	0.20%	11657.51	11680.62	23.1	0.20%	12078.60	11657.51	*-3.49%*	12057.58	11680.62	*-3.13%*
	Utility Based (Coal)	12194.56	11898.47	-296.1	*-2.43%*	11853.4	11888.72	35.4	0.30%	11712.96	11668.38	-44.6	-0.38%	12194.56	11712.96	*-3.95%*	11898.47	11668.38	-1.93%
	Utility Based High	12194.56	11898.47	-296.1	*-2.43%*	11742.6	11755.55	12.9	0.11%	11619.91	11562.96	-56.9	-0.49%	12194.56	11619.91	*-4.71%*	11898.47	11562.96	-2.82%
ES(f)	Clear Sky w/Hg	9769.41	9769.73	0.3	0.00%	9441.0	9472.74	31.7	0.34%	9367.06	9342.03	-25.0	-0.27%	9769.41	9367.06	*-4.12%*	9769.73	9342.03	*-4.38%*
2	Clear Sky wo/Hg	9357.79	9538.40	180.6	1.93%	9269.2	9243.68	-25.5	-0.27%	8967.24	8964.67	-2.6	-0.03%	9357.79	8967.24	*-4.17%*	9538.40	8964.67	*-6.01%*
	NAAQS	9529.03	9462.67	-66.4	-0.70%	9120.7	9105.95	-14.7	-0.16%	8933.65	8858.50	-75.2	-0.84%	9529.03	8933.65	*-6.25%*	9462.67	8858.50	*-6.38%*
	Utility Based (Coal)	9731.31	9359.69	-371.6	*-3.82%*	9314.1	9350.43	36.4	0.39%	9017.18	8997.97	-19.2	-0.21%	9731.31	9017.18	*-7.34%*	9359.69	8997.97	*-3.86%*
	Utility Based High	9731.31	9359.69	-371.6	*-3.82%*	9107.9	9118.18	10.3	0.11%	8876.71	8877.61	0.9	0.01%	9731.31	8876.71	*-8.78%*	9359.69	8877.61	*-5.15%*
P(s)	Clear Sky w/Hg	22806.87	22491.29	-315.6	-1.38%	22342.5	22283.83	-58.7	-0.26%	22344.07	22351.69	7.6	0.03%	22806.87	22344.07	-2.03%	22491.29	22351.69	-0.62%
3	Clear Sky wo/Hg	22119.31	22159.45	40.1	0.18%	22162.7	22066.27	-96.5	-0.44%	21869.02	22047.77	178.8	0.82%	22119.31	21869.02	-1.13%	22159.45	22047.77	-0.50%
	NAAQS	22271.25	22383.45	112.2	0.50%	22271.2	22213.87	-57.4	-0.26%	22042.46	22026.19	-16.3	-0.07%	22271.25	22042.46	-1.03%	22383.45	22026.19	-1.60%
	Utility Based (Coal)	22210.03	22270.08	60.0	0.27%	21954.9	22020.78	65.9	0.30%	21878.24	21833.21	-45.0	-0.21%	22210.03	21878.24	-1.49%	22270.08	21833.21	-1.96%
	Utility Based High	22210.03	22270.08	60.0	0.27%	21910.8	21917.27	6.5	0.03%	21844.70	21738.84	-105.9	-0.48%	22210.03	21844.70	-1.64%	22270.08	21738.84	-2.39%
P(l)	Clear Sky w/Hg	40019.14	39609.24	-409.9	-1.02%	37932.7	37988.67	56.0	0.15%	37322.97	37502.49	179.5	0.48%	40019.14	37322.97	*-6.74%*	39609.24	37502.49	*-5.32%*
4	Clear Sky wo/Hg	37277.97	37984.95	707.0	1.90%	36074.7	36375.24	300.5	0.83%	35038.74	35098.77	60.0	0.17%	37277.97	35038.74	*-6.01%*	37984.95	35098.77	*-7.60%*
	NAAQS	38035.08	37834.37	-200.7	-0.53%	36007.4	36114.31	106.9	0.30%	34766.22	34955.97	189.8	0.55%	38035.08	34766.22	*-8.59%*	37834.37	34955.97	*-7.61%*
	Utility Based (Coal)	38925.22	37364.69	-1560.5	*-4.01%*	36593.4	36875.42	282.0	0.77%	35174.80	34825.12	-349.7	-0.99%	38925.22	35174.80	*-9.63%*	37364.69	34825.12	*-6.80%*
	Utility Based High	38925.22	37364.69	-1560.5	*-4.01%*	35699.1	35756.37	57.2	0.16%	34099.13	33889.70	-209.4	-0.61%	38925.22	34099.13	*-12.40%*	37364.69	33889.70	*-9.30%*
FD(l)	Clear Sky w/Hg	39187.47	38982.95	-204.5	-0.52%	37321.5	37579.47	257.9	0.69%	36368.16	36400.04	31.9	0.09%	39187.47	36368.16	*-7.19%*	38982.95	36400.04	*-6.63%*
6	Clear Sky wo/Hg	36866.71	38105.86	1239.1	**3.36%**	35930.3	36315.65	385.3	1.07%	34111.63	33831.66	-280.0	-0.82%	36866.71	34111.63	*-7.47%*	38105.86	33831.66	*-11.22%*
	NAAQS	37434.41	37174.71	-259.7	-0.69%	35280.3	35284.27	4.0	0.01%	33812.43	33824.93	12.5	0.04%	37434.41	33812.43	*-9.68%*	37174.71	33824.93	*-9.01%*
	Utility Based (Coal)	38972.77	36708.83	-2263.9	*-5.81%*	35641.4	36275.93	634.5	1.78%	34018.50	33501.55	-517.0	-1.52%	38972.77	34018.50	*-12.71%*	36708.83	33501.55	*-8.74%*
	Utility Based High	38972.77	36708.83	-2263.9	*-5.81%*	34862.9	34962.54	99.7	0.29%	32945.65	32844.08	-101.6	-0.31%	38972.77	32945.65	*-15.46%*	36708.83	32844.08	*-10.53%*
S(s)	Clear Sky w/Hg	15708.68	15662.91	-45.8	-0.29%	15263.3	15217.38	-45.9	-0.30%	15234.51	15183.88	-50.6	-0.33%	15708.68	15234.51	*-3.02%*	15662.91	15183.88	*-3.06%*
7	Clear Sky wo/Hg	14913.27	15073.02	159.7	1.07%	14995.6	14949.79	-45.8	-0.31%	14701.46	14757.59	56.1	0.38%	14913.27	14701.46	-1.42%	15073.02	14757.59	-2.09%
	NAAQS	15292.36	15244.76	-47.6	-0.31%	14919.1	14943.34	24.3	0.16%	14930.54	14755.79	-174.7	-1.17%	15292.36	14930.54	-2.37%	15244.76	14755.79	*-3.21%*
	Utility Based (Coal)	15368.98	15369.14	0.2	0.00%	14948.5	15067.31	118.8	0.79%	14830.27	14646.25	-184.0	-1.24%	15368.98	14830.27	*-3.51%*	15369.14	14646.25	*-4.70%*
	Utility Based High	15368.98	15369.14	0.2	0.00%	14701.9	14889.04	187.2	1.27%	14706.62	14699.75	-6.9	-0.05%	15368.98	14706.62	*-4.31%*	15369.14	14699.75	*-4.36%*
S(l)	Clear Sky w/Hg	40626.31	39708.11	-918.2	*-2.26%*	39325.9	39301.92	-24.0	-0.06%	38473.62	38786.44	312.8	0.81%	40626.31	38473.62	*-5.30%*	39708.11	38786.44	*-2.32%*
8	Clear Sky wo/Hg	38432.39	38305.26	-127.1	-0.33%	37297.0	37150.01	-147.0	-0.39%	35648.17	35841.24	193.1	0.54%	38432.39	35648.17	*-7.24%*	38305.26	35841.24	*-6.43%*
	NAAQS	38608.03	38844.22	236.2	0.61%	37302.5	37067.13	-235.4	-0.63%	35572.22	35495.75	-76.5	-0.21%	38608.03	35572.22	*-7.86%*	38844.22	35495.75	*-8.62%*
	Utility Based (Coal)	38914.43	38921.29	6.9	0.02%	37819.4	37976.95	157.6	0.42%	36090.98	35870.30	-220.7	-0.61%	38914.43	36090.98	*-7.26%*	38921.29	35870.30	*-7.84%*
	Utility Based High	38914.43	38921.29	6.9	0.02%	36912.9	37181.24	268.4	0.73%	35798.58	35118.93	-679.6	-1.90%	38914.43	35798.58	*-8.01%*	38921.29	35118.93	*-9.77%*
SB(s)	Clear Sky w/Hg	586.51	586.59	0.1	0.01%	528.9	531.54	2.7	0.50%	538.35	545.22	6.9	1.28%	586.51	538.35	*-8.21%*	586.59	545.22	*-7.05%*
14	Clear Sky wo/Hg	522.04	514.93	-7.1	-1.36%	475.3	469.22	-6.1	-1.28%	441.24	441.27	0.0	0.01%	522.04	441.24	*-15.48%*	514.93	441.27	*-14.31%*
	NAAQS	539.86	540.45	0.6	0.11%	460.6	467.18	6.6	1.43%	441.59	436.28	-5.3	-1.20%	539.86	441.59	*-18.20%*	540.45	436.28	*-19.27%*
	Utility Based (Coal)	572.74	554.97	-17.8	*-3.10%*	514.6	516.13	1.6	0.30%	478.36	469.55	-8.8	-1.84%	572.74	478.36	*-16.48%*	554.97	469.55	*-15.39%*
	Utility Based High	572.74	554.97	-17.8	*-3.10%*	503.9	501.25	-2.6	-0.52%	436.93	453.34	16.4	**3.76%**	572.74	436.93	*-23.71%*	554.97	453.34	*-18.31%*

Note: Positive % Delta >/= 3.0 in **bold**, negative % Delta </= -3.0 in *italic*

TABLE 10-40
NAVPAT Traffic Impacts Middle Ohio River

Fish Species/ Life Stage[1]	Traffic Forecast Scenario	2010				2040				2070				2010-2070			2010-2070		
		Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
ES(s)	Clear Sky w/Hg	9445.39	9432.28	-13.1	-0.14%	9380.2	9404.34	24.2	0.26%	9321.78	9292.59	-29.2	-0.31%	9445.39	9321.78	-1.31%	9432.28	9292.59	-1.48%
1	Clear Sky wo/Hg	9408.03	9407.90	-0.1	0.00%	9278.6	9364.97	86.4	0.93%	9171.98	9196.66	24.7	0.27%	9408.03	9171.98	-2.51%	9407.90	9196.66	-2.25%
	NAAQS	9419.25	9396.92	-22.3	-0.24%	9302.9	9342.72	39.8	0.43%	9164.65	9207.01	42.4	0.46%	9419.25	9164.65	-2.70%	9396.92	9207.01	-2.02%
	Utility Based (Coal)	9423.80	9271.68	-152.1	-1.61%	9251.3	9253.74	2.5	0.03%	9229.99	9137.48	-92.5	-1.00%	9423.80	9229.99	-2.06%	9271.68	9137.48	-1.45%
	Utility Based High	9423.80	9271.68	-152.1	-1.61%	9260.5	9223.90	-36.6	-0.40%	9173.47	9232.71	59.2	0.65%	9423.80	9173.47	-2.66%	9271.68	9232.71	-0.42%
ES(f)	Clear Sky w/Hg	5897.70	5897.65	-0.1	0.00%	5812.9	5812.00	-0.9	-0.02%	5750.76	5740.36	-10.4	-0.18%	5897.70	5750.76	-2.49%	5897.65	5740.36	-2.67%
2	Clear Sky wo/Hg	5882.98	5979.36	96.4	1.64%	5679.4	5796.38	117.0	2.06%	5624.24	5661.09	36.8	0.66%	5882.98	5624.24	*-4.40%*	5979.36	5661.09	*-5.32%*
	NAAQS	5907.47	5858.14	-49.3	-0.84%	5699.1	5712.94	13.9	0.24%	5656.10	5715.37	59.3	1.05%	5907.47	5656.10	*-4.26%*	5858.14	5715.37	-2.44%
	Utility Based (Coal)	5847.57	5765.88	-81.7	-1.40%	5585.6	5660.22	74.6	1.34%	5533.11	5484.33	-48.8	-0.88%	5847.57	5533.11	*-5.38%*	5765.88	5484.33	*-4.88%*
	Utility Based High	5847.57	5765.88	-81.7	-1.40%	5611.9	5652.49	40.6	0.72%	5429.38	5488.38	59.0	1.09%	5847.57	5429.38	*-7.15%*	5765.88	5488.38	*-4.81%*
P(s)	Clear Sky w/Hg	30348.12	30292.82	-55.3	-0.18%	30075.8	30061.83	-13.9	-0.05%	29989.64	30022.26	32.6	0.11%	30348.12	29989.64	-1.18%	30292.82	30022.26	-0.89%
3	Clear Sky wo/Hg	30260.06	30164.57	-95.5	-0.32%	30139.2	30124.45	-14.8	-0.05%	29803.24	29959.62	156.4	0.52%	30260.06	29803.24	-1.51%	30164.57	29959.62	-0.68%
	NAAQS	30300.24	30420.70	120.5	0.40%	30120.3	29989.29	-131.0	-0.44%	29884.29	29746.39	-137.9	-0.46%	30300.24	29884.29	-1.37%	30420.70	29746.39	-2.22%
	Utility Based (Coal)	30349.91	30312.24	-37.7	-0.12%	30090.3	30134.62	44.3	0.15%	29896.55	29870.07	-26.5	-0.09%	30349.91	29896.55	-1.49%	30312.24	29870.07	-1.46%
	Utility Based High	30349.91	30312.24	-37.7	-0.12%	30003.1	29887.75	-115.4	-0.38%	29861.22	29894.18	33.0	0.11%	30349.91	29861.22	-1.61%	30312.24	29894.18	-1.38%
P(l)	Clear Sky w/Hg	41590.71	42118.65	527.9	1.27%	40981.3	40949.45	-31.9	-0.08%	39686.43	39229.54	-456.9	-1.15%	41590.71	39686.43	*-4.58%*	42118.65	39229.54	*-6.86%*
4	Clear Sky wo/Hg	41582.14	41093.11	-489.0	-1.18%	40067.6	40181.18	113.6	0.28%	38764.39	38959.85	195.5	0.50%	41582.14	38764.39	*-6.78%*	41093.11	38959.85	*-5.19%*
	NAAQS	41611.60	42110.21	498.6	1.20%	40731.9	40380.89	-351.0	-0.86%	38624.05	38212.16	-411.9	-1.07%	41611.60	38624.05	*-7.18%*	42110.21	38212.16	*-9.26%*
	Utility Based (Coal)	39765.03	40143.97	378.9	0.95%	38513.3	38274.70	-238.6	-0.62%	37244.57	37233.41	-11.2	-0.03%	39765.03	37244.57	*-6.34%*	40143.97	37233.41	*-7.25%*
	Utility Based High	39765.03	40143.97	378.9	0.95%	38054.9	38138.15	83.3	0.22%	35979.48	35607.77	-371.7	-1.03%	39765.03	35979.48	*-9.52%*	40143.97	35607.77	*-11.30%*
FD(l)	Clear Sky w/Hg	41942.72	42009.99	67.3	0.16%	40860.9	41248.45	387.6	0.95%	39274.06	39288.84	14.8	0.04%	41942.72	39274.06	*-6.36%*	42009.99	39288.84	*-6.48%*
6	Clear Sky wo/Hg	40555.75	41766.71	1211.0	2.99%	40126.9	40287.97	161.1	0.40%	38668.11	38931.99	263.9	0.68%	40555.75	38668.11	*-4.65%*	41766.71	38931.99	*-6.79%*
	NAAQS	41300.32	41011.83	-288.5	-0.70%	40396.2	40672.78	276.6	0.68%	38378.24	38555.44	177.2	0.46%	41300.32	38378.24	*-7.08%*	41011.83	38555.44	*-5.99%*
	Utility Based (Coal)	40330.99	39274.34	-1056.7	-2.62%	38183.7	38205.81	22.1	0.06%	36680.68	36720.24	39.6	0.11%	40330.99	36680.68	*-9.05%*	39274.34	36720.24	*-6.50%*
	Utility Based High	40330.99	39274.34	-1056.7	-2.62%	38189.3	38095.74	-93.5	-0.24%	36305.65	35641.71	-663.9	-1.83%	40330.99	36305.65	*-9.98%*	39274.34	35641.71	*-9.25%*
S(s)	Clear Sky w/Hg	19292.95	19262.54	-30.4	-0.16%	19040.9	18991.37	-49.5	-0.26%	18874.55	18786.44	-88.1	-0.47%	19292.95	18874.55	*-2.17%*	19262.54	18786.44	-2.47%
7	Clear Sky wo/Hg	18977.04	19025.54	48.5	0.26%	18919.7	18800.88	-118.8	-0.63%	18704.14	18666.37	-37.8	-0.20%	18977.04	18704.14	-1.44%	19025.54	18666.37	-1.89%
	NAAQS	19153.90	19345.47	191.6	1.00%	18947.4	18893.42	-54.0	-0.28%	18790.28	18643.51	-146.8	-0.78%	19153.90	18790.28	-1.90%	19345.47	18643.51	*-3.63%*
	Utility Based (Coal)	19198.57	19254.71	56.1	0.29%	18812.2	18842.48	30.3	0.16%	18607.61	18593.61	-14.0	-0.08%	19198.57	18607.61	*-3.08%*	19254.71	18593.61	*-3.43%*
	Utility Based High	19198.57	19254.71	56.1	0.29%	18622.6	18570.24	-52.3	-0.28%	18503.75	18510.23	6.5	0.04%	19198.57	18503.75	*-3.62%*	19254.71	18510.23	*-3.87%*
S(l)	Clear Sky w/Hg	43248.68	43014.87	-233.8	-0.54%	42207.2	42237.80	30.6	0.07%	40541.25	40631.77	90.5	0.22%	43248.68	40541.25	*-6.26%*	43014.87	40631.77	*-5.54%*
8	Clear Sky wo/Hg	42641.91	42792.98	151.1	0.35%	41348.4	41445.95	97.6	0.24%	39813.73	40096.31	282.6	0.71%	42641.91	39813.73	*-6.63%*	42792.98	40096.31	*-6.30%*
	NAAQS	42874.43	43123.03	248.6	0.58%	41398.4	40954.83	-443.5	-1.07%	39412.16	39610.26	198.1	0.50%	42874.43	39412.16	*-8.08%*	43123.03	39610.26	*-8.15%*
	Utility Based (Coal)	41614.14	40845.95	-768.2	-1.85%	39799.7	39474.05	-325.7	-0.82%	38100.03	37950.46	-149.6	-0.39%	41614.14	38100.03	*-8.44%*	40845.95	37950.46	*-7.09%*
	Utility Based High	41614.14	40845.95	-768.2	-1.85%	38956.4	38990.67	34.2	0.09%	37472.09	37519.03	46.9	0.13%	41614.14	37472.09	*-9.95%*	40845.95	37519.03	*-8.15%*
SB(s)	Clear Sky w/Hg	294.84	296.04	1.2	0.41%	294.9	298.39	3.4	1.17%	289.72	293.77	4.1	1.40%	294.84	289.72	-1.74%	296.04	293.77	-0.77%
14	Clear Sky wo/Hg	294.27	299.25	5.0	1.69%	283.5	281.64	-1.9	-0.66%	266.27	273.41	7.1	2.68%	294.27	266.27	*-9.51%*	299.25	273.41	*-8.63%*
	NAAQS	294.03	298.24	4.2	1.43%	274.9	277.56	2.6	0.96%	268.07	275.02	7.0	2.59%	294.03	268.07	*-8.83%*	298.24	275.02	*-7.79%*
	Utility Based (Coal)	279.69	266.07	-13.6	*-4.87%*	266.3	272.82	6.6	2.46%	256.41	256.72	0.3	0.12%	279.69	256.41	*-8.32%*	266.07	256.72	*-3.51%*
	Utility Based High	279.69	266.07	-13.6	*-4.87%*	265.2	266.50	1.3	0.49%	258.72	256.90	-1.8	-0.71%	279.69	258.72	*-7.50%*	266.07	256.90	*-3.45%*

Note: Positive % Delta >/= 3.0 in **bold**, negative % Delta </= -3.0 in *italic*

TABLE 10-41
NAVPAT Traffic Impacts Lower Ohio River

Fish Species/ Life Stage[1]	Traffic Forecast Scenario	2010				2040				2070				2010-2070			2010-2070		
		Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
ES(s)	Clear Sky w/Hg	13789.33	13811.36	22.0	0.16%	13669.6	13675.12	5.5	0.04%	13659.20	13632.06	-27.1	-0.20%	13789.33	13659.20	-0.94%	13811.36	13632.06	-1.30%
1	Clear Sky wo/Hg	13711.34	13704.29	-7.0	-0.05%	13619.3	13669.16	49.9	0.37%	13423.51	13532.62	109.1	0.81%	13711.34	13423.51	-2.10%	13704.29	13532.62	-1.25%
	NAAQS	13728.88	13810.35	81.5	0.59%	13673.5	13663.62	-9.8	-0.07%	13402.17	13392.87	-9.3	-0.07%	13728.88	13402.17	-2.38%	13810.35	13392.87	*-3.02%*
	Utility Based (Coal)	13704.74	13645.82	-58.9	-0.43%	13597.7	13627.68	30.0	0.22%	13494.10	13461.94	-32.2	-0.24%	13704.74	13494.10	-1.54%	13645.82	13461.94	-1.35%
	Utility Based High	13704.74	13645.82	-58.9	-0.43%	13665.4	13682.90	17.5	0.13%	13464.79	13495.49	30.7	0.23%	13704.74	13464.79	-1.75%	13645.82	13495.49	-1.10%
ES(f)	Clear Sky w/Hg	4275.85	4260.41	-15.4	-0.36%	4239.0	4242.81	3.8	0.09%	4213.30	4209.83	-3.5	-0.08%	4275.85	4213.30	-1.46%	4260.41	4209.83	-1.19%
2	Clear Sky wo/Hg	4248.13	4264.12	16.0	0.38%	4217.5	4238.81	21.3	0.51%	4204.15	4186.58	-17.6	-0.42%	4248.13	4204.15	-1.04%	4264.12	4186.58	-1.82%
	NAAQS	4266.73	4258.19	-8.5	-0.20%	4233.7	4249.39	15.7	0.37%	4196.21	4191.65	-4.6	-0.11%	4266.73	4196.21	-1.65%	4258.19	4191.65	-1.56%
	Utility Based (Coal)	4241.13	4254.30	13.2	0.31%	4219.4	4210.36	-9.0	-0.21%	4200.07	4192.43	-7.6	-0.18%	4241.13	4200.07	-0.97%	4254.30	4192.43	-1.45%
	Utility Based High	4241.13	4254.30	13.2	0.31%	4231.6	4234.98	3.4	0.08%	4200.00	4167.42	-32.6	-0.78%	4241.13	4200.00	-0.97%	4254.30	4167.42	-2.04%
P(s)	Clear Sky w/Hg	46966.72	46970.01	3.3	0.01%	46611.5	46621.96	10.5	0.02%	46466.77	46438.07	-28.7	-0.06%	46966.72	46466.77	-1.06%	46970.01	46438.07	-1.13%
3	Clear Sky wo/Hg	46796.24	46829.98	33.7	0.07%	46552.0	46600.16	48.1	0.10%	46163.38	46330.59	167.2	0.36%	46796.24	46163.38	-1.35%	46829.98	46330.59	-1.07%
	NAAQS	46787.74	47059.89	272.2	0.58%	46522.9	46514.73	-8.2	-0.02%	46215.89	46151.66	-64.2	-0.14%	46787.74	46215.89	-1.22%	47059.89	46151.66	-1.93%
	Utility Based (Coal)	46929.00	46886.69	-42.3	-0.09%	46614.7	46604.54	-10.1	-0.02%	46389.96	46320.73	-69.2	-0.15%	46929.00	46389.96	-1.15%	46886.69	46320.73	-1.21%
	Utility Based High	46929.00	46886.69	-42.3	-0.09%	46551.7	46410.39	-141.3	-0.30%	46330.65	46289.99	-40.7	-0.09%	46929.00	46330.65	-1.28%	46886.69	46289.99	-1.27%
P(l)	Clear Sky w/Hg	72767.94	72542.39	-225.5	-0.31%	70723.4	70635.58	-87.9	-0.12%	69014.94	68984.78	-30.2	-0.04%	72767.94	69014.94	*-5.16%*	72542.39	68984.78	*-4.90%*
4	Clear Sky wo/Hg	72330.22	72452.03	121.8	0.17%	69855.0	70063.77	208.7	0.30%	68119.98	68622.47	502.5	0.74%	72330.22	68119.98	*-5.82%*	72452.03	68622.47	*-5.29%*
	NAAQS	72546.06	72177.48	-368.6	-0.51%	69710.1	70394.64	684.5	0.98%	67562.65	67966.07	403.4	0.60%	72546.06	67562.65	*-6.87%*	72177.48	67966.07	*-5.83%*
	Utility Based (Coal)	72139.04	72208.35	69.3	0.10%	69423.1	70082.96	659.9	0.95%	68395.08	67296.81	-1098.3	-1.61%	72139.04	68395.08	*-5.19%*	72208.35	67296.81	*-6.80%*
	Utility Based High	72139.04	72208.35	69.3	0.10%	69999.0	69908.04	-90.9	-0.13%	67227.67	67770.06	542.4	0.81%	72139.04	67227.67	*-6.81%*	72208.35	67770.06	*-6.15%*
FD(l)	Clear Sky w/Hg	71694.64	72641.02	946.4	1.32%	70624.3	70727.51	103.3	0.15%	68743.38	68050.03	-693.3	-1.01%	71694.64	68743.38	*-4.12%*	72641.02	68050.03	*-6.32%*
6	Clear Sky wo/Hg	72023.30	72174.41	151.1	0.21%	70271.6	70289.80	18.2	0.03%	67538.95	69032.97	1494.0	2.21%	72023.30	67538.95	*-6.23%*	72174.41	69032.97	*-4.35%*
	NAAQS	72043.46	72864.84	821.4	1.14%	70639.7	70373.59	-266.1	-0.38%	67950.74	68359.17	408.4	0.60%	72043.46	67950.74	*-5.68%*	72864.84	68359.17	*-6.18%*
	Utility Based (Coal)	72818.65	72540.64	-278.0	-0.38%	70498.8	69890.31	-608.5	-0.86%	69534.96	68294.17	-1240.8	-1.78%	72818.65	69534.96	*-4.51%*	72540.64	68294.17	*-5.85%*
	Utility Based High	72818.65	72540.64	-278.0	-0.38%	69276.4	69939.02	662.6	0.96%	68203.98	67301.66	-902.3	-1.32%	72818.65	68203.98	*-6.34%*	72540.64	67301.66	*-7.22%*
S(s)	Clear Sky w/Hg	21210.17	21218.70	8.5	0.04%	21141.0	21161.42	20.5	0.10%	20720.63	20753.36	32.7	0.16%	21210.17	20720.63	-2.31%	21218.70	20753.36	-2.19%
7	Clear Sky wo/Hg	20968.05	21103.40	135.3	0.65%	20895.0	20843.88	-51.1	-0.24%	20644.11	20688.67	44.6	0.22%	20968.05	20644.11	-1.54%	21103.40	20688.67	-1.97%
	NAAQS	21051.79	21286.10	234.3	1.11%	20817.0	20760.92	-56.1	-0.27%	20769.90	20648.15	-121.7	-0.59%	21051.79	20769.90	-1.34%	21286.10	20648.15	-3.00%
	Utility Based (Coal)	21107.31	21266.13	158.8	0.75%	20857.9	21079.80	221.8	1.06%	20690.78	20671.43	-19.4	-0.09%	21107.31	20690.78	-1.97%	21266.13	20671.43	-2.80%
	Utility Based High	21107.31	21266.13	158.8	0.75%	20863.7	20934.87	71.1	0.34%	20667.05	20772.10	105.1	0.51%	21107.31	20667.05	-2.09%	21266.13	20772.10	-2.32%
S(l)	Clear Sky w/Hg	75394.46	75643.94	249.5	0.33%	73841.6	73748.88	-92.7	-0.13%	71976.38	72242.62	266.2	0.37%	75394.46	71976.38	*-4.53%*	75643.94	72242.62	*-4.50%*
8	Clear Sky wo/Hg	74897.72	75320.95	423.2	0.57%	73581.0	73369.57	-211.5	-0.29%	71300.20	72329.28	1029.1	1.44%	74897.72	71300.20	*-4.80%*	75320.95	72329.28	*-3.97%*
	NAAQS	75373.25	76575.37	1202.1	1.59%	73314.8	73179.28	-135.5	-0.18%	70576.46	71337.94	761.5	1.08%	75373.25	70576.46	*-6.36%*	76575.37	71337.94	*-6.84%*
	Utility Based (Coal)	75446.10	75333.55	-112.6	-0.15%	72733.4	72877.47	144.1	0.20%	71274.24	71017.74	-256.5	-0.36%	75446.10	71274.24	*-5.53%*	75333.55	71017.74	*-5.73%*
	Utility Based High	75446.10	75333.55	-112.6	-0.15%	72749.6	72630.35	-119.3	-0.16%	71188.34	71259.64	71.3	0.10%	75446.10	71188.34	*-5.64%*	75333.55	71259.64	*-5.41%*
SB(s)	Clear Sky w/Hg	286.85	295.43	8.6	2.99%	293.5	292.56	-0.9	-0.31%	278.76	274.75	-4.0	-1.44%	286.85	278.76	-2.82%	295.43	274.75	*-7.00%*
14	Clear Sky wo/Hg	289.43	279.64	-9.8	*-3.38%*	281.7	286.22	4.5	1.59%	267.60	271.78	4.2	1.56%	289.43	267.60	*-7.54%*	279.64	271.78	-2.81%
	NAAQS	287.40	290.33	2.9	1.02%	277.9	274.74	-3.2	-1.15%	263.89	277.06	13.2	**4.99%**	287.40	263.89	*-8.18%*	290.33	277.06	*-4.57%*
	Utility Based (Coal)	296.70	287.71	-9.0	*-3.03%*	281.2	270.73	-10.5	*-3.73%*	273.56	271.28	-2.3	-0.84%	296.70	273.56	*-7.80%*	287.71	271.28	*-5.71%*
	Utility Based High	296.70	287.71	-9.0	*-3.03%*	269.5	269.79	0.3	0.11%	266.13	268.08	1.9	0.73%	296.70	266.13	*-10.30%*	287.71	268.08	*-6.82%*

Note: Positive % Delta >/= 3.0 in **bold**, negative % Delta </= -3.0 in *italic*

5. To illustrate the application of these criteria to the composited data in **Tables 10-38** through **10-40**, the following comments can be made for the Emerald Shiner-Spawning – ES(s) – life stage:

- For the time periods of 2010, 2040, and 2070, all % deltas are less than 3% for all three river segments (no exceedances of 3% out of 45 conditions examined).

- For the comparisons of the WOPCs in 2010 and 2070, and likewise for the WPCs, 25 of the 30 deltas are less than 3%. The five that are 3% or greater include four in the Upper segment and one in the Lower segment. The maximum % delta was minus 4.71% for the Utility Based High (UBH) scenario in the Upper segment under the WOPC scenario. When the delta itself (-574.65 HUs) is considered relative to the total HUs for the Ohio River mainstem (35,296 HUs), the % change considering the entire resource base drops to 1.6%.

6. The information from the two bullets above is summarized in **Table 10-42**. Comparable summary information from **Tables 10-39** through **10-41** is also included for the other seven species/life stages. The following observations can be made relative to **Table 10-42**:

- The differences in HUs between the WOPCs and WPCs for 2010, 2040, and 2070 were less than 3% (no exceedances) for Emerald Shiner-Spawning, Sauger-Spawning, and Sauger-Larval for all three river segments. A total of only 7 exceedances occurred for Emerald Shiner-Fry, Paddlefish-Larval, and Freshwater Drum-Larval, with the majority associated with the UB (Utility Based) and UBH (Utility Based High) traffic scenarios for the Upper segment in 2010. Ten exceedances occurred for Spotted Bass-Spawning, again with the majority associated with the UB and UBH traffic scenarios; however they were not limited to the Upper segment. In fact, they also occurred in the Middle and Lower segments in 2010 and 2040. The Spotted Bass-Spawning exceedances are somewhat overstated due to the small HUs resource base for the species. Further, the main spawning areas are in the side channels, and NAVPAT does not include this habitat.

- An additional consideration related to HU differences between the WOPC and WPC is that navigation traffic is but one contributor to cumulative effects on fish habitat. NAVPAT only evaluates changes in aquatic habitat that occur as a result of commercial traffic movement on the river. Chapter 4 in the CEA report in the **Environmental Appendix** illustrates numerous other actions within and along the mainstem that contribute to fish sustainability.

- The large majority of all exceedances (i.e., delta of 3% or greater) summarized in **Table 10-42** are related to navigation traffic changes for the WOPC in 2010 and 2070, and for the WPC at the same times. Paddlefish-Spawning was the only species that exhibited no exceedances. Further, exceedances often occurred in all

three river segments for all traffic scenarios for the other seven species/life stages. Finally, when the exceedances were adjusted to a total HU basis the percentages typically decreased to about one-third of the percentage loss levels for the individual segments.

TABLE 10-42
Summary of NAVPAT Traffic Impact Results

Fish Species/ Life Stages	Number of Exceedances[a]		
	WOPC-WPC (2010, 2040, &2070)	**WOPC (2010 - 2070)**	**WPC (2010 - 2070)**
ES(s)	0 of 45 conditions	3 of 15 conditions (all in Upper segment for NAAQS, UB, and UBH scenarios; the maximum (-4.71%) is 1.6% of total HUs for mainstem)	2 of 15 conditions (one each in Upper and Lower segment for NAAQS); the maximum (-3.13%) for UBH in the Upper segment is 1.1% of total HUs for mainstem
ES(f)	2 of 45 conditions (-3.82% for UB and UBH in the Upper segment in 2010); this represents 1.9% of total HUs for mainstem	9 of 15 conditions (5 in Upper segment and 4 in Middle segment); the maximum (-8.78% for UBH in the Upper segment) is 4.3% of the total HUs for mainstem	8 of 15 conditions(5 in Upper segment and 3 in Middle segment); the maximum (-6.38% for NAAQS in the Upper segment) is 3.1% of the total HUs for mainstem
P(s)	0 of 45 conditions	0 of 15 conditions	0 of 15 conditions
P(l)	2 of 45 conditions (-4.01% for UB and UBH in the Upper segment in 2010); this represents 1.0% of the total HUs for mainstem	15 of 15 conditions (5 each in Upper, Middle, and Lower segments); the maximum (-12.4% for UBH in the Upper segment) is 3.2% of the total HUs for mainstem	15 of 15 conditions (5 each in Upper, Middle, and Lower segments); the maximum (-11.3% for UBH in the Upper segment) is 3.0% of the total HUs for mainstem
FD(l)	3 of 45 conditions (+3.36% for CSw/o Hg, and -5.81% for UB and UBH in the Upper segment in 2010); the maximum (-5.81%) is 1.5% of the total HUs for mainstem	15 of 15 conditions (5 each in Upper, Middle, and Lower segments); the maximum (-15.46% for UBH in the Upper segment) is 4.0% of the total HUs for mainstem	15 of 15 conditions (5 each in Upper, Middle, and Lower segments); the maximum (-11.22% for CSw/o Hg in the Upper segment) is 2.8% of the total HUs for mainstem
S(s)	0 of 45 conditions	15 of 15 conditions (3 in Upper segment and 2 in Middle segment; the maximum (-4.31% for UBH in the Upper segment) is 1.2% of the total HUs for mainstem	8 of 15 conditions (4 in Upper segment, 3 in Middle segment, and one in Lower segment; the maximum (-4.7% for UB in the Upper segment) is 1.3% of the total HUs for mainstem
S(l)	0 of 45 conditions	15 of 15 conditions (5 each in Upper, Middle, and Lower segments); the maximum (-9.95% for UBH in the Middle segment) is 2.6% of the total HUs for mainstem	14 of 15 conditions (4 in Upper and 5 each in Middle and Lower segments); the maximum (-9.77% for UBH in the Upper segment) is 2.4% of the total HUs for mainstem
SB(s)	10 of 45 conditions (-3.10% for UB and UBH in the Upper segment in	13 of 15 conditions (5 in Upper segment, and 4 each in the Middle and Lower	13 of 15 conditions (5 in Upper segment, and 4 each in the Middle and Lower

Fish Species/ Life Stages	Number of Exceedances[a]		
	WOPC-WPC (2010, 2040, &2070)	**WOPC (2010 - 2070)**	**WPC (2010 - 2070)**
	2010, +3.76% for UBH in the Upper segment in 2070; -4.87% for UB and UBH in the Middle segment in 2040; -3.38% for CS w/o Hg, and -3.03% for UB and UBH in the Lower segment in 2010; -3.73% for UB in the Lower segment in 2040; and +4.99% for NAAQS in the Lower segment in 2070); the maximum negative (-4.87%) change is 1.2% of the total HUs for mainstem	segments); the maximum (-23.71% for UBH in the Upper segment) is 11.9% of the total HUs for mainstem	segments); the maximum (-19.27% for NAAQS in the Upper segment) is 9.1% of the total HUs for mainstem
a = an exceedance is when a % delta is equal to or greater than + or - 3%			

7. Based on the above findings, along with a systematic consideration of the NAVPAT results for the individual pools as contained in the above-mentioned NAVPAT section of the **Environmental Appendix**, additional observations and analysis can be noted. For example, a clear and consistent pattern evident in the Ohio River Mainstem Study NAVPAT output is that, under either With Project or Without Project conditions, increasing river traffic between the years 2010 and 2070 will result in a loss of habitat units for Emerald Shiner-Spawning and Fry, Paddlefish-Spawning and Larval, Freshwater Drum-Larval, Sauger-Spawning and Larval, and Spotted Bass-Spawning. These losses occur under all five traffic scenarios examined, but are notably greater under the two highest traffic prediction scenarios (Utility Based and Utility Based High). These results are not in any way surprising since the model intrinsically generates non-recovery propeller mortality output for all larval or fry life stages. Except for Paddlefish-Larval, Freshwater Drum-Larval, and Sauger-Larval, predicted losses of habitat units for the Ohio River will be negligible to slight. The slight to moderate losses in habitat units for Paddlefish-Larval, Freshwater Drum-Larval, and Sauger-Larval are probably balanced by the great abundance of these three types of habitats all along the river. Since they are the most common existing species/life stage habitats within the Ohio River, a modest decline in the availability of these habitats is not likely to be a factor limiting populations of paddlefish, freshwater drum, or sauger in the river. Further, results of recent studies performed for the Upper Mississippi River/Illinois Waterway demonstrate that mortality of fish larvae from propeller entrainment is less than the 100% assumed in the NAVPAT model.

8. Beyond these nearly self-evident generalizations, it is very difficult to find consistent and reliable patterns of future predicted navigation influences within the massive outputs of the Ohio River Mainstem Study NAVPAT application. As discussed previously, the failure of such patterns to emerge might be related to the large size and

high flows of the Ohio River mainstem, and its ability to absorb predicted additional navigation induced impacts, without significantly influencing existing fishery resources within an already highly modified ecosystem.

9. Some suggestive evidence that system size might be a variable contributing to the differences in Ohio River and Kanawha River NAVPAT results is that the few differences (greater than + or – 5.0 % delta for individual pools) observed between With Project or Without Project conditions noted for the Ohio River are clustered along the Upper and smaller reach of the Ohio River mainstem. Specifically, Emerald Shiner-Spawning habitat unit deltas of –5.9% occurred in Dashields Pool in 2010 under the Utility Based and Utility Based High traffic scenarios. Paddlefish-Larval habitat unit deltas of –5.4% occurred in Racine Pool in the same year under the same traffic scenarios, and Freshwater Drum-Larval habitat unit deltas ranging from –5.2% to –8.2% were observed all along the ten uppermost pools in the river from the Emsworth pool downstream to the Byrd pool, all again for the year 2010 under Utility Based and Utility Based High traffic scenarios. These impacts to Freshwater Drum-Larval in the Upper river over short term, high traffic, and under With Project conditions may be the only non-random habitat unit deltas predicted by the model. With the exception of the Spotted Bass-Spawning species/life stage, no other meaningful changes were observed for any other species/life stage under any traffic scenario in 2040 or 2070, in any pool, under either With Project or Without Project conditions. It should be remembered, that while this clustering was clearly exclusive to the Upper river, it nonetheless amounted to only a modest portion of the total number of 2520 specific species /life stage events predicted by the NAVPAT model for the Ohio River, and attempts to draw conclusions from this apparent pattern, therefore, should be considered speculative at best.

10. The Spotted Bass-Spawning species/life stage exception for individual pools, referred to in the preceding paragraph, consisted of a total of 35 habitat unit deltas in excess of 5.0%, 15 negative and 20 positive, very randomly distributed throughout the 2010 to 2070 study period, and occurring in a random manner within the five different commercial river traffic scenarios. Of all the NAVPAT quantified fish species/life stage habitats, spawning habitat for spotted bass is by far the most limited and the most unevenly distributed fish habitat in the Ohio River; for example, 49% is in the Upper reach, and the remaining 51% is evenly distributed in the Middle and Lower reaches. The very small and rather scattered number of Spotted Bass- Spawning habitat units appears to be very susceptible to random and apparently meaningless model perturbations.

11. In summary, the Ohio River Mainstem Study NAVPAT application successfully quantified habitat required for various life stages of the primary fish assemblages of the Ohio River, as well as the impacts of future navigation activity scenarios to these habitats. The results of this modeling effort demonstrated that increases in navigation traffic through the year 2070 will negatively, but rather modestly, impact certain groups of fishes, especially swiftwater spawning fishes. While benefits to the fishery might accrue from improvements to navigation under With Project conditions, any such benefits are apparently too small to be measured by the NAVPAT model. In

part this might be related to model sensitivity. For instance, NAVPAT programming generalized river cross-sections up to one to two miles in length and normalized traffic input files within the cross-sections. Therefore, this application was not designed to identify reduction in vessel queuing impacts to the aquatic resource. However, the failure of the model to demonstrate substantial future impacts from navigation are most likely overwhelmingly related to the ability of the Ohio River to absorb the predicted additional navigation induced impacts without significantly influencing existing fishery resources within an already highly modified ecosystem.

10.2.3.6.4 Anticipated Improvements to the NAVPAT Model

While the 2005 edition of NAVPAT provides a useful tool for assessment of the impacts of commercial navigation traffic on habitats of various fish species and life stages, a number of improvements to this model would be desirable. ERDC is now in the process of generally upgrading the NAVPAT model, and future applications of NAVPAT will probably find the new ERDC version easier to manage and execute. Also, specific nomenclature should be developed to distinguish between various editions of the model, and the version used in any application should be carefully referenced. A deficiency of both the original version of NAVPAT and the 2005 edition is that neither is able to model conditions nor predict future navigation impacts for the backchannels of river islands. These backchannel reaches are very important habitat components of river ecosystems, and expansion of the model to include this habitat type should be a consideration in future improvement of the NAVPAT model. In addition, during the course of the ORMSS and similar study efforts, such as the modeling of commercial navigation impacts on the Winfield Pool of the Kanawha River, field investigators noted extreme velocity and wave/wake effects from large V-hulled recreational vessels. At least anecdotally, it appears that the impacts of such vessels might equal or perhaps exceed those of commercial tow traffic. Therefore, it is highly recommended that impacts of recreation traffic be incorporated into future NAVPAT model development.

10.3 COMPARISON OF ALTERNATIVE SYSTEM INVESTMENT PLANS (SIPS)

This section is structured into subsections related to requirements from the Corps' planning process, requirements from the NEPA regulations of the Council on Environmental Quality (and supported in the Corps' NEPA regulations), the screening and prioritization process for potential measures which could comprise components of navigated-related and environmental sustainability (ES)-related plans, summary descriptions of the included measures in each plan, comparisons of the overall and detailed features of the navigated-related and ES-related plans, and the combination of the economic and environmental results into a "best NED/NER plan".

10.3.1 Requirements from the Corps' Planning Process

1. As noted in Section 2, the Corps' planning process consists of six steps. Step 1 (identifying problems and opportunities related to both the Ohio River navigation system

and the sustainability of multiple resources, ecosystems and human communities) was addressed in Sections 3 through 6. Likewise, Step 2 (inventorying and forecasting conditions) was also highlighted as appropriate, in Sections 3 through 6. The formulation of alternative plans for both navigation system and environmental sustainability needs was accomplished for Without Project Conditions (WOPC) in Section 8, while Section 9 and the first part of Section 10 did likewise for With Project Conditions (WPC). Evaluating alternative plans (Step 4) relative to economic indicators and ES considerations was also accomplished in Sections 8 and 9 for WOPC and WPC, respectively and in earlier subsections of Section 10 for WPC. This subsection contains summary information related to comparisons of the plans (Step 5). Further, the included discussions of trade-offs among plans provide the basis for Step 6 (selecting a plan).

2. The following definitions and principles from the Corps' Planning Guidance Notebook (ER 1105-2-100; April 22, 2000) are instructive in comparing the plans:

- From Step 3 (1) – Alternative plans shall be formulated to identify specific ways to achieve planning objectives within constraints, so as to solve the problems and realize the opportunities that were identified in Step 1. An alternative plan consists of a system of structural and/or nonstructural measures, strategies, or programs formulated to meet, fully or partially, the identified study planning objectives subject to the planning constraints. A range of alternative plans comprised of various management measures shall be identified at the beginning of the planning process and screened and refined in subsequent iterations throughout the planning process.

- From Step 3 (2) – Each alternative plan shall be formulated in consideration of four criteria: completeness, efficiency, effectiveness, and acceptability. Completeness is the extent to which the alternative plans provide and account for all necessary investment or other actions to ensure the realization of the planning objectives, including actions by other Federal and non-Federal entities. Effectiveness is the extent to which the alternative plans contribute to achieve the planning objectives. Efficiency is the extent to which an alternative plan is the most cost-effective means of achieving the objectives. Acceptability is the extent to which the alternative plans are acceptable in terms of applicable laws, regulations and public policies. Appropriate mitigation of adverse effects shall be an integral component of each alternative plan.

- From Step 5 – In this step, plans (including the no action plan) are compared, with emphasis on the outputs and effects that will have the most influence in the decision making process. Beneficial and adverse effects of each plan must be compared. These include monetary and non-monetary benefits and costs. Identification and documentation of tradeoffs will be required to support the final recommendation. The effects include those identified during the evaluation phase and any other significant effects identified in Step 5. The comparison step can be defined as a reiteration of the evaluation step (Step 4), with the exception that in this step each plan (including the no action plan) is compared against each other

and not against the without-project condition. The output of the comparison step shall be a ranking of plans.

- From Step 6 – A single alternative plan will be selected for recommendation from among all those that have been considered. The recommended plan must be shown to be preferable to taking no action (if no action is not recommended) or implementing any of the other alternatives considered during the planning process. The culmination of the planning process is the selection of the recommended plan or the decision to take no action. The criteria for selecting the recommended plan differ, depending on the type of plan and whether project outputs are NED, NER, or a combination of both.

    (1) The National Economic Development (NED) Plan. For all project purposes except ecosystem restoration, the alternative plan that reasonably maximizes net economic benefits consistent with protecting the Nation's environment, the NED plan, shall be selected.

    (2) The National Ecosystem Restoration (NER) Plan. For ecosystem restoration projects, a plan that reasonably maximizes ecosystem restoration benefits compared to costs, consistent with the Federal objective, shall be selected. The selected plan must be shown to be cost-effective and incrementally justified to achieve the desired level of output. This plan shall be identified as the National Ecosystem Restoration (NER) Plan.

    (3) The Combined NED/NER Plan. Projects which produce both National Economic Development (NED) benefits and National Ecosystem Restoration (NER) benefits will result in a "best" recommended plan so that no alternative plan or scale has a higher excess of NED benefits plus NER benefits over total project costs. This plan shall attempt to maximize the sum of net NED and NER benefits, and to offer the best balance between two Federal objectives. Recommendations for multipurpose projects will be based on a combination of NED benefit-cost analysis, and NER benefits and analysis, including cost effectiveness and incremental cost analysis.

4. To summarize the application of the above definitions and principles in the ORMSS, the following features are noted from Sections 8, 9, and earlier and planned portions of this section:

- The identified navigation-related plans (Reactive Maintenance Alternative from Section 8, and Advanced Maintenance Alternative, Major Rehabilitation Alternative, and Lock Modernization Alternative from Section 9) each include combinations of structural and nonstructural measures and strategies or programs.

- The identified ES-related (ecosystem restoration-related) plans in Sections 8 and 9 each include combinations of various measures to protect and/or enhance aquatic ecosystems of the Ohio River, and terrestrial (riparian) ecosystems associated therewith.

- Screening of various potential navigation-related measures was accomplished in both Sections 8 and 9, with the result that some measures were eliminated from further analysis while others were refined. In an analogous manner, the listed ES measures in Sections 8 and 9 were prioritized into four groups (A to D) based on potential environmental outputs in relation to cost, and their ease of initiation under current authorities.

- Plan evaluation based on the criteria of completeness, efficiency, effectiveness and acceptability is accomplished in a later subsection herein.

- Comparisons of the monetary and non-monetary outputs and effects of each navigation-related and each ES-related plan will also be accomplished in a later subsection herein. Such comparisons are presented in tabular formats and discussed in relation to their trade-offs relative to the "no action plan" and to each other. The ORMSS navigation-related no action plan, or continuation of the status quo activities, is most closely represented by the Reactive Maintenance Alternative comprised only of activities associated with routine maintenance, cyclical maintenance, and unscheduled repairs. The "no action plan" for ES can be defined as the non-implementation of any ES measures listed in **Table 8-9**. The output from these comparisons will be a rank ordering of both the navigation-related and ES-related plans.

- In a subsequent subsection herein, the NED plan is identified from the navigation-related plans, and the NER plan is identified from the ES-related plans. As a result, the combined best NED/NER plan is identified.

10.3.2 Requirements from the NEPA Process

1. The NEPA regulations of CEQ, as supported by the Corps' NEPA regulations, indicate that the analysis of alternatives is the heart of an environmental impact statement prepared under the auspices of NEPA requirements. Section 1502.14 of the CEQ's regulations further indicates that the environmental impacts of all reasonable alternatives, including the ultimate proposed action, should be presented in comparative form. This comparative presentation should aid in defining the issues and providing a clear basis for the choice of the proposed action. Additional guidance in the CEQ's regulations for the analysis of alternatives section includes the following:

- Rigorously explore and objectively evaluate all reasonable alternatives, and for alternatives which were eliminated from detailed study, briefly discuss the reasons for their having been eliminated.

- Devote substantial treatment to each alternative considered in detail including the proposed action so that reviewers may evaluate their comparative merits.

- Include reasonable alternatives not within the jurisdiction of the lead agency.

- Include the alternative of no action.

- Identify the agency's preferred alternative or alternatives, if one or more exists, in the draft statement and identify such alternative(s) in the final statement unless another law prohibits the expression of such a preference.

- Include appropriate mitigation measures not already included in the proposed action or alternatives.

2. To summarize the application of the comparative analyses of alternatives and the CEQ guidance, the following points are noted from Sections 8, 9, and 10:

- Tables are included in later subsections herein to display the comparative features of the navigation-related and ES-related alternative plans described in Sections 8, 9, and earlier portions of Section 10.

- The rigorous exploration and objective evaluation of all reasonable navigation-related and ES-related alternative plans is demonstrated in summary tables of the environmental effects of the navigation-related WOPC and WPC alternative plans in Sections 8 and 9. Detailed information related to these effects is included in the CEA report in the Environmental Appendix. In addition, two composite indicators of the direct environmental effects of the WOPC and WPC, and the differences between the two, are addressed earlier in this section in the analyses of transit days and fish habitat changes calculated with the NAVPAT model. The NAVPAT study report is also included in the **Environmental Appendix**.

- Detailed economic comparisons for each navigation-related alternative are contained in the **Economics Appendix**. Section 8 includes summary economic information on the WOPC alternative plan, and Section 10 does similarly for the WPC alternative plans. This summary information provides the basis for an objective evaluation of the economic features of each of the four navigation-related alternative plans.

- Several navigation-related measures that could have been included in the alternative plans were evaluated, discussed, and then eliminated in Sections 8 (WOPC alternative plan) and 9 (WPC alternative plans).

- The best combined NED/NER plan is identified in a later subsection herein. This plan is expected to become the Corp's preferred alternative.

- Appropriate mitigation measures will be identified during the specific design and planning phases for future WPC projects or activities. In some cases, EISs will be required (e.g., lock modernization at EDM) while in other cases EA-levels of analysis will be appropriate.

3. Additional NEPA-related instruction on appropriate ranges of alternatives in EISs can be found in case law. Specifically, the 2001 edition of The NEPA Book by Bass, Henson, and Bogdan (Solano Press, 2001, pp. 94-95) contains the following case law principles related to the "range of alternatives":

- The range should be governed by the "rule of reason" – in the case of ORMSS, the navigation-related alternative plans are broad and encompass both structural and non-structural measures; the ES-related alternative plans also encompass numerous measures based on the input of subject matter experts on the aquatic and terrestrial (riparian) resources of the Ohio River.

- The range must achieve the proposed action's objectives as stated in the purpose and need (planning objectives) addressed in the EIS – the relative compliance of each navigation-related and ES-related plan to the three planning objectives delineated in Section 6 is addressed in a following subsection herein.

- The range must foster rather than constrain the options available to the decision makers – considerable flexibility is provided related to timing and specific design features of both the navigation-related and ES-related plans; further, considerable size and locational flexibility is available for the specific measures in the ES-related plans.

- The range must be feasible – both economic and technical feasibility exists for the navigation-related plans. The measures associated with the ES-related plans are scientifically feasible; however, specific determinations of the environmental outputs (benefits) of the measures, and their associated incremental and total costs have not yet been made. These evaluations of the ES-related plans will need to be done when planning site-specific actions including mitigation in order to provide appropriate bases for specific decision making.

- Alternatives that are remote or speculative need not be considered in an EIS – remote and speculative measures were not included in the formulation of the navigation-related or ES-related alternative plans.

- Alternatives with more significant adverse effects than the proposed actions need not be evaluated in an EIS – no attempts were made to identify "maximum adverse effects" plans which could be used for comparison with the reasonable navigation-related and ES-related plans.

- Alternatives with impacts that are indistinguishable from the proposed action need not be evaluated in an EIS – all of the navigation-related alternative plans, as well

as all of the ES-related plans, are distinguishable from each other relative to costs, benefits, environmental effects, and influence on ES.

10.3.3 Screening Process for Navigation-Related Plans

1. A screening process based on either preliminary economic evaluations or consistency with the definitions of WOPC or WPC was used for navigation-related measures. This process is described in Section 8 for WOPC and in Section 9 for WPC. As a result, some considered measures were eliminated for the plans addressing both conditions. For example, **Table 8.4** indicates that the following maintenance measures were eliminated from further consideration in the WOPC plan – full implementation of a miter gate quick changeout system for lock gate replacement, scheduled component replacements, major rehabilitation, and replacement-in-kind. However, it should be noted that even though all four of these measures were eliminated from the WOPC plan, they were included for consideration in the WPC plans. Further, **Table 8-5** lists two operational and low-cost structural measures that were eliminated from the WOPC plan; they are operational traffic scheduling and low-cost structural guide/guard wall extensions. Detailed economic and related policy information associated with the elimination of each of the measures listed in **Tables 8-4** and **8-2** is in the **Economics Appendix**.

2. Relative to the screening process applied to measures for potential inclusion in the WPC plans, **Table 9-1** indicates that two measures carried forward from Section 8 (full implementation of a miter gate quick changeout system for lock gate replacement, and replacement-in-kind) were eliminated from the WPC plans. However, the other two measures carried forward from Section 8 (scheduled component replacements and major rehabilitation) were included in the WPC plans. Regarding operational and low-cost structural measures, **Table 9-2** indicates that four measures were eliminated from the WPC plans; namely, operational traffic scheduling, congestion fees, traffic scheduling by the Corps, and low-cost structural guide/guard wall extensions. The first and last of these four measures had also been eliminated from the WOPC plan.

3. Regarding various lock modernization measures evaluated for the WPC plans in Section 9, **Table 9-6** indicates that four types of measures were eliminated from the WPC plans – they include (1) extensions less than 600 ft. for all existing auxiliary chambers with dimensions of 600 ft. by 110 ft.; (2) third locks at any of the 19 existing or authorized lock and dam projects; (3) lengths of new locks at Emsworth, Dashields and Montgomery (EDM) between 600 ft. and 1200 ft.; and (4) widths of new locks at EDM less than 110 ft. A fifth, the removal of any of the 19 locks and dams comprising the Ohio River mainstem navigation system, was not evaluated in this study. Again, detailed economic and related policy information associated with the elimination of each of the measures listed in **Tables 9-1**, **9-2**, and **9-6** is in the **Economics Appendix**.

10.3.4 Description of Components within the Navigation-Related Alternative Plans

1. Based on the screening process for navigation-related plans as described in Sections 8 and 9, as well as earlier information in this section, the included measures for four such plans can be identified. **Table 10-43** begins with a descriptive listing of the measures in the WOPC plan, also called the Reactive Maintenance Alternative (RMA). The WOPC plan includes three maintenance measures, four operational measures, and three low-cost structural measures.

2. **Table 10-43** includes a descriptive listing of the measures in the least comprehensive of the three WPC plans; the AMA. The AMA includes each of the measures from the RMA, as well as two new maintenance measures (lock gate replacement and scheduled component replacements). As a result, the AMA includes five maintenance measures, four operational measures, and three low-cost structural measures. Information related to applying routine and cyclical maintenance measures, along with the timing of lock gate replacements and scheduled component replacements is shown, as appropriate, for 16 of the current lock and dam projects in **Tables 10-15 through 10-31**. Specific application of the AMA to the Greenup and Myers projects was not done since these projects are subject to current authorized improvements; further, application of the AMA was not evaluated for locks and dams 52 and 53 because they will be replaced by the "under construction" Olmsted lock and dam project.

3. **Table 10-43** continues with a descriptive listing of the measures in the middle comprehensive of the three WPC plans; this plan is referred to as the Major Rehabilitation Alternative (MRA), which includes each of the measures in the AMA, as well as one new maintenance measure (major rehabilitation). As a result, the MRA includes a total of six maintenance measures, four operational measures, and three low-cost structural measures. As noted above, timing and locations associated with the application of these measures are shown, as appropriate, in **Tables 10-15 through 10-31**.

TABLE 10-43

Navigation-Related Measures in the WOPC Plan
And the WPC Alternatives

Navigation-Related Measures in the WOPC Plan – Reactive Maintenance Alternative
Maintenance Measures
Routine Maintenance – Small jobs such as painting, equipment lubrication, repair of equipment, landscaping, and repair of random minor component failures.
Cyclical Maintenance – Scheduled inspections and repairs to major components, including chamber dewatering.
Unscheduled Repairs – All unscheduled repairs of major components are repaired under emergency conditions.
▪ **Operational Measures**
N-up/N-Down Lockage Policy
Advanced Notice of Main Chamber Closures
Adjustment of Shipment Schedules by Industry

Helper Boats by Industry
▪ **Low-Cost Structural Measures**
Tow Haulage
Mooring Cells
Temporary Mooring Facilities During Main Chamber Closures
Navigation-Related Measures in the Least Comprehensive WPC Plan - Advanced Maintenance Alternative
Includes all Maintenance, Operational and Low-Cost Structural Measures listed above for WOPC, plus:
Maintenance Measures
Lock Gate Replacement – Only current capabilities are considered. No additional features are implemented during planning period.
Scheduled Component Replacements
Navigation-Related Measures in the Middle Comprehensive WPC Plan – Major Rehabilitation Alternative
Includes all Maintenance, Operational and Low-Cost Structural Measures listed above for WPC – Advanced Maintenance Alternative, plus:
Maintenance Measures
Major Rehabilitation – Repair, replacement, or reconstruction of major components costing at least $10.6 million for projects starting in FY 2006 (October 2005 – September 2006)
Navigation-Related Measures in the Most Comprehensive WPC Plan – Lock Modernization Alternative
Includes all Maintenance, Operational and Low-Cost Structural Measures listed above for WPC – Major Rehabilitation Alternative, plus:
Lock Modernization Measures
New 110' x 600' lock at Emsworth project
New 110' x 600' lock at Dashields project
New 110' x 600' lock, or possibly a new 110' x 1200' lock at Montgomery project

4. **Table 10-43** concludes with a descriptive listing of the measures in the most comprehensive of the three WPC plans. This plan is referred to as the Lock Modernization Alternative (LMA) and includes each of the measures in the MRA, as well as lock modernization measures for EDM. Extensions of 600 ft. were considered for four 600 ft. long auxiliary chambers downstream of the Montgomery project; however, none were economically justified. As a result, the LMA includes a total of six maintenance measures, three lock modernization measures, four operational measures, and three low-cost structural measures. As mentioned above, timing and locations associated with the application of the maintenance measures and lock modernization measures are shown, as appropriate, in **Tables 10-15 through 10-31**.

5. **Table 10-44** presents the projected initial year of three categories of site-specific projects, by existing project, in the three WPC alternatives (these tabulations were compiled from **Tables 10-15 to 10-31**). In addition, it should be noted that the timing of the site-specific projects are dependent on the navigation traffic scenario. Further, such projects will have different durations; e.g., advanced maintenance of selected components, depending upon the component, may require up to 2 years for completion.

Major rehabilitation projects can take up to 5 years, and new locks may extend to 7 years. Some observations related to the timing and site-specific economically justified projects listed in **Table 10-35** are as follows:

- The decade from 2010 to 2020 includes one new lock each at the Emsworth, Dashields, and Montgomery projects (2010 to 2012 depending on the navigation traffic scenarios). Major rehabilitations are projected for the Pike Island (2015 to 2016), Hannibal (2011 to 2012), Belleville (2017 to 2028), Racine (2019 to 2020), Meldahl (2010 to 2013), Markland (2010), Cannelton (2016 to 2017), Newburgh (2015 to 2025), and Myers (2011-2013) projects. Further, advanced maintenance, including scheduled replacements of selected components, is identified for the New Cumberland (2015), Pike Island (2015), Meldahl (2017), Markland (multiple replacements beginning in 2013 – see **Table 10-26**), McAlpine (2010 to 2030; includes multiple replacements – see **Table 10-27**), and Smithland (2013) projects.

- The decade from 2021 to 2030 also includes major rehabilitation efforts at Willow Island (2027 to 2028), and Byrd (2030 to 2045) projects. Advanced maintenance projects are also scheduled for the Markland and McAlpine projects during this decade.

- The four decades from 2031 to 2070 include possible major rehabilitation efforts at the Byrd and Markland (auxiliary chamber) projects, depending upon the navigation traffic scenario. Advanced maintenance projects are also listed for the Pike Island (2051 to 2069), Hannibal (2065), Racine (2048 to 2052), Meldahl (2063), and Markland (auxiliary chamber) projects, again depending upon traffic scenario.

6. The above tabulations illustrate that a major infrastructure program is required for the Ohio River mainstem navigation system in the time period from 2010 to 2030.

TABLE 10-44
Composite List of Site-Specific Projects[a] for the Navigation System on the Ohio River Mainstem (2010 to 2070)

Existing Lock and Dam	Initial Year		
	Advanced Maintenance Projects	Major Rehabilitation Projects	New Lock Projects
Emsworth			2010
Dashields			2010
Montgomery			2010
New Cumberland	2015		
Pike Island	2015 2068-2069	2015-2016 2043	
Hannibal	2065	2011-2012	

Willow Island		2027-2028	
Belleville		2017-2028	
Racine	2048-2052	2019	
Byrd		2030-2045	
Greenup[d]			
Meldahl	2017 2056, 2068	2010-2013	
Markland	2013-2046[b]	2010	
McAlpine	2010-2032[c]		
Cannelton		2016-2017	
Newburgh		2015-2025	
Myers[e]			
Smithland[f]	2010-2054		
Olmsted[g]			

[a] compiled from Tables 10-15 to 10-30
[b] see multiple listings in Table 10-26
[c] see multiple listings in Table 10-27
[d] Greenup is authorized and scheduled for auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).
[e] Myers is authorized and scheduled for auxiliary chamber extension by 2010 (includes replacement of gates and the electrical system).
[f] see multipole listings in Table 10-31
[g] Olmsted is currently under construction

10.3.5 Prioritization Process for Environmental Sustainability-Related Plans

1. As discussed in Section 8.8.1, a prioritization process was used to progressively group the 26 identified ES measures (see **Table 8-10**) according to their planning requirements, relative costs, and implementation complexity. The purpose of the prioritization was not to eliminate any measures; rather, it was to delineate groups of ES-related measures that could be formulated into ES alternative plans. The fundamental concept for the plans was that some measures could be implemented in the near term, while others would need more planning and greater funding levels. Further, some measures might require new authorizations for implementation. The characteristics of the resultant four groups are described as follows:

- Group A: 4 measures for which authority already exists and which involve minimal costs. These measures would involve minimal costs; increase awareness of key VECs, focus on impact prevention, and could be implemented relatively quickly.

- Group B: 10 measures for which authority already exists, but which would require some costs for planning and/or construction. These measures focus on key VECs and incorporate restoration and enhancement goals.

- Group C: 5 measures for which some authority already exists, but new authority may be needed for some opportunities. Planning and construction costs may be

relatively high. These measures generally encompass broad descriptions of opportunities that may need refinement, thus the focus tends toward broader-level environmental needs.

- Group D: 7 measures which require new authorities or are primarily addressed through authorities of other agencies (e.g., USEPA). Planning and construction costs may be relatively high. These measures generally encompass broad descriptions of opportunities that may need refinement, thus the focus tends toward broader-level environmental needs.

2. **Table 10-45** lists the individual ES measures associated with each group (these measures are extracted from **Table 8-10**). Although there are descriptive tables in Sections 8 (**Table 8-6**) and 9 (**Table 9-10**) that address the potential beneficial and adverse effects of the measures in the four groups on five major VECs (water quality, fish, mussels, riparian resources, and recreation), it is stressed that no detailed analysis of the environmental benefits from the measures, or their anticipated costs for implementing the measures, was conducted within the ORMSS. Conducting such a study should be a high priority in the near term.

3. From a policy perspective consistent with the definitions of the Without Project and With Project Conditions in Sections 8 (WOPC) and 9 (WPC), the four groups of ES measures can be divided as follows:

- WOPC measures for ES – Groups A and B

- WPC measures for ES – add Groups C and D

On this basis, three ES-related alternative plans can be formulated as follows:

- ES-related Minimal Plan – includes Groups A and B measures

- ES-related Moderate Plan – includes Groups A, B, and C measures

- ES-related Maximum Plan – includes all four groups of measures

4. As noted above, the individual ES measures included in each plan are listed in **Table 10-45**.

10.3.6 Overall Comparisons of the Alternative Plans

1. As noted in Section 10.6.1 above, the Corps' Planning Guidance Notebook indicates that each alternative plan should be evaluated relative to their accomplishment of the study objectives, as well as in relation to four specified criteria – completeness, efficiency, effectiveness, and acceptability. For purposes herein, the overall comparisons will be separately considered for the four navigation-related plans and the three ES-related plans. This separation will facilitate the identification of an NED plan and an

NER plan. For this study, the National Ecosystem Restoration (NER) plan will be the optimum of the three ES-related plans. Therefore, the NER plan for the Ohio River mainstem will be referred to as the National Environmental Sustainability (NES) plan.

2. **Table 10-45** summarizes the overall comparisons of the four navigation-related alternative plans. As mentioned earlier, the plans are progressive from left to right. That is, the AMA includes the RMA; the MRA includes the AMA; and the LMA includes the MRA. The rows in **Table 10-45** reflect three groups of comparisons; namely, achievement of planning objectives, compliance with four planning criteria as specified in the Planning Guidance Notebook (ER 1105-2-100), and the extent of new authorizations needed. Definitions for the four planning criteria are included in the footnotes, along with definitions of the descriptive comparisons used within the table. The selected descriptive codes are based upon information contained in Sections 6, 8, and 9, as well as the earlier portions of this section.

Table 10-45
Overall Comparisons of the Features of the Navigation-Related Alternative Plans

Evaluation Factors	Navigation-Related Plan			
	WOPC (RMA)	WPC (AMA)	WPC (MRA)	WPC (LMA)
Planning Objectives				
(1) Ensuring future navigability				
• Provide appropriate maintenance measures to existing facilities	yes	yes	yes	yes
• Provide new, improved or replacement facilities (as economically justified)	no	yes	yes	yes
(2) Improving navigation efficiency				
• Schedule and execute maintenance	partial yes	yes	yes	yes
• Include low-cost structural options to maximize NED	yes	yes	yes	yes
(3) Enhancing ES				
• Minimize degradation of natural resources	no	partial yes	partial yes	yes
• Improve sustainability of resources in and along the Ohio River	no	no	no	no
Decision Criteria				
Completeness[a]	least best	third best	second best	best
Efficiency[b]	least best	third best	second best	best
Effectiveness[c]	least best	third best	second best	best
Acceptability[d]	least best	third best	second best	best
New Authorizations				

Evaluation Factors	Navigation-Related Plan			
	WOPC (RMA)	WPC (AMA)	WPC (MRA)	WPC (LMA)
Authorizations needed[e]	none	none	some	most

Definitions of factors

[a] Completeness = the extent to which the alternative plan provides and accounts for all necessary investment or other actions to ensure realization of the planning objectives, including actions by other Federal and non-Federal entities

[b] Efficiency = the extent to which an alternative plan is the most cost-effective means of achieving the objectives

[c] Effectiveness = the extent to which the alternative plan contributes to achieving the planning objectives

[d] Acceptability = the extent to which the alternative plan is acceptable in terms of applicable laws, regulations, and public policies

[e] Authorizations needed = new authorizations needed to accomplish the plan

Definitions of descriptive codes

yes = the plan satisfies the sub-objective statement

no = the plan does not satisfy the sub-objective statement

partial yes = the plan partially satisfies the sub-objective statement

best = relative to the four plans, this is the "best plan" for either satisfying the sub-objective or an individual decision criterion (completeness, efficiency, effectiveness, or acceptability)

second best = second best plan as per definition of best plan above

third best = third best plan as per definition of best plan above

least best = least best plan as per definition of best plan above

most = most new authorizations are needed to accomplish the plan

some = some new authorizations are needed to accomplish the plan

none = no new authorizations are needed to accomplish the plan

3. The following summary observations can be made based on the relative comparisons in **Table 10-45**:

- Relative to the planning objectives, the MRA and LMA both satisfy the two navigation-related planning objectives – ensuring future navigability and improving navigation efficiency. Neither plan satisfies the objective related to enhancing ES.

- Relative to the four decision criteria, the LMA is considered as the best plan for satisfying the completeness, efficiency, effectiveness, and acceptability specifications. The RMA is the least best in these comparisons.

- In relation to new authorizations, the LMA will require the most because it is the most all-inclusive and most comprehensive of the four plans.

Finally, based on the overall comparisons in **Table 10-34,** the following rank order from highest to lowest can be delineated for the four plans:

4 = best plan = LMA
3 = second best plan = MRA

2 = third best plan = AMA
1 = least best plan = RMA

Based on this rank order, the LMA could tentatively be identified as the NED plan.

4. **Table 10-46** summarizes the overall comparisons of the three ES-related alternative plans. As was the case with the navigation-related plans, the ES plans are also progressive from left to right. That is, the ES-related Minimal Plan includes Groups A and B measures; while the ES-related Moderate Plan includes Groups A, B, and C measures. The ES-related Maximum Plan includes all four groups of measures. As was the case for **Table 10-45**, **Table 10-46** also reflects three groups of comparisons. Further, the footnotes include definitions for the four planning criteria and descriptor word comparisons used in the table. The selected descriptive codes are based upon information contained in Sections 8 and 9.

TABLE 10-46
Overall Comparisons of the Features of the ES-Related Alternative Plans

Evaluation Factors	ES-Related Plan		
	Minimal (A, B)	Moderate (A, B, C)	Maximum (A, B, C, D)
Planning Objectives			
(1) Ensuring future navigability			
• Provide appropriate maintenance measures to existing facilities	no	no	no
• Provide new, improved or replacement facilities (as economically justified)	no	no	no
(2) Improving navigation efficiency			
• Schedule and execute maintenance	no	no	no
• Include low-cost structural options to maximize NED	no	no	no
(3) Enhancing ES			
• Minimize degradation of natural resources	partial yes	partial yes	partial yes
• Improve sustainability of resources in and along the Ohio River	partial yes	yes	yes
Decision Criteria			
Completeness[a]	least best	second best	best
Efficiency[b]	least best	best	second best (many unknowns)
Effectiveness[c]	least best	best	second best (many

Evaluation Factors	ES-Related Plan		
	Minimal (A, B)	Moderate (A, B, C)	Maximum (A, B, C, D)
			unknowns)
Acceptability[d]	least best	best	second best (many unknowns)
New Authorizations			
Authorizations needed[e]	none	some	most

Definitions of factors

[a] Completeness = the extent to which the alternative plan provides and accounts for all necessary investment or other actions to ensure realization of the planning objectives, including actions by other Federal and non-Federal entities

[b] Efficiency = the extent to which an alternative plan is the most cost-effective means of achieving the objectives

[c] Effectiveness = the extent to which the alternative plan contributes to achieving the planning objectives

[d] Acceptability = the extent to which the alternative plan is acceptable in terms of applicable laws, regulations, and public policies

[e] Authorizations needed = new authorizations needed to accomplish the plan

Definitions of descriptive codes

yes = the plan satisfies the sub-objective statement

no = the plan does not satisfy the sub-objective statement

partial yes = the plan partially satisfies the sub-objective statement

best = relative to the three plans, this is the "best plan" for either satisfying the sub-objective or an individual decision criterion (completeness, efficiency, effectiveness, or acceptability)

second best = second best plan as per definition of best plan above

least best = least best plan as per definition of best plan above

most = most new authorizations are needed to accomplish the plan

some = some new authorizations are needed to accomplish the plan

none = no new authorizations are needed to accomplish the plan

5. The following summary observations can be made based on the relative comparisons in **Table 10.46**:

- Relative to the planning objectives, none of the three ES-related plans satisfy the planning objectives related to ensuring future navigability and improving navigation efficiency. For the "enhancing ES" objective, all three plans would aid to some extent, in the sub-objective related to minimizing degradation of natural resources. For the "improve sustainability" sub-objective, the Moderate Plan and the Maximum Plan both receive a "yes" since they will both aid in improving resource sustainability.

- Relative to the four decision criteria, the Moderate Plan is considered as the "best plan" for satisfying the decision criteria. The comprehensiveness of the Maximum Plan is accompanied by several scientific, policy, funding and timing uncertainties that led to its designation as "second best". Further, the broad scale

of several actions (see Group D of **Table 8-9**) considered under the Maximum ES Plan also adds to the complexity and uncertainty of this option.

- In relation to required new authorizations, the most would be associated with the Maximum Plan, with some such authorizations also required for the Moderate Plan.

- Finally, based on the overall comparisons in **Table 10-46**, the following rank order from highest to the lowest plan, can be delineated as follows:

  3 = best plan = Moderate Plan
  2 = second best plan = Maximum Plan
  1 = least best plan = Minimal Plan

6. Based on this rank order, the ES-related Moderate Plan could tentatively be identified as the NES Plan.

10.3.7 Detailed Comparison of the Alternative Plans

1. In addition to the overall comparisons of the four navigation-related plans in Section 10.3.6, as well as such comparisons for the three ES-related plans, the Corps' Planning Guidance Notebook also infers that detailed comparisons should be accomplished. Specific comparative factors should be selected based on appropriate identified economic and ES metrics. Such metrics should be connected to the planning objectives of the specific study. As was the case in Section 10.3.6, the four navigation-related plans and three ES-related plans are subjected to separate detailed comparisons herein to facilitate the identification of a NED plan and a NES plan.

2. **Table 10-47** summarizes the detailed comparisons of the four navigation-related alternative plans. Again, the plans are progressive from left to right. That is, the AMA includes the RMA; the MRA includes the AMA; and the LMA includes the MRA. The rows in **Table 10-47** reflect seven economic metrics and five ES metrics. Summary descriptions of the metrics, and their units of expression, are contained in the footnotes.

Table 10-47
Detailed Comparisons of the Features of the Navigation-Related Alternative Plans

Evaluation Factors	Navigation-Related Plan			
	WOPC (RMA)	WPC (AMA)	WPC (MRA)	WPC (LMA)
Economics Metrics[a]				
• Range of system benefits	$2252.8(CS)[b] - 2460.1(UBH)	$2365.8(CS) - 2584.4(UBH)	$2368.6(CS) - 2597.7(UBH)	$2400.6(CS) - 2693.4(UBH)
• System costs	$99.0(CS) - 100.2(MCS & UBH)	$100.0(UB) - 101.7(NAAQS)	$97.4(UB) - 98.8(NAAQS)	$118.0(CS) - 121.5(NAAQS)

• Net benefits	$2153.8(CS) - 2360.1(UBH)	$2265.0(CS) - 2484.1(UBH)	$2269.5(CS) - 2500.2(UBH)	$2282.6(CS) - 2574.9(UBH)
• Plan BCR	22.7(CS) - 24.6(UBH)	23.5(CS) - 25.8(UBH)	23.9(CS) - 26.7(UBH)	20.3(CS) - 22.7(UBH)
• Incremental system benefits over RMA	0	$95.1(CS) - 174.1(NAAQS)	$115.7(CS) - 181.9(NAAQS)	$147.8(CS) - 259.8(NAAQS)
• Incremental system costs over RMA	0	$0.2(UBH) - 2.8(CS)	($0.0) (CS) – (-2.6) (UBH)	$18.4(UBH) - 21.5(NAAQS)
• Incremental net benefits over RMA	0	$94.8(CS) - 172.4(NAAQS)	$115.7(CS) - 183.2(NAAQS)	$128.8(CS) - 238.3(NAAQS)
Environmental Sustainability Metrics				
• Effects indicator – eroded savings[c]	$75.8(CS) - 124.1(NAAQS)	$17.6(CS) - 74.4(MCS)	$17.6(CS) - 62.7(MCS)	$12.9(CS) - 23.6(UBH)
• Effects indicator – transit time differences (WOPC - WPC/LMA)[d]	NA[e]	NA	NA	15,500 (2015-2020); 33,500 (2030-2070); 1,725,000
• Effects indicator – HUs (NAVPAT) differences (WOPC - WPC/LMA)[f]	NA	NA	NA	See Note 1 below
• Localized direct and indirect effects on 6 key VECs[g]	See Table 10.36	See Table 10.36	See Table 10.36	See Table 10.36
• Influence on ES[h]	See Table 10.36	See Table 10.36	See Table 10.36	See Table 10.36

Descriptions of factors

[a] With the exception of the benefit cost ratio, BCR, a unitless metric, the remaining six economic metrics are average annual benefits or costs over the 2010 to 2070 study period; these annualized metrics are expressed in millions of dollars (FY03) at a discount rate of 5 1/8%. The data for the economic metrics are in Section 8 (WOPC) and the first portions of Section 10 (WPC).

[b] The letters in parenthesis refer to the five navigation traffic scenarios as follows: CS = Clear Skies, MCS = Modified Clear Skies, NAAQS = National Ambient Air Quality Standards Growth, UB = Utility Based, UBH = Utility-Based High

[c] The displayed metrics are in units of annual average eroded savings over the 2010 to 2070 study period; these annualized metrics are expressed in millions of dollars (FY03) at a discount rate of 5 1/8%. The data for these metrics are in Section 8 (WOPC) and the first portions of Section 10 (WPC).

[d] Differences in transit time within or through the navigation system are shown for equilibrium traffic for the WOPC and WPC/LMA plans, hence only the WPC/LMA column is used. The first two listed numbers represent annual reductions, in cumulative annual days, for two time periods; the final number is the cumulative transit days reduction to the 2070 end of the study period. Reductions refer to the difference in transit days between the WOPC and WPC conditions. From the viewpoint of both navigation efficiency and minimizing effects on aquatic resources, greater differences are more desirable.

[e] NA = the cell is not applicable for displaying comparative information for the factor

[f] HUs refers to habitat units associated with seven species/life stages analyzed by the NAVPAT model. HUs per se reflect both habitat quality and spatial size. Differences in HUs between the WOPC plan and the WPC/LMA plan were analyzed for all five traffic scenarios in 2010, 2040, and 2070. Further, such differences were determined for the WOPC plan from 2010 to 2070, and for the WPC/LMA plan for the same time period. [g] Brief descriptions in Table 10-36 to summarize relative direct and indirect effects on water quality, fish, mussels, riparian resources, recreation, and health and safety. Detailed descriptions of effects are in Tables 8-8 (WOPC-RMA) and 9-12(WPC-AMA, MRA, and LMA). [h] Brief descriptor words are used in Table 10.36 to summarize the influence of each plan on the overall ES of water quality, fish, mussels riparian resources, recreation, and health and safety, as appropriate. Detailed descriptions of the influences are in Sections 8.7.2 and 8.7.3 for the WOPC/RMA plan, and in Sections 9.7.1 and 9.7.2 for the three WPC plans.
Note 1: Minimal changes noted for WOPC minus WPC plans for 2010, 1040, and 2070. Some potential concerns noted for 2070 forecasts and for specific species/life stages at some lock and dam projects

3. The following summary observations can be made based on the relative comparisons in **Table 10-47:**

- The seven economic metrics can be divided into two groups. The first four are related to metrics for the four individual plans, and the latter three display incremental differences relative to the WOPC/RMA. Ranges of the metrics are included along with designators as to the traffic scenario that prompted the lowest and highest data within the range.

- Regarding the plan-related first four economic metrics, the ranges for system benefits and system costs generally increase from the RMA to the LMA plans. The LMA plan system costs are the highest of the four plans; as a result, the BCR range for the LMA plan is reduced to 20.46 to 22.56. The BCR ranges for the other three plans are from 23.40 to 27.07. The lowest BCRs for all four plans are associated with the Clear Skies scenario, while the highest are for the Utility-Based High scenario.

- Regarding the incremental benefits, costs, and net benefits, the LMA plan exhibits both the highest incremental benefits range ($84.6 million to $176.9 million) and the highest net benefits range ($66.2 million to $157.2 million). Again, the low side of both ranges is for the Clear Skies traffic scenario, and the high side is for the Utility-Based High scenario.

- Based upon the above observations relative to the seven economic metrics, the WPC/LMA plan represents the optimum choice as a navigation-related plan.

- The "eroded savings" effect indicator was described in Section 10.2.3.1. Ranges of the comparative data for each plan across the traffic scenarios are included in **Table 10-47**. For this indicator, lower "eroded savings" are reflective of lesser queuing in tailwater areas below locks, and also lesser negative effects on the tailwater habitats. For this indicator the WPC/LMA plan again reflects the optimum choice among the navigation-related plans.

- The transit time effects indicator is based on the differences in system transit days with the WOPC plan versus the WPC/LMA plan. As illustrated in **Table 10-35**, positive values for transit days are desirable because they represent system reductions in transit days between the WOPC/RMA plan and the WPC/LMA plan. **Table 10-47** indicates positive cumulative annual values for two time periods, and an overall cumulative value accrued to 2070. These displayed differences indicate that the WPC/LMA plan would be a better choice than the WOPC/RMA plan. Although not presented in **Table 10-47**, lesser positive differences would also occur for the WPC/MRA and WPC/AMA plans. Reductions in transit days are environmentally beneficial since less queuing in important tailwater habitat areas would occur. Accordingly, the WPC/LMA plan represents the optimum choice based on the transit time difference.

- Relative to the HU effects indicator, a summary discussion of the effects is in Section 10.2.3.6.3. The effects are based on differences between the WOPC/RMA plan and the WPC/LMA plan. In general, the large majority of the forecasted differences are less than the NAVPAT model's output variability threshold (plus or minus 3%); thus significant changes in HUs are not anticipated. However, further refinement of the model will improve its forecasting capabilities, and further evaluations of future HUs could be incorporated in a follow-on adaptive management program. Based upon the information in Section 10.3.7, and as included in **Table 10-47**, the WPC/LMA plan again represents the optimum choice among the four plans.

4. The final two listed factors in **Table 10-47** are summarized in **Table 10-48** and discussed as follows. To begin, it should be noted that construction of new locks at EDM requires permanent new impacts that are outside of the following summary discussion of the impacts resulting from maintenance of an existing infrastructure. Permanent new impacts include the loss of aquatic habitat within the 'footprint' of each new 600'x110' lock (approximately 2 acres), new approach dredging and maintenance, and changes to flow patterns resulting from the new lock configuration. While the ES tradeoffs of these new impacts are discussed in a qualitative fashion within the context of this Programmatic EIS, more detailed and quantitative assessment of such impacts should be addressed in project specific assessments when such projects are recommended for feasibility studies. As noted above, **Table 10-48** summarizes the ES tradeoffs of the navigation-related alternative plans with these permanent new impacts excluded.

Table 10-48
Summary of Effects of Navigation-Related Plans on ES

RMA	Individual	Impacts occur due to unscheduled repair events; impacts are temporary/local and proportional to duration/complexity of repairs. Impacts reduced somewhat by N-up/N-down & related operational & low-cost structural measures.
	Cumulative	Increasing frequency and duration of impacts as system ages.

AMA	Individual	Repair events approximately equivalent to RMA repairs, but queuing impacts somewhat reduced by scheduling vs. 'fix-as-fail'.
	Cumulative	Increasing frequency and duration of impacts as system ages, reduced by incremental effects of scheduling. Some postponement of negative ES effects of queuing.
MRA	Individual	Repair event impacts are bigger, longer duration than AMA.
	Cumulative	Reduced frequency of impacts due to consolidation of events, longer recovery between events. Additional postponement of negative ES effects vs. AMA includes reduced construction impacts.
LMA	Individual	Project impacts similar to big MRA project, longer duration.
	Cumulative	Long term benefits of increased capacity and renovated condition: repair induced queuing approaches zero and frequency of repairs declines. Notes: reduced construction related impacts due to new condition of new locks at EDM and subsequent reduction in frequency of repair events. Construction induced queuing approaches zero due to equivalent capacity of the older lock.

5. Individual impacts in **Table 10-48** refer to a single repair event that represents the most important activity for each alternative. These events are:

RMA – emergency repair in response to component failure
AMA – scheduled repair prior to expected failure of a component
MRA – scheduled repair of multiple components
LMA – construction of a new 600' x 110' lock at Emsworth, Dashields, or Montgomery

6. Cumulative impacts in this context refer to the long term effects of implementing each alternative plan as it applies to a specific lock and dam project. A follow up step for cumulative assessment would aggregate cumulative project specific impacts for the total system of 19 lock and dam projects.

7. Impacts can be subdivided into two principal categories: construction impacts and construction induced queuing. Construction impacts are directly proportional to the scope and duration of the overall project, while queuing impacts are directly proportional to the duration of main chamber lock closures that occur during the construction.

8. The following represent a rank ordering of the individual and cumulative effects of the three WPC plans:

AMA Individual impacts
-construction related AMA=RMA
-queuing AMA<RMA

AMA Cumulative impacts
-construction related AMA=RMA
-queuing AMA<RMA

MRA Individual impacts
-construction related MRA>AMA=RMA
-queuing MRA>AMA<RMA

MRA Cumulative impacts
-construction related MRA<AMA=RMA
-queuing MRA<AMA<RMA

LMA Individual impacts
-construction related LMA>MRA>AMA=RMA
-queuing LMA>MRA>AMA<RMA

LMA Cumulative impacts
-construction related LMA<MRA<AMA=RMA
-queuing LMA<MRA<AMA<RMA

9. To summarize the above rank ordering, if the WPC/LMA plan is selected, the individual direct and indirect effects will be greater than the other two WPC plans, with the difference primarily related to construction effects for locks at EDM. However, from a cumulative effects perspective, the LMA plan would result in lesser effects than the other two plans. Further, the lesser cumulative effects would be a positive contribution to the ES of the six key VECs (water quality, fish, mussels, riparian resources, recreation, and health and safety).

10. Finally, based on the detailed comparisons in **Tables 10-36** and **10-37**, and more extensive comparative information in Section 8 (WOPC), Section 9 (WPC), and earlier portions of Section 10 (WPC), the following rank order from the highest to the lowest plan, can be delineated for the four plans as follows:

4 = best plan = LMA
3 = second best plan = MRA
2 = third best plan = AMA
1 = least best plan = RMA

This rank order confirms the selection of the LMA as the NED plan. This same finding occurred in Section 10.3.6 for the overall comparisons.

11. **Table 10-49** summarizes the detailed comparisons of the three ES-related alternative plans. The ES plans are progressive from left to right; that is, the Minimal Plan includes the Groups A and B measures, the Moderate Plan includes the Groups A, B, and C measures, etc. The comparative information in **Table 10-49** is entirely based on the use of descriptive codes, which are defined in the explanatory notes. This approach

the use of descriptive codes, which are defined in the explanatory notes. This approach was necessary since neither a detailed analysis of the costs of the three plans, nor their environmental benefits, effects, and specific influences on ES, has been conducted. Nevertheless, the following summary observations can be made relative to the comparisons in **Table 10-49**:

- Relative to the economics-related metrics, the Moderate Plan is anticipated to be the best choice at this time. While the Maximum Plan has the potential to be the best ES-related plan, there are unknowns as to the effectiveness and costs of the Group D measures.

- Relative to the ES metrics, the Moderate Plan is anticipated to be the best choice at this time. Unknowns and uncertainties are still associated with the Maximum Plan.

Based on the above information, the rank order of the three ES-related plans are as follows:

3 = best plan = Moderate Plan
2 = second best plan = Maximum Plan
1 = least best plan = Minimal Plan

Based on this rank order the Moderate Plan could tentatively be identified as the NES Plan. This same finding occurred in Section 10.3.6 for the overall comparisons.

10.3.8 The Combined NED/NES Plan

Based on the overall comparisons in Section 10.3.6, and the detailed comparisons in Section 10.3.7, the combined NED/NES plan is as follows in **Table 10-49**: NED (WPC/LMA Plan) and NES (Moderate ES Plan).

Table 10-49
Detailed Comparisons of the Features of the ES-Related Alternative Plans

Evaluation Factors	ES-Related Plan		
	Minimal (A, B)	Moderate (A, B, C)	Maximum (A, B, C, D)
Economics-Related Metrics[a]			
• Plan environmental outputs (benefits)[b]	Minimal	Moderate	Maximum
• Plan costs	Minimal	Moderate	Maximum
• Plan net benefits	Minimal	Moderate	Maximum (but has unknowns and uncertainties)
• Plan Justified?	>Yes - lowest	>Yes - optimal	>Yes but has unknowns and

	outputs	outputs	uncertainties
• Incremental environmental outputs (benefits) relative to Minimal Plan	0	Positive	Positive
• Incremental costs relative to Minimal Plan	0	Greater	Greater
• Incremental net benefits relative to Minimal Plan	0	Positive	None Assigned
Environmental Sustainability Metrics[c]			
• Effects indicator-eroded savings[d]	NA	NA	NA
• Effects indicator-transit days[e]	NA	NA	NA
• Effects indicator-HUs (NAVPAT)[f]	NA	NA	NA
• Localized direct and indirect effects on 6 key VECs[g]	Minimal	Moderate	Maximum
• Influence on ES	Positive	More Positive	Most Positive

Definitions of factors

[a] With the exception of environmental outputs and BCR, the listed metrics would normally be expressed in similar units as those displayed in Table 10-35. However, since a detailed analysis of the economic parameters for the ES-related plans was not conducted, descriptive codes are used in Table 10-37. Information related to the measures included in Groups A, B, C, and D comprising the plans is in Sections 8.0 (WOPC) and 9.0 (WPC).

[b] Environmental outputs (or benefits) would typically be expressed in Habitat Units, quality improvements, or by other means. A detailed study to quantify the anticipated outputs has not been accomplished, thus descriptor codes are used in Table 10.37.

[c] The environmental sustainability of six key resources (water quality, fish, mussels, riparian resources, recreation, and health and safety) represents the focus of the three ES-related plans. The first four listed factors potentially contribute to ES, and the fifth factor represents a composite consideration of the first four.

[d, e, f, g] See definitions in Table 10.35.

Definitions of Descriptive Codes

Minimal = minimal (or least) metric in terms of the three ES-related plans and the related factor

Moderate = a mid-scale value in terms of the three ES-related plans and the related factor

Maximum = maximum (or highest) metric in terms of the three ES-related plans and the related factor

Positive = better than the Minimal Plan in relation to environmental outputs, net benefits, or influence on ES

None Assigned = no descriptor code used due to unknowns and uncertainties associated with the incremental comparisons

Greater = the costs for the Moderate Plan are greater than the costs for the Minimal Plan

NA = not applicable relative to the ES-related plan and the factor

More Positive = better than the Minimal Plan in relation to influence on ES

Most Positive = for the three ES-related plans, has the greatest potential for influencing ES

10.4 PREFERRED PLAN

The preferred plan includes all features of the best navigation (NED Plan) and environmental sustainability (NES Plan) investment plans as described in Sections 10.1 and 10.2. This combined plan maximizes the sum of net economic and environmental

benefits. The focus on planning and budgeting for low cost projects or site specific studies will be based on the combined plan. These actions will be spelled out as recommendations in Section 12.

10.4.1 Mitigation

1. A comprehensive investigation was conducted to determine mitigation opportunities and authorities available to the Corps. That discussion can be found at 8.5.2.1 of the SIP/PEIS. It must be understood that this document is programmatic in nature and does not seek authorization for any specific projects. Instead, it provides a roadmap for the most efficient modernization strategy to keep the navigation system functioning for the next 60 years and identifies types of ecosystem sustainability improvement needs. With the aid of this report, the Corps will develop feasibility level plans for each major recommendation that will identify the site specific plan that is most economically justified and environmentally beneficial. It is at this level that environmental impacts are best understood and site specific mitigation is best designed.

2. There are commitments the Corps will make toward mitigating systemic environmental impacts. Foremost of these, the Corps will adopt sustainability-focused mitigation measures as identified in the SIP/PEIS for its future actions. While potential measures identified in mitigation plans have typically focused on replacement-in-kind for anticipated adverse effects of planned projects, plans for future mitigation could include measures directed toward enhancing the environmental sustainability of affected resources and ecosystems. Such measures would be perceived as "sustainability-focused mitigation measures".

3. The Corps recognizes that actions it has taken in the past, prior to enactment of the National Environmental Policy Act, have had and continue to have profound impacts on certain environmental resources associated with the river, most notably mussels and lithophilic fishes. These adverse effects are a result of the navigation dams that have inundated and facilitated siltation of extensive reaches of formerly clean gravel or rubble substrate. Although impacts from the presence of the navigation projects will continue, several types of measures were identified that would improve conditions for aquatic and riparian resources. In regard to improving stewardship of Ohio River environmental resources, at the invitation of the Fish and Wildlife Service an annual meeting will be held between the Lakes and Rivers Division and District Commanders of the Corps and the Regional Directors of the USFWS Regional Offices with jurisdiction over the Ohio River to discuss where the agencies could become better stewards of the environment and participate, within our authorities, in making the river more sustainable.

The Corps of Engineers does not have an authority that would allow compensatory mitigation for impacts of past actions at full Federal expense. For ecosystem restoration where a Corps project caused or contributed to the degradation, Congress authorized Section 1135 of WRDA 1986, as amended, for the Federal government to provide a greater share of project costs than under other ecosystem

restoration authorities. Section 1135 is cost shared at 75% Federal and 25% non-Federal, whereas most other ecosystem restoration authorities are cost shared at 65% Federal and 35% non-Federal. Section 1135 has a Federal funding limit of $5,000,000 per project. Therefore it could not be used on large scale efforts to correct problems caused by existing projects. Section 8.5.2.1., paragraph 7. describes another authority, Section 216 of the River and Harbor and Flood Control Act of 1970 that could be used for large scale modification of projects. Section 216 projects require cost sharing with a non-Federal sponsor for feasibility study costs and project implementation.

4. The Corps recommended plan in the SIP/PEIS is the first step toward mitigating (i.e., minimizing) for traffic impacts. The areas of the river most subjected to navigation related impacts are the downstream approaches to the lock chambers where most of the remaining riverine habitat exists. By increasing reliability of the existing chambers (and constructing new chambers in the upper river), the time it takes to move traffic through this stretch of river will be reduced greatly. Transit Days are the days it takes to move one tow from point of origin to its destination. By implementing reliability improvements, we estimate that Transit Days will be reduced by 1.5 million over the study period. Since interpool transit rates will not change due to recommended improvements, the reductions will all be accounted for at the locks. Those days should be equally divided between up-bound and down-bound, therefore, there should be 750,000 less Transit Days, and concomitant impacts, in the lower approaches.

5. To address more systemic issues related to the navigation system, the Corps will incorporate several environmental components into future site specific studies that this report recommends:

a. Evaluation and, if feasible, implementation of fish passage strategies at each lock and dam along the Mainstem during studies for lock modernization and major rehabilitation.

b. Continuance and expansion, as needed, of the Interagency Working Group to participate in and to review and comment on studies as they progress.

c. Identification, description and quantification of riverine habitat within the individual project's area of influence.

d. Incorporatation of sustainability planning within each individual project's area of influence.

e. Development of a National Environmental Restoration (NER) Plan that will become part of the Combined NED/NER Plan for authorization of each site specific project. As required for navigation investments, however, all separable restoration costs will require a cost sharing partner.

SECTION 11
COORDINATION AND COMMENTS ON DRAFT REPORT

Public review of the May 2006 Draft System Investment Plan/Programmatic Environmental Impact Statement (SIP/PEIS) Main Report and Economic, Engineering, Environmental, and Communications Appendices occurred during the period May 26 – July 25, 2006. The Louisville District sent copies of the main report and appendices to various state, Federal, and local agencies – in partial fulfillment of the requirements of the National Environmental Policy Act (NEPA) - either in hard copy or Adobe Acrobat format on CDROM-disk. Copies were also sent to individuals who had previously indicated an interest in the study. **Table 11-1** lists all agencies receiving the report either in hard copy or in CDROM-disk at the beginning of the public review period.

The report was also sent to libraries in 13 major population centers along the Ohio River. In addition, over 3000 copies of a "Notice of Availability of the draft SIP/PEIS" were mailed at the same time. (A copy of the information contained in this mailing is shown in Exhibit 1.) This larger distribution included Federal, State and local agencies and government officials; transportation groups; navigation interests; environmental groups that have been active in navigation issues; U.S. Senators and Congressmen; libraries and news media in the Ohio Valley; and individuals who previously indicated an interest in Ohio River navigation.

Following distribution of the Notice, copies of the report on CDROM-disk were distributed to the general public on request. Digital versions of these documents were also available for download to Personal Computers via the Internet from the Louisville District public Internet site. The official review period comprised 60 days.

Table 11-1
Agencies and Organizations Receiving Report
at Beginning of Review Period

Illinois Department of Natural Resources, Springfield
Indiana Department of Natural Resources, Indianapolis
Ohio Department of Natural Resources, Hebron
Ohio River Sanitary Commission, Cincinnati
Pennsylvania Fish and Boat Commission, Bellefonte
U.S. Environmental Protection Agency, Region 5, Chicago, Illinois
Kentucky Department of Fish and Wildlife Resources, Frankfort, Kentucky
U.S. Environmental Protection Agency, Region 4, Atlanta, Georgia
U.S. Environmental Protection Agency, Region 3, Philadelphia, Pennsylvania
U.S. Geologic Service, La Crosse, Wisconsin
U.S. Fish and Wildlife Service, Region 3, Fort Snelling, MN
U.S. Fish and Wildlife Service, Region 4, Atlanta, Georgia
U.S. Fish and Wildlife Service, Region 5, Hadley, Massachusetts
U.S. Fish and Wildlife Service, Frankfort, Kentucky
U.S. Fish and Wildlife Service, Marion, Illinois
U.S. Fish and Wildlife Service, Cartersville Fisheries Office, Marion, Illinois
U.S. Fish and Wildlife Service, Bloomington, Indiana
U.S. Fish and Wildlife Service, Reynoldsburg, Ohio
U.S. Fish and Wildlife Service, Elkins, West Virginia
U.S. Fish and Wildlife Service, Ohio River Islands, Parkersburg, West Virginia
The Nature Conservancy, Dublin, Ohio
Ohio River Foundation, Cincinnati, Ohio
Southern Illinois University, Carbondale, Illinois

Public meetings were held in Monaca, PA (just outside Pittsburgh), Marietta, OH, Huntington, WV, Metropolis, IL, Evansville, IN, and Covington, KY. The meetings were announced in four ways:

- All meetings were announced in the Notice of Availability of the draft SIP/PEIS described above.

- The Huntington, Louisville and Pittsburgh District Public Affair's offices issued news releases to the news media organizations in their respective Districts. (A copy of the Pittsburgh District's news release is included as Figure 11-2

- ***Federal Register*** Notice dated May 26, 2006 (Volume 71, Number 102) {Page 30391 – 30393).

- Meeting information and the text of the "Notice of Availability" of the report were available via computer on the Louisville District public Internet site, with links to this information placed on the Huntington and Pittsburgh District public Internet sites.

There were four ways that formal comments could be submitted: statement at any of the public meetings, letter, e-mail, or by phone. All comments were considered in preparation of this final draft. Comments were received from the following agencies and individuals:

1. R. Mike Morton, area resident
2. Irving Materials
3. Lyndon LaRouche Political Action Committee
4. Dave Clark, Paducah Power
5. Douglas Hess, Jr., Clearchannel
6. Rob Webb, Crounse Corp.
7. Anthony Davis, Louisville District, Corps of Engineers
8. Kentucky Department of Fish & Wildlife Resources, Commerce Cabinet
9. Pennsylvania Environmental Council
10. Ohio River Foundation
11. Eric Hollins, area resident
12. Riverfields, Inc.
13. U. S. Department of the Interior
14. Waterways Council, Inc.
15. Pennsylvania Fish and Boat Commission
16. Illinois Department of Natural Resources
17. U.S. Environmental Protection Agency, Region 5
18. Western Pennsylvania Conservancy
19. Indiana Department of Natural Resources
20. Port of Pittsburgh Commission
21. Southwestern Pennsylvania Planning Commission
22. Ohio Department of Natural Resources, Division of Wildlife

23. Claire Rieger, area resident
24. Unidentified Speakers at Public Meetings
25. LaRouche Youth Movement
26. Evansville, Indiana Port Authority Board
27. Inland Marina, Evansville
28. Bob Dieg, area resident
29. Evansville Marine Service
30. Moser Crushed Stone
31. Nick Damosko, area resident
32. Rick Pope, area resident
33. Russell Swankey, area resident
34. Wayne Lithow, area resident

All comments are either reprinted or summarized and Corps responses are provided in **Table 11.2**, along with the report section if any that was modified to accommodate the response. The number before the dash in each comment number indicates the commenter noted above.

TABLE 11-2
Comments on Draft Report And Responses

Comment #	Comment	Response	Revised Section
1-1	Disappointed at lack of discussion of environmental restoration, ecological restoration and recreational access improvements at the public meeting. What is status of advertised restoration of resources mentioned in "Ohio River, Future Navigation and Environmental Improvements" brochures?	The Corps shares your concern about the importance of improving ecological and recreational activities on the river. We spent a great deal of time reviewing these and other resources to better understand if they are sustainable or not. The Corps has authorities that allow us to address ecological and recreational issues and stand ready to use them if a suitable non-federal cost sharing partner steps forward. Just as navigation improvements are cost shared with the navigation industry, ecological and recreational improvement must be also. Until then, we will do what we can to address your concerns under good environmental design and mitigation for site specific features.	None
2-1	Supports a schedule of much needed repairs and replacements (not reactionary) to structures well into, at, or beyond their projected service life.	Support for study recommendations is noted and appreciated.	None
3-1	Supports the proposed Lock Modernization Alternative and construction needs at Emsworth, Dashields, and Montgomery L/Ds.	Support for study recommendations is noted and appreciated.	None
4-1	Nothing mentioned in Executive Summary about needs at Smithland, is it because it's new?	Smithland is relatively new, less than 40 years old and has twin 1200' long chambers. Therefore it is a low priority. Projected maintenance needs at Smithland are listed in Section 10, Table 10-31.	None
5-1	Disappointed in advertising public meeting in Marietta, Ohio.	We will work to improve our methods for notifying the public about upcoming meetings.	None

Comment #	Comment	Response	Revised Section
6-1	Would ton miles be a more accurate indicator of growth on the Ohio River?	Perhaps, but not necessarily. Corps analysis to estimate benefits from an improved inland navigation system is guided by Engineering Regulation (ER) 1105-2-100. The regulation defines National Economic Development (NED) benefits as cost reduction, shift of mode, shift of origin or destination, or a new movement and identifies the total tonnage that could benefit from using the waterway. The regulation directs us to cost navigation movements on a per ton basis. All of our transportation rate analyses, conducted by transportation specialists at the Tennessee Valley Authority (TVA), are performed on a per ton basis in accordance with ER 1105-2-100. However, we do use ton-mile measures. Ton-miles measure freight when we extrapolate rate data to the population of unsampled movements. Also, ton-miles are used as a metric in the annual Corps budget process to prioritize different navigable waterways and channels.	None
7-1	Observations that maintenance backlogs continue to grow and that failure of a navigation structure would create logistical problems for shippers.	A desired outcome of the SIP is the development of maintenance policies that reduce and eventually eliminate these backlogs. Of course, our ability to accomplish this will be subject to future funding levels for Operations and Maintenance.	None

Comment #	Comment	Response	Revised Section
8-1	Adaptive Management: Resource agency involvement should be a critical component of an adaptive management plan promoted in the Ohio River Mainstem System Study. Stakeholder involvement with each future project development should include individual state resource agencies.	Section 13.10 of the CEA report states that developing and implementing an adaptive management program for the Ohio River system could occur over time through the efforts of many stakeholders, but would be unlikely to occur in a focused way without 1) authorization of an agency to initiate a program, 2) formation of a broadly representative stakeholder group (including state resource agencies), and 3) funding over a long term.	None
8-2	Fish passage: The ORMSS should consider the potential need to address fish passage and opportunities. Fish passage should be considered in the context of the entire river. Individual projects should seek to implement fish passage components to meet identified needs.	Concur. Fish Passage has been identified as a system mitigation feature that will be evaluated at the site specific level.	10.4.1
8-3	Ecosystem Funding: Funding should be programmed for the selection and implementation of ecosystem restoration projects. Funding for implementation is lacking. Existing programs like Section 206 and 1135 do not effectively meet ecosystem needs. Matching requirements for these two programs are not attractive to sponsors. Where Ohio River ecosystem grants have been available, there have been funds for planning stages but not for implementation. As a result, Section 206 or 1135 projects are not cost effective or are not attractive to state wildlife agencies because of inadequate funding for project completion.	Current law and Corps policy requires cost sharing with a non-federal sponsor for ecosystem restoration projects. If a non-federal partner is identified, the Corps now has the authority to develop an ecosystem restoration plan that would become part of the combined plan and be authorized along with each site specific navigation project. The Corps is not authorized to administer any grants programs for implementing ecosystem restoration.	None
8-4	Ecosystem restoration should be fully funded concurrently with future projects on the river to achieve sustainability. Using ecosystem grants that require matching contributions from state or organizations should not be a required source of funding.	The Ohio River Ecosystem Restoration Program is now eligible for deauthorization. The fact that it is yet unfunded and eligible for deauthorization will be more clearly communicated throughout the final report.	Executive Summary and Other Sections

Comment #	Comment	Response	Revised Section
8-5	Ecosystem projects should be fully funded without cost share requirements	The Ohio River Ecosystem Restoration Program is now eligible for deauthorization. The fact that it is yet unfunded and eligible for deauthorization will be more clearly communicated throughout the final report.	Executive Summary and Other Sections
8-6	A formal lead or team should be created to identify and promote the development of ecosystem restoration projects.	This will be decided during the implementation of the PIP should the Ecosystem Restoration Program receive funding for implementation.	None
8-7	There should be adequate funding to complete ecosystem restoration project implementation, not just preliminary planning.	The Ohio River Ecosystem Restoration Program is now eligible for deauthorization. The fact that it is yet unfunded and eligible for deauthorization will be more clearly communicated throughout the final report.	Executive Summary and Other Sections
8-8	Mitigation through Section 10/404 should be included as potential sources of matching non-federal funds when opportunities exist.	Using mitigation funds under the Sections 10/404 or any other type of mitigation as the non-federal cost share is prohibited by Corps Regulation.	None
8-9	Watershed based perspective should be given to matching funds requirements. Projects with Ohio River benefits but which may not be physically connected to a specific ecosystem project should be considered as a viable source of matching funds.	The program is currently limited to the Ohio River mainstem and its floodplain. Congress would have to modify the authority to extend the program into the watershed.	None
8-10	Funding should be added to individual Corps projects in the future as a potential means to implement ecosystem restoration projects.	The Corps' policies do not allow implementation of ecosystem restoration at 100% federal expense. Where compensatory mitigation is required for project impacts, such restoration is a project feature and is cost shared with the inland navigation trust fund for navigation projects.	None

Comment #	Comment	Response	Revised Section
8-11	Individual and/or competitive grants could be developed for implementation of individual ecosystem projects.	A list of federal conservation grants available to states and local governments and NGOs has been added to Section 8.5.4. The Corps does not currently have an authorized conservation grant program. It is unknown which, if any, of these could be used as a non-federal share of a cost shared ecosystem restoration project.	8.5.4
8-12	Floodplains-Bottomland Forest, Wetlands, and Riparian Corridor: Emphasis on restoring floodplains, wetlands, and riparian corridors should be prioritized with an emphasis on building upon existing conservation lands and maximizing opportunities. There are several identified opportunities along the Ohio River which would serve as viable restoration projects.	Floodplains, Bottomland Forests, wetlands, and riparian corridors were all identified for restoration efforts under the Ohio River Ecosystem Restoration Program. Aquatic habitat was also identified as targets for restoration. The sustainability needs analysis conducted for the ORMSS SIP/PEIS also included the need for action in these types of habitat.	None
8-13	We specifically highlight the need for enhancing areas with some existing free-flow conditions, restoring connectivity to tributary systems or embayment habitat, and restoring adjacent wetlands as part of the sustainability model. Several ecosystem projects in these areas have been identified previously but remain unfunded at the same time that commercial projects are being constructed.	Restoration of connectivity, both laterally and longitudinally were determined to be high priority needs in the sustainability analysis. Ecosystem restoration projects to address this need could be constructed but require cost sharing partners to proceed.	None
8-14	We specifically highlight the need for enhancing areas with some existing free-flow conditions, restoring connectivity to tributary systems or embayment habitat, and restoring adjacent wetlands as part of the sustainability model. Several ecosystem projects in these areas have been identified previously but remain unfunded at the same time that commercial projects are being constructed.	Restoration of connectivity, both laterally and longitudinally were determined to be high priority needs in the sustainability analysis. Ecosystem restoration projects to address this need could be constructed but require cost sharing partners to proceed.	None

Comment #	Comment	Response	Revised Section
8-14	It is appropriate to consider off-setting the cumulative effects to fish and wildlife through supplemental stocking and habitat restoration methods. In light of identified cumulative effects and the difficulty in getting habitat restoration implemented, it is appropriate to include supplemental fish and wildlife stocking as a reasonable and achievable option for addressing sustainability. We recommend that the Corps consider funding supplementing rearing or stocking efforts as a potential ecosystem restoration project. Fish or mussel stocking programs are on-going and might be used to supplement ecological restoration projects or to supplement populations in existing habitat.	Corps of Engineers Ecosystem Restoration efforts emphasize improving ecosystem function (in areas degraded by human activities) to a more natural condition. Supplemental stocking would not be included under ecosystem restoration, although there may be situations where reestablishment of extirpated species or communities could be considered following habitat restoration.	None
8-15	The Corps should work with stakeholders in a comprehensive fashion. For example, in some cases the Corps has not been receptive to coupling Section 10/404 mitigation to ecosystem projects, even in planning phases and when funding was entirely separated. This is counter-productive to achieving a desirable end result and ignores long-term and comprehensive ecosystem needs. The Corps should work under a comprehensive approach that is inclusive of watershed interests.	Using mitigation funds under the Sections 10/404 or any other type of mitigation as the non-federal cost share is prohibited by Corps Regulation. Such use would amount to"double counting." The Corps' Environmental Operating Principles require the agency strive for Environmental Sustainability and to respect the views of others. To be consistent with these principles, the Corps is seeking ways to develop a comprehensive approach to the way we do business on the river.	None
9-1	The Council supports the comprehensive study and plan for navigational improvements, particularly upgrades to Emsworth, Dashields and Montgomery Locks and Dams.	Noted.	None
9-2	It is crucial to conduct the navigational improvements while at the same time implementing ecological restoration efforts along the Ohio River corridor.	If a non-federal partner is identified, The Corps now has the authority to develop a National Environmental Restoration (NER) Plan that would become part of the Combined NED/NER Plan and be authorized along with the each site specific navigation project.	None

Comment #	Comment	Response	Revised Section
9-3	Efforts to maintain and restore riparian areas in the upper river will aid in abating flooding and preventing pollutant loading downstream. In order to accomplish this, the Council recommends the Corps obtain funding for Ohio River Ecosystem Restoration Program authorized by WRDA 2000.	The Ohio River Ecosystem Restoration Program is now eligible for deauthorization. The fact that it is yet unfunded and eligible for deauthorization will be more clearly communicated throughout the final report.	Executive Summary and Other Sections
9-4	Pursue planning and implementation of measures to improve environmental sustainability, including all reasonable and prudent measures identified in the ESA Section 7 consultation.	Noted.	None
9-5	Initiate preparation of the Program Implementation Plan for the Ohio River Ecosystem Restoration Program.	The Ohio River Ecosystem Restoration Program is now eligible for deauthorization. The fact that it is yet unfunded and eligible for deauthorization will be more clearly communicated throughout the final report.	Executive Summary and Other Sections
10-1	Disappointed that study recommendations do not include mitigation at the locks and dams to improve the ecology of the river. As detailed in section 8.5.2, legal authority exists for the Corps to institute mitigation measures now. These measures do not require funding under the authorized Ohio River Ecosystem Restoration Program, for example, fish passage.	Mitigation has been added to the final report under section 10.4.1.	10.4.1
10-2	It is not the intent or design of the Ohio River Ecosystem Restoration Program to fund mitigation projects. For the Corps to suggest otherwise would be an abrogation of its legal responsibility to mitigate for impacts caused by any of its projects or operations.	The Ohio River Ecosystem Restoration Program was authorized to restore habitat along the mainstem. It was not intended to fund mitigation.	None
10-3	By its failure to recommend what mitigation actions should be taken, the Corps fails to understand that in an attempt to avoid it legal responsibilities it will be undermining the efforts of thousands of Ohio River valley citizens.	Mitigation has been added to the final report under section 10.4.1.	10.4.1

Comment #	Comment	Response	Revised Section
10-4	Itemize the benefits in Table 2 in Executive Summary (ES). What do the costs in Table 2 represent? How much of the savings is subsidies?	The benefits in Table 2 are the transportation rate savings associated with system equilibrium traffic relative to least cost all-overland (alternative) routing. This also is in compliance with ER 1105-2-100. The costs represent a base-level estimate of federal expenditure on the operation, maintenance and repair of the mainstem to provide a minimum level of service. This federal expenditure could be conceived as a subsidy to the shipping public that utilizes the Ohio River mainstem much the same way that commercial trucking benefits from federally funded highway projects and railroads benefit from free lands and rights-of-ways.	None
10-5	Same questions for Table 4 of ES as Table 2.	Incremental benefits are the additional transportation rate savings for with-project equilibrium traffic relative to without-project equilibrium traffic. Most of this benefit is derived from cost reduction and shift-of-mode associated with a more efficient and reliable navigation system. The incremental costs are the additional federal and waterway trust fund dollars that buy the more efficient, reliable navigation system. Incremental net benefits are the difference in these two and the benefit cost ratio is simply the incremental benefit to incremental cost ratio. Total federal/trust fund costs range around $118 m per year for each of the next 60-years.	None

Comment #	Comment	Response	Revised Section
10-6	Implications of Assumption #4 on benefits, modeled or actual? If modeled, are they such when operating at full capacity? Why use full capacity for benefits when, as shown in Figure 6-2, locks are operating at less than capacity?	Assumption 4 means the tributary locks are modeled under normal operation which includes cyclical maintenance and random minor closures. We do not include reliability-based closures for the tributary locks; however, they are still capacity constrained by cyclical and random minor closures. The ORMSS SIP analysis limited lock reliability to the Ohio River mainstem projects.	None
10-7	What are "Reasonable and Prudent Measures"?	As a matter of policy, the USFWS requires all ESA consultations to have an Incidental Take Statement that specifies the amount and extent of unintentional take (to harm or harass) that will not jeopardize the continued existence of a listed species. The Incidental Take Statement will also include any Reasonable and Prudent Measures along with the terms and conditions to implement the measures that USFWS consider necessary to minimize impact to listed species. The Reasonable and Prudent Measures and the terms and conditions are nondiscretionary.	None
10-8	What is the Ohio River Basin Study? Why is the Corps the best choice to do it?	As stated in the Study Recommendation in Section 12, the Ohio River Basin Comprehensive Study will assess water resource opportunities throughout the basin in collaboration with other interests. Planning efforts will include identification and evaluation of opportunities to improve environmental sustainability throughout the basin including the tributaries.	None

Comment #	Comment	Response	Revised Section
10-9	What % of tows transiting Ohio River locks were empty (data in Section 4)? In Fig. 4-2, what percentage or number of tows are empty? What year does Fig 4.2 represent?	Most tows transiting the Ohio are a mix of empty and loaded barges. We do not model fully loaded tows or fully empty tows. ORNIM was calibrated to 2001 WCSC data and utilized the following average percent empty barges per tow: Montgomery 35.7% empty barges Greenup 41.2% empty barges Myers 34.1% empty barges The percent empty is sensitive to commodity type. Future shipment lists generated for forecast traffic will have slightly different percent empty ratios because tow commodity make up will vary. The purpose of Fig 4.2 is to simply show the uniformity of traffic arrivals along the Ohio River. Arrivals are fairly uniform across the year, month, week and day. LPMS 2001 data were used.	None
10-10	What are detailed numerical cost advantages of river vs. other transport modes?	A general rule of thumb provided by transportation specialists at TVA quote barge transportation rates at about 3/4 of rail and 1/8 of truck, on average, in the Ohio River Basin (ORB).	None

Comment #	Comment	Response	Revised Section
10-11	If barge transport is such a cost advantage, why do many generating plants have rail options for delivers? He understands that plants are adding rail capability, not barge capability, what is reason for that decision?	Shippers attempt to optimize choice by developing and utilizing competition between modes. The 2003 unscheduled Greenup closure made some shippers aware of costly over dependence on water; they need greater supply flexibility. A mix of truck, rail and barge transportation options allows a shipper to take advantage of more competitively priced transportation opportunities. If plants are adding rail capacity relative to barge capacity – this might suggest shipper perception that the existing waterway infrastructure is degrading and becoming less reliable. Continued under investment in maintenance will only exacerbate this perception.	None
10-12	In light of flat traffic from 1994-2004, why is there only traffic growth (Fig 4, page ES-7)? Is there no scenario under which growth would continue to be low or negligible? Could not the same conditions continue that caused the lack of growth from 1994-2004?	We believe that the Clear Skies Scenario reflects a reasonable low-growth outcome for the Ohio River. Under Clear Skies, utility steam coal traffic (which makes up about half of total traffic) initially declines and then flattens at a level below the coal traffic levels of the mid-1990s. For the total traffic forecast over the 2000-2030 period the annual growth rate is about 0.6 percent per annum, or less than one-third of the historical (1970-2000) growth rate of about 2.1 percent. Since the mid 1990s Ohio River traffic has been affected principally by a near total loss of foreign export coal traffic, the effects of increasingly stringent environmental regulations and, in certain years, by lengthy shutdowns at major coal-fired electric generating plants. The Clear Skies Scenario reflects an evolution of increasingly stringent environmental regulations, with the expected dampening effects on Ohio River traffic.	None

Comment #	Comment	Response	Revised Section
10-13	Statement that future navigation investments would not adversely impact long-term resource sustainability contradicts claim that they (navigation investments) are responsible for failure of these species to achieve sustainability.	Navigation investments are only one of many past, present, and future actions that affect the sustainability of resources on the Ohio River. The study concludes that future navigation investments will result in slightly improved environmental conditions over existing operations due to a decrease in transit times.	None
10-14	There is no discussion of flooding impacts from increasing river level from 18 inches to 13-35 feet pool levels. What are impacts resulting from higher pool levels created by the current lock/dam system? Have there been prior studies that address this issue, if so, provide citations.	The navigation dams are designed to create navigation pools. When river levels reach the top of the dams, the river is essentially run-of-river which means the dams have no added effect on river levels. Flood levels are the same as if there were no dams.	None
10-15	Disagree with statement that congestion fees "do not address the maintenance and structural investment needs of the mainstem." If congestion fees have the effect of reducing some of the delays then would it not have an impact on the need for certain navigation investments?	Congestion is only a problem on the mainstem during a main chamber closure. It seems likely that a congestion fee would be most appropriately applied during these times in order to reduce the inefficient queuing of tows and allow the market to relieve congestion. Having said this, it is not clear how the implementation of a congestion fee will do anything to improve the structural integrity of an aging lock project. Congestion fees do nothing to prevent the normal aging and wear-and-tear of system infrastructure.	None

Comment #	Comment	Response	Revised Section
10-16	Does any Corps modeling take into consideration additional rail access of utilities or environmental or economic costs of operating the barge system now and in the future? Describe or why not?	One of the forecasting approaches considers improved rail access of utility plants inasmuch as this improved rail access is reported by the electric utilities in their survey responses. The alternative approach (the linear programming approach) considers only existing receiving capabilities of the electric utility plants. The environmental impacts of operating the barge system are specifically modeled (NAVPAT). The economic costs of operating the barge system are specifically modeled as well.	None
10-16	Nationally, the Corps has identified that its P&G manual limits its ability to more completely adopt practices using current methods of economic/environmental analysis and stewardship. Disappointed that this was not identified as a constraint in ORMSS and call for updating the P&G to current economic/environmental standards.	Our responsibilities (at the District level) in carrying out general investigation studies such as the ORMSS do not include assessing the appropriateness of P&G guidelines. We do, however, firmly believe that we are able to properly formulate and evaluate alternatives in compliance with current P&G requirements and that this report fully meets those requirements. Therefore, we should not be expected to identify the P&G as a constraint in our completion of ORMSS or call for an update of the P&G. If others in the Administration or Congress succeed in modifying the P&G by changes in laws or Administration policy, we (Corps) will certainly follow whatever the changes turn out to be.	None

Comment #	Comment	Response	Revised Section
10-17	Corp continues to take no action to mitigate for negative impacts from its operations which endangers further recovery and continues to suppress local economies of many Ohio River communities. It must demonstrate stewardship by not delaying any further mitigation measures. (The report) does not recommend any actions be taken now at the locks and dams to improve the ecology of the river, even though it identifies specific measures (Table 6-5) that could and should be taken. Those remedial measures that are related to Corps projects and operations should be listed in Table 6-6 (EnvironmentalSustainability Strategies Under the Navigation Stewardship Program). The identified measures will mitigate impacts at the locks and dams now and do not require funding under the authorized Ohio River Ecosystem Restoration Program.	Mitigation has been added to the final report under section 10.4.1. Regarding your comment concerning specific measures identified in Table 6-5 that the Corps should take now at the locks and dams to improve the ecology of the river, we would like to respond by first explaining our general capability for approaching ecosystem restoration and mitigation before we discuss the specific actions we intend to take pursuant to the SIP. Whereas most agencies with environmental missions were created through organic legislation that empowered them to use their discretion to fund authorized activities, the Corps of Engineers has no such programmatic authority. The Corps pursues missions such as navigation and ecosystem restoration as agreed upon between Congress and the President through project-specific legislation. Corps projects are authorized through Water Resources Development Acts and funded through annual appropriations bills. Implementation of the ecosystem restoration and mitigation measures would require a dedicated stream of funds and specific authorization to carry out. We currently lack both of these requisites. Also, since the SIP is a planning document and is not meant to go forward for Congressional authorization, we don't see obtaining them through this study. To address more systemic issues related to the navigation system, the Corps will incorporate several environmental components into future site specific studies that this report recommends: evaluation of fish passage strategies at each lock and dam along the Mainstem during studies for lock modernization and major rehabilitation; continuance of the Interagency Working Group concept at the local level to participate in and to review and comment on future studies as they progress; identification, description, and quantification of riverine habitat within the individual project's area of influence; incorporation of sustainability planning within each individual project's area of influence; and, if a non-federal partner is identified, development of an Environmental Restoration Plan that will become part of the Combined Plan for authorization of each site specific project. As required for navigation investments, however, all separable restoration costs will require a cost sharing partner.	10.4.1

Comment #	Comment	Response	Revised Section
11-1	The fact that the ERP is authorized, but as yet unfunded, should be more clearly communicated throughout the discussion of ecosystem sustainability and restoration issues addressed by the ORMSS study reports.	The Ohio River Ecosystem Restoration Program is now eligible for deauthorization. The fact that it is yet unfunded and eligible for deauthorization will be more clearly communicated throughout the final report.	Executive Summary and Other Sections
11-2	Study recommendations should be presented in a manner that reflects the study conclusion that "high priority ecosystem sustainability measures are needed…" The recommendation for an Ohio River Navigation System Investment Plan should explicitly include the integration of ecosystem restoration analysis and decision making within the expanded program capacity.	The recommendations in the Executive Summary include the following: " Pursue planning and implementation of measures to improve environmental sustainability in collaboration with other interests."	Executive Summary
11-3	Environmental improvements to the Ohio River ecosystem would benefit from incorporating the following as additional recommendations of the ORMSS Study: • Implement pilot or demonstration projects under the ERP concurrently with the preparation of the Program Implementation Plan. • Amend the ERP authorization to expand to the entire Ohio River basin and allow cost sharing by non-governmental organizations.	The Ohio River Ecosystem Restoration Program is now eligible for deauthorization. The fact that it is yet unfunded and eligible for deauthorization precludes implementing these recommendations.	Executive Summary and Other Sections
11-4	Any discussion of measures to reduce the impacts of lock and dam maintenance should include mooring cells. When available, mooring cells help to reduce tow queuing impacts and conserve fuel consumption by providing a tie-off point that allows tows to shut down their engines during lock passage delays. There does not appear to be any reference to mooring cells in the Executive Summary.	Mooring cells require little if any maintenance and therefore are not a factor in discussions of lock and dam maintenance (by the Corps). The benefits noted apply to the towing industry. The Corps will continue to maintain all of their existing mooring cells on the Ohio River mainstem.	None

Comment #	Comment	Response	Revised Section
11-5	The discussion of minor repairs and small jobs is confusing. These actions (as well as measures such as N-up/N-down lockage to reduce impacts of such actions) are present in the WOPC and in all alternatives under the WPC. The difference is the extent to which more progressive (WPC) repair strategies can reduce the impacts of increasingly frequent repairs under the WOPC. The conclusion regarding “Minor repairs and small jobs…” should be deleted.	This conclusion is consistent with text in Section 8.3.1.1, specifically, that such work involves few, if any, environmental impacts associated with routine operations and maintenance. Further, this work is not a function of more progressive repair. This work is broken into "Normal O&M" and "Random Minor" categories in tables 8-8, 10-6, 10-9 and 10-12 (the first for the Without Project Condition and the latter three for With Project Alternatives involving more aggressive maintenance). Note that the expenditures are the same or nearly the same for all traffic scenarios and across alternatives, i.e. $46.7M for Normal Routine O&M and $2.2-$2.4 million for Random Minor, signifying the lack of influence of more aggressive maintenance on these routine expenditures.	None
12-1	Cannot support study findings in the absence of funding of the Ohio River Ecosystem Restoration Program.	Noted.	None
12-2	Conceptually agree with schedule of navigation investments.	Noted.	None
12-3	It is essential that future Congressional appropriations for navigation improvements be coupled with comparable funding of the Ohio River Ecosystem Restoration Program. Without funding for the ERP, the Corps will not achieve its stated goals of environmental sustainability for the river and its environs.	The Ohio River Ecosystem Restoration Program is now eligible for deauthorization. The fact that it is yet unfunded and eligible for deauthorization will be more clearly communicated throughout the final report.	Executive Summary, Sections 2.2.1, 3.2, 8.5.1, 8.9.2, & 10.2.2.2 and TABLE 9-10

Comment #	Comment	Response	Revised Section
12-4	The Ecosystem Restoration Program and the navigational improvements cannot be undertaken separately and then considered simultaneously when it is convenient to do so, especially when restoration efforts have yet to be funded. The current SIP/PEIS does not meet its stated objectives because it is premised on full funding of separate programs with separate appropriations.	Noted.	None
12-5	The environmental sustainability of all aspects of the Ohio River aquatic community is assumed to continue to improve over time. Some increases may occur if water quality continues to improve, but little hard evidence that water quality will improve significantly beyond current conditions.	All of our methodologies, definitions, and assumptions used in our analysis are provided in the CEA Chapter 3.	None
12-6	Nonpoint source pollution is currently and will continue to be the primary factor affecting fish communities and aquatic life and will increase in the river over time.	Nonpoint source pollution is an important factor influencing fish communities. However, programs are being developed and implemented to reduce key sources such as combined sewers, runoff from disturbed sites, and acid mine drainage.	None
12-7	The potential impacts of all invasive species, such as the Asian snakehead, are not addressed.	Several invasive species, including some not yet confirmed in the Ohio River, were recognized in the report. It would be virtually impossible to address all possible invasive species that may appear over the planning horizon.	None
12-8	Improvements in navigation structures to allow greater between pool dispersal of native fish would likely also hasten and facilitate the invasion of exotic species. Efforts to improve long-term connectivity of native populations may result in their ultimate demise.	We recognize that facilitating interpool movement of fishes would make it easier for invasive species to disburse throughout the river. During a discussion with the IWG regarding fish passage, there was consensus that the system currently in place would not serve as an effective barrier to invasive fish species.	None

Comment #	Comment	Response	Revised Section
12-9	Sustainability will require: federal regulation of and incentives for reduced nonpoint source pollution; strict federal limits on floodplain development of public and private lands; restoration and protection of in-river habitat features; additional controls on the introduction of invasive species; and federal funding for research to determine the invasive potential of numerous aquatic species.	This was indeed a concern of the resource representatives on the Interagency Working Group and the resource experts consulted on sustainability needs. It was the group consensus, however, that positive benefits of connectivity outweighed the negatives.	None
12-10	The potential influences of global climate change on the Ohio River ecosystem or its contributing watersheds are not mentioned.	CEQ Guidelines stress the need to define geographical and temporal limits on the analysis because "it is not practical to analyze the cumulative effects of an action on the universe". Localized impacts caused by global warming are still theory and not suitably forecast for meaningful analysis.	None
12-11	ORMSS does not evaluate the incorporation and development of hydroelectric power projects during repair and modernization of the navigation structures. Why isn't hydroelectric and alternate energy production evaluated in the SIP/PEIS?	Hydropower is not a Corps mission and no considerations are given to hydropower when operating the L/D. Federal development of hydropower dams comes under the authority of the Federal Energy Regulatory Commission and would require a separate authority. At this time, there we see no indications that this will occur.	None
12-12	Environmental sustainability is addressed in qualitative terms. Bar charts can not be evaluated in any meaningful way as there is no stated scale identified for the y-axes. All of these evaluations only consider best-case outcome for all factors discussed. The inclusion of pseudo-quantitative data that portrays only best-case scenarios is not appropriate as a basis for future decision-making.	CEQ Guidelines acknowledge the difficulty of assessing sustainability. Their guidance was to identify predefined thresholds. In the absence of thresholds, national, regional, state or community goals should be used. The Corps attempted to use this guidance by identifying indicators of sustainability and got the concurrence for these from the IWG. Once established, these became the measures of sustainability; the bar charts serve merely as a graphic aid to portray the findings.	None

Comment #	Comment	Response	Revised Section
12-13	The final draft report should incorporate any impacts from ORSANCO rulemaking proposal (relaxation of bacterial loading allowances based on river flow rates) on recreational users.	ORSANCO is cooperating with several other entities to develop an Ohio River Total Maximum Daily Load (TMDL) for bacteria. This is a work-in-progress with an unknown outcome. Speculation regarding the final TMDL or its effects is premature at this time.	None
12-14	This report does not include a consideration of current research on larger river systems conducted at the University of Louisville and elsewhere. The latest research and findings related to large river ecosystems should be considered and incorporated into decision-making processes over the projected 60-year span of ORMSS and its component studies.	The report draws on a large body of knowledge of large rivers from a number of researchers.	None
12-15	Many projections, models, and assumptions presented in the report do not include information for the stated 60-year scope of investigation (Sections 4, 8, 10 and 12 are cited, of the main report?).	We attempted to use current research augmented by primary research.	None
12-16	Numerous statements in the report and appendices do not provide any reference for the assertions made.	CEQ regulations require that NEPA documents are to be written in plain language that is understandable to the general public and to decision makers. Therefore citations were held to a minimum in the SIP/PEIS. Many more citations are used for statements made in the technical appendices.	None
12-17	Include them (info@riverfields.org) on mailing list for subsequent Corps actions on the ORMSS, SIP/PEIS, and ERP.	Noted.	None
13-1	Unless the ERP is fully implemented, it is difficult to discern how the Corps can claim success in improving ecosystem sustainability while balancing economic and environmental improvements.	While the Corps remains supportive of the ERP, the reality is that this program is now a candidate for de-authorization because no funds have been appropriated.	None
13-2	The IWG should be continued, improved upon, and include others partners.	Continuation of the IWG has been identified as a mitigation feature to be included in site specific studies.	10.4.1

Comment #	Comment	Response	Revised Section
13-3	Environmental restoration measures need to be implemented, not just identified, planned or designed.	We agree, implementation is essential to achieving environmental benefits. However, the program remains unfunded and is a candidate for de-authorization.	None
13-4	Conclusion of achieving sustainability of fisheries resources may be overly optimistic especially given habitat constraints, dams, exotic species, and other challenges discussed.	Noted. The assumptions used for that conclusion are stated. The Conclusions were also reviewed by the IWG.	None
13-5	Prediction of increasing sustainability for both mussels and riparian habitat may also be overly optimistic, no reasonable justification for this is provided.	Noted. The assumptions used for that conclusion are stated. The Conclusions were also reviewed by the IWG.	None
13-6	Adaptive management will not be effective without specific program authorization or funding.	Agree.	None
13-7	As no indication of black carp control is mentioned, the USGS suggests the 2005 publication (Nico, et al) to help develop a mitigation strategy for the Ohio River mainstem and tributaries.	We have added this reference.	5.2.2.1.2
13-8	Unless the term “exotic" is intended to refer only to species not native to any U.S. ecosystem, perhaps replacing the term with "nonnative" throughout the document would be more appropriate.	In this report, "exotic" is defined as not native to the Ohio River ecosystem.	None
13-9	Page ES-5, 1st paragraph, last sentence: It is stated here that the purpose of the ORMSS was “modified to include the identification of measures to improve ecological sustainability to improve a balance between economic and environmental improvements.” We suggest reviewing the document to ensure a consistent project purpose is described throughout the document.	Revised Section 2.1 to use the same language as on page ES-5.	2.1

Comment #	Comment	Response	Revised Section
13-10	Page ES-9, 2nd paragraph, first and third sentences: This is a critical assumption that must be considered as the Corps reports on environmental sustainability of natural resources into the future. The estimates of future environmental sustainability "assumes full implementation of the as yet unfunded Ohio River Ecosystem Restoration Program and 14 specific types of measures (26 total specific environmental sustainability measures)…" Short of full implementation, efforts will fall short of successfully improving environmental sustainability and balancing economic and environmental improvements. This is critical and should justify new authorities for the Corps to be able to fully implement the Restoration Program and the identified measures.	The Ecosystem Restoration Program is now a candidate for de-authorization because the program has never been funded. This is a provision of Water Resources Development Acts. As it does not appear likely the program will be funded, the assumption that it will be fully implemented has been eliminated from both the without and with project conditions. It should be noted that full implementation of the program would not have brought resources into full sustainability. At best, it would have contributed to improving 2-3% of resources adversely affected by human activities.	8.5.1, 8.9.2, And Table 9-10,
13-11	Page ES-10, first two sentences: "the Corps will develop and implement Reasonable and Prudent Measures being identified." This language justifies a responsibility by the Corp to implement environmental restoration measures. It is unclear what the restoration authorities referenced in the second sentence are. We suggest adding text to clarify this issue.	Reasonable and prudent measures in this context are referring to outcome of the Endangered Species Act Section 7 Consultation for on-going Operation and Maintenance. The restoration authorities include all ecosystem restoration authorities available to the Corps. The text has been modified to make this clear.	ES-5.a.2).
13-12	Page ES-13, last paragraph: "The added components of the Moderate Plan would require funding in addition to that provided for the Ohio River Ecosystem Restoration Plan." To our knowledge, that plan has not received funding. It is unclear how will these and other identified restoration measures, necessary to improve environmental sustainability be funded.	References to the Ecosystem Restoration Program have been eliminated from both the Without and With Project Conditions. The sustainability measures were developed without constraints of funding, responsibility, implementation concerns, etc. The effort was focused only on identification and agreement on highest priority needs of the resources.	ES-5.a.2), And ES-5.b.2).
13-13	Page ES-14, 1st sentence: "the need for new or modified authorities" is at least in part identified in the CEA. Is there an Implementation Plan for the Restoration Program or is this awaiting funding?	The Ecosystem Restoration Program authority provides federal funding to prepare a Program Implementation Plan.	None

Comment #	Comment	Response	Revised Section
13-14	Page ES-14, last sentence: There is a discrepancy here; how does this study provide "the means to optimize returns on investment" if the needed authorities and appropriations do not exist to implement the needed restoration actions to improve ES? We recommend adding text to remove this discrepancy.	The majority of the needed authorities do exist and are funded although some only marginally. Only the Ecosystem Restoration Program, among the array of restoration programs, lacks appropriations. See Section 8.5.1 for the list of Corps authorities and Table 8-7 for other agency authorities.	None
13-15	Page ES-15, 7th bullet: New authorities may be necessary to implement some restoration measures with 100 percent full Federal funding. The Environmental Sustainability of fish resources is also dependent upon such authorizations and appropriations for implementation of the identified environmental restoration needs. We suggest adding text that addresses this point.	The Corps does not have any restoration authorities that provide paying for measures with 100% federal funds nor does its policies allow for such an authority. Chapter 4 of the CEA lists the assumptions made in predicting full sustainability for fishes considering future reasonable actions.	None
13-16	Page ES-16, 3rd bullet: Follow-on studies are recommended to include environmental restoration measures to improve environmental sustainability.	This sentence was modified to address the concern.	ES-16
13-17	Page ES-16, 6th bullet: We suggest adding fish to last sentence. This bullet is good biological justification for the needed environmental restoration measures, but should go a step farther to conclude that new authorizations and appropriations are warranted to ensure environmental sustainability improvements.	This sentence was modified to address the concern.	ES-16
13-18	Page ES-16, last bullet: This study may have been assessed in accordance with the Corps Operating Principles, but without necessary authorization and appropriations to implement environmental restoration measures, it is unclear how this project will be implemented. We suggest adding clarifying text.	This bullet is only intended to state our compliance with our internal Operating Principles. The need for restoration measures is stated elsewhere.	None

Comment #	Comment	Response	Revised Section
13-19	Page ES-17, 2nd bullet: the results of the CEA are dependant upon the implementation of the identified restoration measures. Without large-scale implementation, many of the natural resources would not be expected to become fully sustainable and could potentially degrade. We suggest you review this bullet and provide text that addresses this issue.	Of the 87 RFFAs identified, the ERP was one. Because so many other actions affect resources, elimination of the program would not substantially change CEA results.	None
13-20	Page ES-17, 5th /6th bullets: We recommend system improvements at Meldahl, Hannibal, Myers, and Pike Island (and other future LDs) include fish passageways, as appropriate.	Concur. Fish Passage has been identified as a system mitigation feature that will be addressed at the site specific level.	10.4.1
13-21	Page ES-17, 7th bullet: implementation of some restoration measures without non-Federal cost-share partners is needed for success. We recommend additional text be added to address issue.	Corps policy is that ecosystem restoration projects are usually funded at 65% Federal and 35% non-federal. Funding projects at 100% Federal expense is not supported by the Corps.	None
13-22	Page ES-17, 8th bullet: The Corps should maintain the IWG for implementation of this Program and other identified restoration measures.	Noted. 10.4.1	
13-23	Page ES-18, 1st bullet: This recommendation should include an environmental component. The IWG should also be included in this new stand alone program for consultation on environmental considerations.	The Ohio River Navigation System Investment Program is intended to expand the ORMSS to the dams and tributary structures. This program would have a strong environmental component and would include establishment of an IWG.	None
13-24	Env Appendix – CEA Chapter 1): General comment – Text in this section identifies a responsibility of the Corp to implement environmental restoration measures, not just identify or plan unfunded projects. We believe justification exists for the Corps to seek broad environmental oriented authorization independent of, or in conjunction with, system improvements and we encourage the Corps to do so.	The Corps has been seeking funds to implement ecosystem restoration measures. To date, these efforts have not been successful, and the Ecosystem Restoration Program is now a candidate for de-authorization.	None

Comment #	Comment	Response	Revised Section
13-25	Env Appendix- CEA Page 1-3: 1.3.1 Environmental Operating Principles – These principles provide terrific justification throughout the document for the responsibility of the Corps to act and implement Environmental Sustainability approaches into Corps SOP for "process and work". We support these principles.	Noted.	None
13-26	Env Appendix - CEA Page 1-3, 3rd paragraph: This paragraph defines Environmental Sustainability and provides additional key wording regarding an effective balance of economic and environmental considerations throughout all Corps process, including construction, operation, and maintenance. We recommend the Corps implement environmental restoration measures after appropriate identification, planning and design is done.	The Corps agrees that implementation is necessary to achieve ecosystem benefits.	None
13-27	Env Appendix - CEA Page 1-4, 1st paragraph, last two sentences: To a large extent, the greatest damages have already been incurred. We agree the incorporation of these principles can help to minimize additional impacts from future actions, but we believe they are most valuable to justify actions to minimize continuing effects of past actions.	Noted.	None
13-28	Env Appendix – CEA Page 1-4, last paragraph, 2nd sentence: "…will guide or prescribe alternative means…environmentally compatible navigation system…upon which future Corps actions will be based." We recommend the Corps include strong recommendations that will ensure that restoration measures will be implemented.	The Corps' recommendations include numerous restoration measures.	None

Comment #	Comment	Response	Revised Section
13-29	Env Appendix – CEA Chapter 4, P. 4-12, 2nd paragraph: The recovery of some fishes does not indicate that the sustainability of certain fishes will move to a sustainable level in spite of the navigation system. Water quality has improved and many fishes are now occurring in portions of the river that they had not been found in for years (even decades) prior, but active management practices (i.e., restoration stocking) may also explain the recovery of some species within the upper Ohio River. In addition, although some fishes may be re-colonizing portions of the river as water quality and management practices improve, the abundances of many fishes may still be much lower than historical levels due to maintenance of the navigation system. We recommend the Corps include in this paragraph that the level of sustainability of fishes is uncertain.	Operation and maintenance of the navigation system comprises only a few of the 87 reasonably foreseeable future actions potentially affecting fish communities. The rationale and justification for our conclusions is presented in Section 4.12.2.	None
13-30	Env Appendix – CEA Chapter 4, P. 4-12, last paragraph, 1st sentence: We question the value of this paragraph. The significance of such a comparison is minimal considering the different collection methods and without knowing the habitats where the electrofishing was conducted. Additionally, an electrofishing survey followed by a rotenone survey of the same lock chamber could yield differing results because of gear bias. We recommend this paragraph (and table) could be deleted without compromising the content of this chapter.	This is information from published literature and proves some background despite gear bias. We choose to keep this paragraph and the tables.	None
13-31	Env Appendix – CEA Chapter 4, P. 4-14, Introduced and Extirpated Species: These are such different topics that we recommend separating them into different sections. At a minimum, an additional level of sub-headings is needed to separate the two discussions.	Agree. The discussion has been separated by sub-headings.	CEA Ch 4

Comment #	Comment	Response	Revised Section
13-32	Env Appendix – CEA Chapter 4, P. 4-14, Introduced and Extirpated Species: This section needs to be rewritten. There are many incorrect or inaccurate statements within this section, especially within the bullets. Specific comments follow (next 14 comments):	This section has been extensively modified.	CEA Ch 4
13-33	Env Appendix – CEA Chapter 4, 1st sentence: It is likely that more than 14 fish species have been introduced into the Ohio River. We recommend deleting the first half of this sentence. The second half of the sentence needs to be clarified by replacing the word “had” with “known to have.”	Note that this is by 1992 and is a cited literature source.	None
13-34	Env Appendix – CEA Chapter 4, 3rd sentence: We do not recommend using the adjective “important” to describe common carp. There are large numbers and biomass of common carp within the Ohio River, but this does not make them an important species. Although common carp have been in the United States since the late 1800’s, this non-native species is still a concern to natural resources management agencies. Seven species of carp have been introduced into the US. Species of concern include common, bighead, silver, grass, and black. (Some could also argue that the goldfish is a management concern.) All of these species are established within the Ohio River except the black carp which is not considered established (yet) within the United States.	This has been changed to “a substantial component of the Ohio River fish community.”	CEA Ch 4
13-35	Env Appendix – CEA Chapter 4, 2nd paragraph: This is incorrect. Three of the four species listed were already in the Ohio River before the 1993 and 1995 floods. These fish escaped to the river from many potential sources, but very few are documented. Grass carp likely first escaped from a USFWS facility and have been actively stocked all across the country.	The reference to 1993 and 1995 floods has been removed.	CEA Ch 4

Comment #	Comment	Response	Revised Section
13-36	Env Appendix – CEA Chapter 4, 1st bullet: Black carp have not established reproducing populations anywhere in the US; small sport fisheries do exist for common and grass carp; bow fishing for Asian carps is growing in popularity. We suggest including this information in this bullet.	This has been corrected.	CEA Ch 4
13-37	Env Appendix – CEA Chapter 4, 2nd bullet: Grass carp and common carp have distinctly different feeding niches and behaviors. Common carp uproot vegetation but do not "feed aggressively" on plants. We suggest including this information in this bullet.	Text has been revised to reflect this information.	CEA Ch 4
13-38	Env Appendix – CEA Chapter 4, 3rd bullet: Please include here that native larval fish do feed on plankton and may compete with bighead and silver carps for food resources if plankton becomes limiting. Competition requires a limited resource; plankton are not limited at this time. Some dietary overlap may also exist with native planktivores such as gizzard shad, paddlefish, and bigmouth buffalo.	Information included in text.	CEA Ch 4
13-39	Env Appendix – CEA Chapter 4, 4th bullet: Among other reasons, population studies are made difficult by the fact that standard sampling gears and fishing techniques for native fishes are not effective at sampling bighead and silver carp. Bighead carp rarely if ever jump from the water except when sampled by electrofishing gear. Silver carp and the occasional grass carp are known to jump from the water. The silver carp is the fish of concern relative to their jumping behavior and their potential to injure biologist, as well as recreational boaters and fishers. Please include this information in this bullet.	This is a literature citation.	None

Comment #	Comment	Response	Revised Section
13-40	Env Appendix – CEA Chapter 4, 5th bullet: Black carp do not compete for food with native fish species at all life stages. They will compete for food with native molluscivores if food resources are limited. Animals of riparian zones are only likely to be affected if they are dependent upon molluscan resources and these resources are limited in availability. This sentence should be cited. The black carp is not in the process of being listed as an injurious wildlife species. An important distinction is that it has been petitioned for listing and is currently being considered for listing, but a decision to list has not been reached. We suggest adding text to clarify this.	This information has been added to text.	CEA Ch 4
13-41	Env Appendix – CEA Chapter 4, P. 4-15, 1st paragraph: This paragraph has no relevance to the discussion of introduced species in the Ohio River and we suggest it be removed.	Paragraph removed.	CEA Ch 4
13-42	Env Appendix – CEA Chapter 4, P. 4-15, 2nd paragraph: The release of the Asian carp management plan needs to be updated from mid-2005 to August 2006. Please note that this document should be available at www.anstaskforce.gov in August 2006.	Text revised to reflect this release date.	CEA Ch 4
13-43	Env Appendix – CEA Chapter 4, P. 4-15, 2nd paragraph: Change third sentence to read “The potential impacts.”	Text changed.	CEA Ch 4
13-44	Env Appendix – CEA Chapter 4, P. 4-15, 3rd paragraph: Delete text before “Pearson”. The sentence should begin “Pearson and Pearson (1989) reported…”	Text changed.	CEA Ch 4

Comment #	Comment	Response	Revised Section
13-45	Env Appendix – CEA Chapter 4, P. 4-15, 3rd paragraph, line 5: We suggest this change to this sentence "…may interfere with migratory species such as paddlefish and sturgeons (shovelnose and lake)…"	Text changed.	CEA Ch 4
13-46	Env Appendix – CEA Chapter 4, P. 4-15, 3rd paragraph, last three sentences: The second and third sentences should be inverted. The collection of the juvenile lake sturgeon should be cited. If juvenile lake sturgeon have been stocked in the upper Ohio River or tributaries this sentence is not relevant.	Text changed.	CEA Ch 4
13-47	Env Appendix – CEA Chapter 4, P 4-16, next to last paragraph: We suggest the referenced species and reproductive guilds need to be verified. We believe that lake sturgeon are lithophils, the same as shovelnose sturgeon.	Text changed.	CEA Ch 4
13-48	Env Appendix – CEA Chapter 4, P. 4-16, last paragraph, 1st sentence: delete text following "in the river."	Text changed.	CEA Ch 4
13-49	Env Appendix – CEA Chapter 4, P. 4-22, 2nd paragraph, 1st sentence: change "jurisdictional" to "interjurisdictional."	Text changed.	CEA Ch 4
13-50	Env Appendix – CEA Chapter 4, P. 4-24, 4th sentence: This discussion down plays the effects of mainstem dams on native fishes. There is a wealth of literature that attributes increases in the abundance of lacustrine fishes and decreases in riverine fishes to the construction and maintenance of mainstem dams. Movement data also indicate that dams affect fish movements. Dams have affected habitat availability and connectivity, directly affecting fish abundance and survival. We suggest including language here that reflects this information.	Paragraph not changed. The ensuing paragraphs describe results of studies conducted on as part of the ORMSS on fish passage relative to dams.	None

Comment #	Comment	Response	Revised Section
13-51	Env Appendix – CEA Chapter 4, P. 4-25, last paragraph: The 1st sentence illustrates that anglers are well aware of the fact that dams stop longitudinal movements of fishes. Targeted effort (p. 4-26) is for migratory species. We suggest clarifying language reflecting these thoughts be included.	Text modified to reflect this.	CEA Ch 4
13-52	Env Appendix – CEA Chapter 4, P. 4-27, 3rd paragraph, 2nd sentence: We do not believe correlation (or coincidence) means causation. The amount of lockage events only suggests that there are opportunities for fish to move upstream through locks, but does not indicate that the "fish generally move" through locks. We suggest including language that shows locks to be ineffective as a passageway for riverine species, especially in biologically significant numbers.	Locks have been shown to provide opportunities for upstream movement in addition to that provided via gate passage.	None
13-53	Env Appendix – CEA Chapter 4, P. 4-28, A2: Operational modifications that would minimize head difference at a single gate would likely create more meaningful opportunities for upstream movements than through lock chambers. Meaningful modifications of locks or dams will be very site specific because of hydrologic variation between each. Please include clarifying language here that reflects these thoughts.	This is discussed in Section 4.8.1.3.	None
13-54	Env Appendix – CEA Chapter 4, P. 4-28, A3: This discussion downplays the effects of dams on the native fish populations. Please include language that indicates pre-dam fish distribution and recent information demonstrate the effects of limited movement of fish due to dams.	This comment does not pertain to answering Q.3. Further, these Q&As were developed during a structured discussion with the IWG. It would be inappropriate to add information not drawn from this discussion in this series of Q&As.	None

Comment #	Comment	Response	Revised Section
13-55	Env Appendix – CEA Chapter 4, P. 4-28, A4: Importance of downstream movements is downplayed. Please include text that indicates downstream fish movement is likely to be important, but that information on this subject is not well documented. Paddlefish have been demonstrated to move out of the Ohio River and then throughout the open portions of the Mississippi River and its tributaries. We suggest including text that downstream movement may also be important in the transport of mussel glochidia.	These Q&As were developed during a structured discussion with the IWG. It would be inappropriate to add information not drawn from this discussion in this series of Q&As.	None
13-56	Env Appendix – CEA Chapter 4, P. 4-29, A5: Big river species are actively managed by natural resources management agencies. Management practices, including restoration stockings, may contribute to upstream recolonization by some species. We suggest including these sentences.	These Q&As were developed during a structured discussion with the IWG. It would be inappropriate to add information not drawn from this discussion in this series of Q&As.	None
13-57	Env Appendix – CEA Chapter 4, P. 4-29, A6: Although adequate fish hosts may occur in the upper river, these fishes may be present in too low of abundances. Dams could be limiting abundances of important fish host species. Dams may also be preventing adequate movement of glochidia infested fish hosts past dams. We suggest including these sentences.	This may be true, but A.6 is based on a report prepared for the ORMSS by Ohio State University.	None
13-58	Env Appendix – CEA Chapter 4, P. 4-29, 4.8.1.3, 2nd sentence: We suggest changing to “Some fish” are able to migrate…	Text changed.	CEA Ch 4

Comment #	Comment	Response	Revised Section
13-59	Env Appendix – CEA Chapter 4, P. 4-29, 2nd paragraph: We suggest including language that indicates not all fish species can migrate through dams during periods of high velocity, that there are numerous migratory species of varying size and swimming abilities, and that connectivity was available at all flow conditions prior to the construction of the dams.	Although the Fish Passage research was inconclusive, it could not rule out that some fish species are blocked from migration by the dams. The text was modified to include the language provided in your comment.	CEA Ch 4
13-60	Env Appendix – CEA Chapter 4, P. 4-30, 1st paragraph: Please include that fish passageways should be constructed.	The report identifies fish passage as a systemic need and includes consideration of it at all L/Ds as a mitigation need. Text added to this paragraph.	CEA Ch 4
13-61	Env Appendix – CEA Chapter 4, P. 4-30, 3rd paragraph, last sentence: A citation should be provided for this statement.	This sentence was deleted.	CEA Ch 4
13-62	Env Appendix – CEA Chapter 4, P. 4-30, 3rd paragraph: Please include in this paragraph that the presence of fish hosts does not mean there are adequate abundances of host species or adequate movement throughout the river to allow for mussel populations to sustain, let alone expand.	This language was added to the text.	CEA Ch 4
13-63	Env Appendix – CEA Chapter 4, P. 4-30, 4th paragraph, 1st sentence: Change sentence to both upstream and downstream movements of “some” fishes…	Text changed.	CEA Ch 4
13-64	Env Appendix – CEA Chapter 4, P. 4-30, 4th paragraph, third sentence: It should be noted here that the abundance of fish hosts and ability of fish hosts to move upstream and downstream past dams may be affecting the reestablishment of mussel communities.	The mussel experts at OSU do not concur. See 4.8.1.2.	None
13-65	Env Appendix – CEA Chapter 4, P. 4-30, 4th paragraph, line 9: Please indicate here that fish passage facilities should be constructed and not just considered.	The report identifies fish passage as a systemic need and includes consideration of it at all L/Ds as a mitigation need.	CEA Ch 4

Comment #	Comment	Response	Revised Section
13-66	Env Appendix – CEA Chapter 4, P. 4-33, 1st full paragraph, 2nd sentence: We suggest clarification of the terms main channel and artificial in this text to make it more meaningful.	This is clarified in Tables 4-7 and 4-8 which were referenced at the beginning of this paragraph.	None
13-67	Env Appendix – CEA Chapter 4, P. 4-34, last sentence: We suggest including the following: Tributaries, which were demonstrated to provide important winter refugia, are often disconnected and are not available for fish to access.	This sentence was modified to address the concern.	CEA Ch 4
13-68	Env Appendix – CEA Chapter 4, P. 4-35, 7th and 8th paragraphs: We suggest including information on the importance of low flow refugia during cold water temperature that was demonstrated in this and other studies. We suggest the phrases “although some concern” and “relatively sheltered” be explained more fully.	Text was modified to clarify ambiguous wording. Refer to Environmental Appendix, Volume 2, Report titled “Winter Habitat Used by Fishes in Smithland Pool and Belleville Pool, Ohio River” for detailed information on importance of low flow refugia during cold water temperatures.	CEA Ch 4
13-69	Env Appendix – CEA Chapter 4, P. 4-39, 3rd paragraph, last sentence: Change “appears to aggressively” to “has the potential to …”	This sentence was modified to address the concern.	CEA Ch 4
13-70	Env Appendix – CEA Chapter 4, P. 4-49: 4.10.2: We suggest including here that canalization and O&M of the navigation system prohibit natural disturbance process important to the continual development and heterogeneity of riverine habitats.	Droughts and significant flood events continue to occur on the Ohio River mainstem. Mainstem dams do not have the capability to store floodwaters; their only purpose is to maintain a minimum nine foot navigation channel to provide year round navigation.	None
13-71	Env Appendix – CEA Chapter 4, P. 4-53, 1st paragraph, last sentence: We suggest including in this sentence that the negative effects of Asian carp and most other invasive species have not been demonstrated. (The exception is zebra mussel effects on native mussels.)	This sentence was modified to address the concern.	CEA Ch 4

Comment #	Comment	Response	Revised Section
13-72	Env Appendix – CEA Chapter 4, P. 4-57, 2nd sentence: Natural climatic events will have minimal effects as the Corp manages to prevent the habitat changes that are driven by natural events. "Unnatural" projects that create disturbance and habitat heterogeneity will have the greatest positive effects as long as the river is canalized and dammed. We recommend the Corps seek opportunities to allow for natural disturbance process to create habitat in off channel areas.	The Corps does not manage the Ohio River mainstem to prevent habitat changes that are driven by natural events. As stated above, dams on the Ohio River do not store floodwaters. Also, natural disturbance processes in off channel areas continue to occur as events dictate.	None
13-73	Env Appendix – CEA Chapter 4, P. 4-64, last bullet: We suggest including here that the Environmental Sustainability of fishes would decline in the short-term and will only improve substantially towards Environmental Sustainability if the restoration measures are implemented.	Of the 87 RFFAs identified, 61 were determined to have moderate to high potential to affect fish communities. Ecosystem Restoration was just one of these 61. Unfortunately, the Ecosystem Restoration Program appears to be a missed opportunity as it would contribute to improved sustainability. However, given that so many other actions are also affecting fish communities, the overall conclusion would not change substantially in the absence of this program.	None
13-74	Env Appendix – CEA Chapter 4, P. 4-65, 2nd paragraph: We suggest including text here stating that riparian habitats are important to processes for improving water quality and nutrient cycling; and processes that are important to fish, mussels, and other natural resources.	A sentence was added.	CEA Ch 4
13-75	Env Appendix – CEA Chapter 4, P. 4-66, 2nd paragraph: We suggest including language that the availability, connectivity between, and access to complex habitat types that provide for spawning, nursery, feeding, and over-winter refugia is very dynamic.	A sentence was added.	CEA Ch 4

Comment #	Comment	Response	Revised Section
13-76	Env Appendix – CEA Chapter 4, P. 4-66, 3rd paragraph, 5th sentence: We suggest clarification of this sentence. Is this saying that the effects of the system of locks and dams were evident even before construction of the initial system was complete?	This sentence pertains to non-navigational activities. The sentence has been clarified.	CEA Ch 4
13-77	Env Appendix – CEA Chapter 4, P. 4-66, last sentence: We suggest including language here that the modern navigation system prevents many processes important to the sustainability of natural resources, including disturbance processes that drive the production of dynamic habitats.	Droughts and significant flood events continue to occur on the Ohio River mainstem. Mainstem dams do not have the capability to store floodwaters; their only purpose is to maintain a minimum nine foot navigation channel to provide year round navigation.	None
13-78	Env Appendix – CEA Chapter 4, P. 4-67, 1st paragraph: Include language here that the high lift dams have also reduced connectivity and movements of many riverine fishes.	Sentence added.	CEA Ch 4
13-79	Env Appendix – CEA Chapter 4, P. 4-67, 1st paragraph, last sentence: Include here that the importance of embayments have been documented, but many in the lower river are not accessible to fishes when they are most critical.	Sentence added.	CEA Ch 4
13-80	Env Appendix – CEA Chapter 4, P. 4-67, 1st paragraph, last sentence: Include here that the importance of embayments have been documented, but many in the lower river are not accessible to fishes when they are most critical.	Sentence added.	CEA Ch 4
13-81	Env Appendix – CEA Chapter 4, P. 4-67, 4th paragraph, 2nd sentence: Indicate where the results of these studies are summarized, at a minimum these studies should be referenced.	This sentence was modified to address the concern.	CEA Ch 4
13-82	Env Appendix – CEA Chapter 4, P. 4-67, last paragraph: Include in this paragraph how many Ohio River fishes are considered migratory?	There is no universal agreement on this topic.	None

Comment #	Comment	Response	Revised Section
13-83	Env Appendix – CEA Chapter 4, P. 4-67, last paragraph, line 12: We suggest including text here that open river conditions are less likely to occur in the upper river.	This has been added.	CEA Ch 4
13-84	Env Appendix – CEA Chapter 4, P. 4-70, last paragraph: Indicate in this paragraph where the results are discussed?	Location of results is now indicated.	CEA Ch 4
13-85	Env Appendix – CEA Chapter 4, P. 4-75: We suggest including language that pollution control efforts will continue to have positive effects on water quality and fishes, but that without habitat construction and connectivity, environmental sustainability of many fish species will remain marginally sustainable at best.	As stated above, many factors affect fish communities with restoration effort being among them.	None
13-86	Env Appendix – CEA Chapter 4, P. 4-75: We suggest including language here that the effects of Asian carp are over stated, that they are of concern, but effects have yet to be demonstrated or quantified.	Sentence modified as suggested.	CEA Ch 4
13-87	The projected ES bar graphs (figure 6-10 on page 6-31 and 10-19 on page 10-67) for mussels and riparian habitat still show an increase for the future. We suggest including here justification for the qualitative improvement predicted. These figures do not agree with others in the text, e.g., ES charts in Figure 6-6 and 6-7, and figure 10-10 and 10-11, but they should be the same. Both will likely remain marginally sustainable at best, but not more so in the future than now. We suggest a program to reverse the loss of riparian habitat from industrial, recreational and urban development.	Figure 6-10 does depict mussel resources improving in the future over the present although the resource is marginally sustainable throughout the study period. This does not agree with figures 6-6 and 10-10. We will correct figure 6-10. The full discussion of this assessment is in Chapter 5 of the Cumulative Effects Assessment (CEA) in the Environmental Appendix. The Figures for the Riparian resource will also be adjusted for consistency in all the figures. The full Riparian discussion is contained in Chapter 6 of the CEA.	Figure 6-10

Comment #	Comment	Response	Revised Section
13-88	Other existing authorities where the Corps can make a difference in future environmental quality is the Section 10/404 program. The Corps permit program has a direct effect on the quantity and quality of riverine and riparian habitat throughout the river systems. The document should stress the need for a unified approach within all the districts within the Ohio River Division on environmental sustainability; mitigation; baseline data needs and impact assessments; and compliance monitoring. This could be another column in table 9-10 as a means to enhance ecosystem sustainability.	Though not completely uniform, regulatory activities under the Section 10 and 404 authorities are guided by a common set of rules and guidelines. Although the SIP/PEIS is intended to guide future decisions on navigation improvements and ecosystem sustainability, the document, especially the CEA, could serve as a resource for many other purposes, including the Section 10 and 404 programs.	None
14-1	Letter of support.	Noted.	None
15-1	Letter of support.	Noted.	None
16-1	Disagrees with conclusion that the Lock Modernization Alternative will make a positive contribution to various resources, suggests that it would have less negative impacts than other alternatives.	The comment misrepresents the statement. The Conclusion states a reduction in cumulative effects is a positive contribution.	None
17-1	Supports Adaptive Management-Need to enhance AM discussion in final EIS; clearly identify the process, data needs and key steps that will be used.	CEA Chapter 13 contains discussion of adaptive management. Corps preference in site specific studies is to work with stakeholders to evolve a strategy wherein all participants interact.	None
17-2	Institutional Arrangements-There are a wide range of jurisdictions, organizations, ongoing authorized projects and other factors that influence the Ohio River Navigation System performance and ecological health. Describe course of action and schedule to define new authority & relationship to existing institutional arrangements. Formalize and continue collaboration on implementation of new management strategies.	Throughout the ORMSS, the IWG was instrumental in success of the effort. Means of continuing the IWG were explored, and while there was considerable support, the Corps would need authority and on-going funding to lead this effort.	10.4.1

Comment #	Comment	Response	Revised Section
17-3	Institutional Arrangements- Include institutional arrangements in the ROD. Include draft ROD in the Final EIS.	Following issuance of the final EIS, additional reviews will occur that could affect the Corps' decision. Therefore, it would be premature to include a draft ROD with the FEIS.	None
17-4	Environmental Justice-Additional focus should be given to census tracts where minority and/or low-income populations exceed state averages. Discuss how benchmark value of 1.5 times the state poverty level was determined.	This issue is not ripe for decision at the programmatic tier. This will be included in site specific NEPA documents. Benchmark value of 1.5 was selected by the study team as a measure to denote significance at this scale.	None
17-5	Cumulative Impacts and Mitigation Plan-Cumulative Impact analysis is incomplete without corresponding comprehensive system wide mitigation plan.	Concur. Section 10.4.1 (Mitigation) added.	10.4.1
17-6	NPDES Permitting- Recommends Corps undertake early coordination with bordering states on potential NPDES permit needs.	Agree. If NPDES permit requirements are identified, the Corps will obtain permits prior to discharge.	None
17-7	Hydroelectric Power Generation-Programmatic EIS should consider potential adjunct use of L/D impoundment structures serving as reservoirs for hydro power projects and if such use would impact lock operations.	Hydropower at Corps navigation dams use run-of-river flows; no considerations are given to hydropower when operating the L/D.	None
17-8	Structure Design for Fish Protection-Programmatic EIS should include a commitment to examine design of L/D structural modifications to promote the protection of aquatic life including portal passages.	Concur. Fish Passage has been identified as a system mitigation feature that will be addressed at the site specific level.	10.4.1
18-1	Sustainability concerns around habitat degradation, fragmentation and loss should be more fully addressed prior to issuing a final ORMSS. Plans to reduce these concerns must be included in site specific projects.	One piece of the mitigation plan in 10.4.1 is to prepare a sustainability plan within the area of influence of each site specific study recommended in the SIP.	10.4.1
18-2	Add a VEC for river ecosystem function as the fundamental support system for discrete VECs currently identified.	List of VECs to consider coordinated extensively with the IWG and public early in the study. Ecological Functions discussed within individual VECs.	None

Comment #	Comment	Response	Revised Section
18-3	WPC would like to identify clean gravel substrates to uses as refugia. River sections just below dams and select island locations will be the most promising, but also the most likely to be impacted during lock and dam modification work.	The Corps is very interested in the results of this effort.	None
18-4	The LMA will minimize degradation of natural resources but will not improve sustainability of resources in and along the Ohio River.	The comment misrepresents the statement. The Conclusion states a reduction in cumulative effects is a positive contribution.	None
18-5	WPC would like to participate with the Corps in the Ohio River Basin Comprehensive Study and other efforts to pursue planning and implementation of measures to improve sustainability.	Participation by the WPC in the Ohio River Basin Comprehensive Study would be welcome.	None
18-6	WPC formally requests to be notified of public participation opportunities related to Upper Ohio River Navigation Feasibility Study.	This notification and participation by WPC has occurred.	None
19-1	Add Section noting state-listed plant and animal species as an affected resource and as a resource of concern.	This issue is not ripe for decision at the programmatic tier. This will be included in site specific NEPA documents.	None
19-2	This proposal may require the formal approval of our agency pursuant to the Flood Control Act for any proposal to construct, excavate or fill in or on the floodway of a stream or other flowing waterbody which has a drainage area greater than one square mile.	This issue is noted but is not ripe for decision at the programmatic tier. This issue will be coordinated with the State of Indiana at the site specific level.	None

Comment #	Comment	Response	Revised Section
19-3	Project programs not involving new lock and dam construction with improvement of some existing ones would perpetuate a condition of frequent backups at locks, which have negative impacts on aquatic habitats. However, new L/Ds with significant construction at old ones will result in permanent loss of aquatic and riparian habitat w/potential losses to mussel resources. An alternative that does not involve a permanent loss of habitat in and along the Ohio River should be selected. The LMA will result in the permanent loss of 2+ acres of aquatic habitat at upper Ohio River pools, may permanently eliminate fish habitat and mussel beds and cause extensive and lasting bank erosion including to river islands. The LMA could reduce tow queuing and the negative environmental effects it causes; however, the report indicates low-cost structural practices can minimize and in some cases eliminate tow queuing and its negative environmental effects. The LMA will cause significant environmental harm and is not recommended.	The LMA involves construction of a larger lock at Emsworth, Dashields, and Montgomery locks, in each case to replace the very small 56'x360' lock. These very small locks, designed for traffic that disappeared from the waterways by WWII, present bottlenecks whenever the main chambers are closed and all traffic is forced thru the auxiliary for extended periods of time. Low cost structural measures can not significantly affect queues during those times. In addition to having economic advantages, this study has shown that replacement of these outdated locks has environmental advantages as well, advantages that appear to be substantially greater than the negative effects of the permanent loss of habitat cited.	None
19-4	Recommendations of the Draft FWCA Report should be fully implemented by the Corps.	Noted.	None
19-5	Recent Corps project designs have included bank stabilization using large expenses of rip-rap, eliminating the existing riparian habitat, and riparian habitat connectivity.	Noted.	None

Comment #	Comment	Response	Revised Section
19-6	Recommendations: -revegetate all bare and disturbed areas -Minimize in channel disturbance and the clearing of trees and brush -Do not work in the waterway from April 1 through June 30 -Do not cut any trees suitable for Indiana bat roosting -Do not construct any temporary runarounds or causeways -Use minimum average 6 inch graded riprap stone extended below the normal water level to provide habitat for aquatic organisms in the voids -Appropriately designed measures for controlling erosion and sediment must be implemented -Seed and protect all disturbed streambanks and slopes	These issues are noted but are not ripe for decision at the programmatic tier. These issues will be coordinated with the State of Indiana at the site specific level.	None
20-1	Ohio River navigation system important to region and nation, (there are 45,000 people who derive their livelihood from the river directly and 217,000 direct/indirect and induced jobs dependent on this river {regionally}) and welcomes progress toward addressing needs at Emsworth, Dashields and Montgomery Locks and Dams.	Noted.	None

Comment #	Comment	Response	Revised Section
21-1	Disappointed that the report did not account for costs and impacts on everyday lives of residents incurred due to shift of river traffic to land modes that are caused by lock closures.	The Corps policy on accounting for these types of costs was being developed during the ORMSS study effort and therefore it was better that these costs were not included. Corps HQ did issue a memorandum on September 1, 2006 that stated or clarified the policy on "reduced travel benefits" related to the Southwest Arkansas Navigation Study. The basic findings were (taken from the Economics Appendix of the Upper Ohio Feasibility Scoping Meeting Package): 1) the reduction of congestion on overland modes (externality) is an indirect benefit that can be included as a NED benefit with the following qualification; 2) the externality cannot be used to determine economic feasibility, but can only be added after economic feasibility has been determined. Therefore the impacts of shifting traffic to land-based modes due to lock failures can be accounted for as an economic benefit with the above qualification. The on-going feasibility study considering new locks at Emsworth, Dashields and Montgomery will consider the following externalities: 1) Value of Travel Time (congestion) 2) Highway Safety 3) Fuel Consumption 4) Air Pollution The first of these can be accounted for as economic benefits after economic feasibility and has been determined.	None

Comment #	Comment	Response	Revised Section
22-1	Has there been any interest in addressing a recommendation from the USFWS to change the 65/35 (Fed/non-Fed) cost share to 90/10 for environmentally-related work.	No. Issues being discussed by Congress related to a possible WRDA include expanding the authorization of the Ohio River Ecosystem Restoration program to Ohio River tributaries and to allow NGOs to participate as project sponsors under that program.	None
23-1	Was there a projection as to how long the Ohio River Locks and Dams last?	Lock and Dams are designed for a 50-year life. Several Ohio River Projects are already past their design life.	None
23-2	Taking into consideration the design life, why weren't there provisions for needed repairs taken at projects already past their design life before now?	Federal decision makers must prioritize investments in nation's resources. This report provides information for decision makers to prioritize investments.	None
24-1	Based on experience with funding of projects like Kentucky & Olmsted, how can we know that the SIP can be funded implemented as indicated in the report?	We can not guarantee as to future funding. This report establishes the road map (for Ohio River maintenance needs) to allow for prioritization of federal investments and to address the issue raised.	None
24-2	Are statements supporting proposed program as important as dissenting views.	It is very important for stakeholders to state the value of the navigation system so that these views can be factored into the federal decision making process.	None
24-3	In Paducah, there's something on the order of 1,800 direct jobs associated with the river and 25,000 indirect jobs, a lot of people affected.	Statement of Support.	None
24-4	Have there been any discussions as to how to organize efforts to ensure funding for the recommended projects?	No, the Corps is not in a position to do that. Such decisions are worked out in budgets developed between the administration and Congress. Information like that provided in this report facilitates that process and subsequent decisions about how our nation's resources are allocated.	None

Comment #	Comment	Response	Revised Section
24-5	What would a maximum program mean in terms of employment for the Corps and the region in terms of people that would be involved directly with the Corps?	Little impact to Corps employment, construction would be performed by contractors. The majority of money required by these projects would go back into small and large businesses in the region.	None
24-6	What percentage of traffic on the Ohio is import and export, either northbound or southbound of the Gulf of Mexico?	The Corps does not maintain data on imports and exports and can not provide the requested information.	None
24-7	Northbound freight suspected to be more prominent, with apparent focus on upper three projects, the southern projects can't be allowed to deteriorate.	New locks are needed on the upper three locks due to age, but the entire system will be maintained to ensure that the entire river system is reliable.	None
25-1	Long-term perspective and funding for Ohio River Navigation System is needed.	Statement of Support.	None
25-2	Maintenance of nation's infrastructure such as recommended by this report is essential for current and future generations. 70-year perspective considered by study is impressive, funding for these needs is critical.	Statement of Support.	None
25-3	Needed perspective for funding (the Ohio River investment needs) likened to that for the Eisenhower's highway program considering associated improvements in productivity in the economy.	Statement of Support.	None
25-4	Similar to supporting comments that Mr. Morris made at Evansville, IN public hearing and discussed above.	Statement of Support.	None
25-5	Similar to supporting comments that Mr. Morris made at Evansville, IN public hearing and discussed above.	Statement of Support.	None
25-6	Similar to supporting comments that Mr. Morris made at Evansville, IN public hearing and discussed above.	Statement of Support.	None

Comment #	Comment	Response	Revised Section
26-1	Could auxiliary locks be slowly converted to full service locks to help cope with increased traffic and during needed maintenance?	No. The only way for auxiliary locks to provide the same service as a larger main is if they are enlarged (reconstructed) to the size of the main chamber.	None
27-1	Need to maintain Ohio River System and for provision of 1200' auxiliary chambers at all projects soon.	All new locks, including 1200' auxiliary chambers, must be economically justified before recommendation can be made for construction.	None
28-1	Supports study and recommendations.	Statement of Support.	None
29-1	Were container ships considered?	Traffic forecasts for this study focused on existing trends. There has been a pilot study for Port of Pittsburgh containers. We did not include containers at this time, but if such traffic develops, future updates of this study take that into account.	None
29-2	River system supports just-in-time delivery, so industry can't wait on a system that's shut down, as well as national security by providing the best way to transport troops and equipment.	Statement of Support.	None
30-1	Supports Corps efforts to keep the system running, noted importance to keeping environmentally compliant coal and stone movements going which in turn allows for provision of reliable electrical service.	Statement of Support.	None
31-1	What is cost breakdown concerning environmental restoration and what are the associated benefits?	There were no estimates of costs or benefits. Instead, a framework of the important issues to be addressed in subsequent studies was identified. (The Ohio River Ecosystem Restoration Program is one vehicle by which these studies may occur.)	None
31-2	Is the restoration part of work associated with locks?	The ecosystem restoration could be accomplished separate from work at the locks.	None

Comment #	Comment	Response	Revised Section
31-3	Why do bottom lands need to be converted to hardwoods and wetlands restored? Land conversion should be on a voluntary basis.	Conversion of bottom lands to hardwood forests or wetlands was identified by the group of experts convened to determine high priority ecosystem needs. Much of these habitats have been converted to other uses through the years. There is no implication in the report that such conversions would be on a non voluntary basis.	None
31-4	Were impacts on agriculture considered in association with conversion of bottom lands?	We recognize that conversion of bottom lands would likely affect some agricultural lands.	None
32-1	Suggests that the Corps implements any ecosystem restoration program rather than turning over such responsibility to state or local governments.	Implementation of ecosystem restoration is envisioned to be a collaborative effort involving many organizations and individuals regardless of which organization leads the effort.	None
33-1	Was control of riverbank erosion considered as part of the ecosystem restoration program?	Yes, riverbank erosion is one of many sources of riparian habitat degradation that resulted in the need for restoration.	None
34-1	Noted that there is a sharp drop-off, about 4-5 feet out in the Emsworth Back Channel, near Montour Run, directly across from a dock.	Noted on Phone. Will put on mail list for Upper Ohio Feasibility Study.	None

SECTION 12
CONCLUSIONS AND RECOMMENDATIONS

1. Study Conclusions. From the engineering, economic, and environmental analyses preformed for this study, the following conclusions can be drawn:

The Ohio River mainstem is an important natural resource to the nation and is the backbone of the Ohio River Navigation system which together with its six navigable tributary rivers provides efficient water transportation for a vast portion of the Nation. Annually, more than 240 million tons of coal, stone, grains, ores, steel and other commodities move on the Ohio River mainstem. There are 57 coal-fired generating plants on the river which provide 20 percent of the nation's coal-fired electric generation capacity. The Ohio River's navigation infrastructure with main chamber average age of 42 years is essential to the national and regional economy and provides recreation opportunities as well as environmental amenities. The Ohio River is a critical artery of commerce through which billions of dollars of savings are realized by businesses and consumers.

- Each of the traffic scenarios studied are reasonable assumptions of future navigation conditions. The actual future traffic demand will likely be somewhere within the range encompassed by the scenarios and is expected to be reasonably similar to one of them. All of the scenarios studied show increases in navigation traffic in the study period.

- At the present time, 25 percent of locks on the Ohio have exceeded their design life. Within 10 years, 50 percent of the locks will be beyond their original design. Operation and Maintenance funding at the level required for a reactive maintenance scenario has a benefit to cost ratio ranging from 22.7 to 24.6:1. This study also clearly shows the prudence of performing proactive maintenance to include both component replacements and major rehabilitation to provide reliable navigation on the Ohio River mainstem. Such maintenance would provide national economic development benefits of hundreds of millions of dollars annually over and above the benefits achieved through reactive maintenance. The benefit cost ratio for the WPC ranges from 7.8 to 12.7:1.

- No additional authorities are necessary at this time to address the needs related to the reliability of the locks. Follow-on studies are needed for several major rehabilitations and lock improvements.

- The need for early construction of new main locks at the three upper Ohio River locks is apparent across all traffic forecast scenarios. An Upper Ohio Navigation Study is underway.

- Minor repairs and small jobs associated with routine maintenance would cause only localized and limited effects on the ten VECs evaluated in the cumulative effects analysis. Routine maintenance, scheduled maintenance, and an N-Up/N-Down lockage policy would be expected to reduce tow queuing prior to passage through the locks, and to facilitate tow movement through the locks in a timelier manner and thus provide beneficial impacts (effects) on several VECs. Such beneficial effects would result from reductions in localized water turbidity levels; decreases in habitat disturbances for fish, mussels, and riparian resources; lowered accident potentials; and improved recreation opportunities.

- High priority ecosystem sustainability measures are needed for the Ohio River, its tributaries and its associated natural resources on a large scale. These include habitat protection and restoration, control of exotic species, reintroduction of native species, improved connectivity of habitats, and reduction of sources of degradation. These measures are needed to help improve sustainability of many resources including mussels and riparian/floodplain habitats and the species they support.

- The conduct of this study was assessed in accordance with the seven Corps of Engineers Environmental Operating Principles and was found to be consistent with all of them.

- The Lock Modernization Alternative would result in lesser cumulative effects than the other plans. Reduction of cumulative effects would be a positive contribution to sustainability of water quality, fish, mussels, riparian resources, recreation, and health and safety.

- The Cumulative Effects Assessment indicated that future navigation investments would not adversely impact long-term resource sustainability. However, mussels and riparian/floodplain resources are not expected to become fully sustainable in the future due to continued degradation from previous actions combined with the future actions identified.

2. Study Recommendations. The ORMSS SIP is not seeking Congressional Authorization for any new construction projects. Rather, it is a long term planning tool for decision makers in the budgeting and asset/infrastructure management process. It encompasses the entire Ohio River mainstem lock navigation system to optimize funding requirements for anticipated construction, normal operation and maintenance, maintenance and rehabilitation needs. The ORMSS SIP recommendation for the combined plan, which is also the environmentally preferred plan, follows. The annual costs for the SIPs over the period 2010 to 2030 are shown in **Table 12-1**.

Table 12-1
Annual Costs of Optimal SIP Actions,
By Scenario Over Time Period 2010 to 2030
($ Millions)

Year	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
2010	237.87	237.67	238.25	237.45	237.43
2011	124.76	134.59	135.39	127.90	134.41
2012	107.97	111.76	112.67	108.67	111.78
2013	92.95	95.83	95.75	100.90	95.94
2014	231.80	280.39	216.65	285.21	281.20
2015	292.74	295.82	320.75	289.95	294.27
2016	292.61	295.95	323.06	295.10	299.68
2017	152.21	100.12	205.62	101.66	95.86
2018	91.01	101.02	96.56	106.10	91.00
2019	72.95	84.09	73.13	85.60	78.40
2020	72.27	79.11	74.84	80.00	76.83
2021	78.02	73.38	79.94	73.32	73.40
2022	73.59	64.86	69.22	64.80	67.12
2023	67.55	66.20	66.85	66.13	68.46
2024	56.24	55.09	55.35	55.01	56.73
2025	69.22	66.38	62.18	64.39	62.23
2026	69.70	57.68	59.92	57.59	57.69
2027	78.33	68.10	68.76	68.26	61.86
2028	63.57	64.78	63.70	62.40	71.40
2029	71.51	66.54	64.39	66.27	79.29
2030	74.44	66.18	73.36	71.70	74.93

Specific recommendations are:

- Increase Operation and Maintenance (O&M) investments to maximize economic efficiency by realizing the replacement and major rehabilitation of major components when economically justified. Complete all authorized navigation improvements; Olmsted, JT Myers, Greenup, Lower Monongahela, Kentucky Lock and Chickamauga.

- Provide optimal funding for the Upper Ohio River Study currently underway in order for this project to be included in a WRDA in the FY 2010 time frame.

- Initiate main chamber rehabilitation studies for Meldahl, Hannibal, and Myers as soon as possible.

- Initiate main chamber rehabilitation study for Pike Island in the near term (before 2015)..

- Pursue planning and implementation of measures to improve environmental sustainability in collaboration with other interests.

- Initiate preparation of the Program Implementation Plan for the Ohio River Ecosystem Restoration Program.

- Incorporate all Reasonable and Prudent Measures into the Operation and Maintenance of the river.

- Complete work on the Markland gates as soon as possible. Funds provided in FY 2006 will initiate design and continued funding in FY 2007 and beyond will be used to construct the gates and place them in service.

- All detailed evaluation of site-specific impacts for follow on studies and other actions would be tiered from the SIP/PEIS.

- Initiate the Ohio River Basin Comprehensive Study in order to assess water resource opportunities throughout the basin in collaboration with other interests. Planning efforts should include identification and evaluation of opportunities to improve environmental sustainability throughout the basin including the tributaries.

- Establish a stand alone program (Ohio River Navigation System Investment Program) to update the data and models used in preparing the System Investment Plan. Expand the program capability to include the Ohio River dams and include tributary (Allegheny, Monongahela, Kanawha, Green, Tennessee and Cumberland Rivers) locks and dam structures to support navigation investment decisions and manage future system risk. Use these tools in annual budget formulation.

- Use the Ohio River Navigation System Investment Program to reexamine the medium and long term needs identified in the SIP to optimize investments on these projects.

- All detailed evaluation of site-specific impacts for follow on studies and other actions would be tiered from the SIP/PEIS.

- The System Investment Plan was not developed considering a constrained federal budget or considering the total Ohio River System. Follow on actions need to be conducted to analyze investment strategies with a constrained federal budget and expanded to include all navigation locks, dams and channels on the Ohio River and its navigable tributaries.

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Woolpert Inc.			
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	BS Biology	sciences & biology, Pittsburgh District (retired)	support
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GLOSSARY
OHIO RIVER MAINSTEM SYSTEM STUDY/PROGRAMATIC ENVIRONMENTAL IMPACT STATEMENT

Measure — action designed to address problems or needs that can be implemented as part of an alternative.

Alternative — set of measures implemented at various times throughout the planning period to address problems and needs.

Cumulative Impact — the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what governmental agency or person undertakes such actions.

System Investment Plan — Master plan or timetable for implementing maintenance of major lock and dam components, non-structural efficiencies and low-cost structural measures, and establishing budgets for future major rehabilitation and lock modernization feasibility studies for Ohio River navigation projects. These activities would supplement routine or day-to-day maintenance and cyclic maintenance activities that are required to keep any navigation facility operational. Major rehabilitation studies would be required for costly maintenance projects meeting requirements for that program. Feasibility studies would be required for Congressional authorization of the construction of larger locks. This plan also addresses high priority ecosystem needs for the Ohio River.

ITR — Independent Technical Review, a procedure followed by the Corps to ensure overall quality of a variety of products ranging from planning studies to construction projects. All ITRs involve review by qualified independent personnel not affiliated with the development of the product being reviewed for the purpose of confirming the Corps studies are done in accordance with clearly established professional principles, practices, codes and criteria.

Environmental Sustainability — capability of remaining in a healthy and viable state for future generations. ES is identified in the Corps' recently published Environmental Operating Principles as "a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations" (U.S. Army Corps of Engineers, 2002).

Valued Environmental Components — significant environmental resources based on political, legal, public, and professional significance considerations. The following ten VECs were identified for the Ohio River: 1) water and sediment quality, 2) fish, 3) mussels, 4) riparian and floodplain resources, 5) health and safety and 6) river-based recreation, 7) air quality, 8) transportation and traffic, 9) socioeconomics and 10) cultural resources. The first six of these were considered more significant and received greater emphasis in the environmental sustainability analysis.

Ohio River Ecosystem Restoration Program — Authorized by the Water Resource Development Act of 2000, this program would identif3' and prioritize ecosystem needs for the Ohio River corridor consistent with current law and Corps policy. Non-Federal sponsors would fund *35* percent of site-specific project first costs and 100 percent of operation, maintenance, repair, rehabilitation, and replacement. Projects would be designed by a partnership composed of representatives from government resource agencies, universities, and other environmental concerns. This program would involve monitoring, evaluating and managing the Ohio River ecosystem. A corridor-wide ecosystem needs assessment and strategy, or Program Implementation Plan, would be developed initially to refine ecosystem goals and prioritize restoration efforts. As of the date of this report, this program has not been funded.

Programmatic Environmental Impact Statement — one type of environmental documentation stipulated by Council of Environmental Quality regulations that can be used to assess the implications of policies and programs of federal agencies or actions that are similar in nature or broad in scope.

National Economic Development Plan — that plan that reasonably maximizes the economic value to the nation consistent with sound environmental design principles.

National Ecosystem Restoration Plan — that plan that reasonably maximizes ecosystem quality of environmental resources under consideration in a cost effective manner.

National Ecosystem Sustainability Plan — that plan that reasonably ensures ecosystem sustainability of environmental resources under consideration in a cost effective manner.

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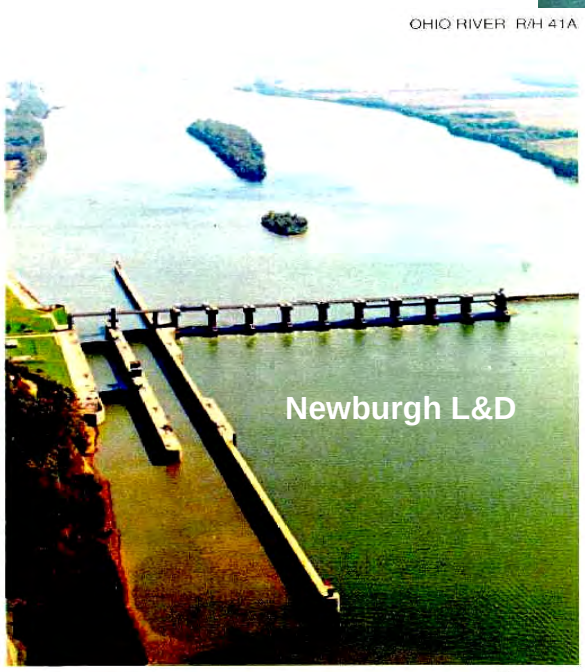
US Army Corps
of Engineers
Great Lakes and Ohio River Division
LOUISVILLE DISTRICT / HUNTINGTON DISTRICT / PITTSBURGH DISTRICT

Ohio River Mainstem Systems Study (ORMSS)

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Engineering Appendix and Economics Appendix



July 2011

DEPARTMENT OF THE ARMY
U.S. ARMY ENGINEER DISTRICT, LOUISVILLE
CORPS OF ENGINEERS
P.O. BOX 59
LOUISVILLE, KENTUCKY 40201-0059

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Engineering Appendix

July 2011

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List of Acronyms

ATC	Average Towing Cost
BEA	Bureau of Economic Analysis
BTU	British Thermal Unit
CAAA	Clean Air Act Amendments
COE	Corps of Engineers
CR	Component Replacement
DOE	Department of Energy
EDM	Emsworth, Dashields and Montgomery
EIA	Energy Information Administration
EQ	Equilibrium Model
ER	Engineering Regulation
HQ	Headquarters (Corps)
IWR	Institute for Water Resources
L/D	Lock(s) and Dam
LPMS	Lock Performance Monitoring System
LRD	Great Lakes and Ohio River Division
LRM	Lock Risk Module
MRS	Marginal Rate Savings
MTC	Marginal Towing Cost
NAAQS	National Ambient Air Quality Standards
NAVPAT	Navigation Predictive Analysis Technique
NED	National Economic Development
NER	National Ecosystem Restoration
ODC	Origin-Destination-Commodity
O&M	Operation and Maintenance
OM	Optimization Module
ORB	Ohio River Basin
ORMSS	Ohio River Mainstem Systems Study
ORNIM	Ohio River Navigation Investment Model
ORNL	Oak Ridge National Laboratory
ORS	Ohio River System
P&G	Principles and Guidelines
PMP	Project Management Plan
PRB	Powder River Basin
RM	Reactive Maintenance
SIP	System Investment Plan
TCM	Tow Cost Model
TVA	Tennessee Valley Authority
USACE	US Army Corps of Engineers
WAM	Waterway Analysis Model
WCSC	Waterborne Commerce Statistical Center
WOPC	Without-Project Condition
WPC	With-Project Condition
WSDM	Waterway Supply Demand Module

Section 1

INTRODUCTION TO ENGINEERING APPENDIX

1.1 PURPOSE OF THE ENGINEERING APPENDIX

The Ohio River Mainstem Systems Study (ORMSS) Engineering Appendix is intended to give the reader a detailed overview of the multiple engineering features associated with this study. An overview of the ORMSS System Investment Plan (SIP) and the purpose of the study are provided in the ORMSS Main Report. The reader is referred to the Main Report to learn more about that type of information. There were many technical engineering features associated with the analysis of the SIP, such as Without Project O/M costs, analytical reliability models for critical components, probabilistic analysis supporting the determination of major rehabilitation needs, and conceptual With Project designs and costs estimates for select, larger-scale projects such lock extensions of auxiliary chambers and new lock chambers. There are four primary features of the ORMSS Report: Environmental, Engineering, Economics, and Plan Formulation. Engineering is fully integrated with each of the other aspects of the study and this appendix details both the supporting analyses as well as information provided as it relates to the overall economic analysis.

A historical perspective on the Ohio River in terms of navigation is provided in Section 2 of this appendix. Information in this section focuses on the effort to provide year round navigation on the Ohio River with the earliest efforts of canalization. There is also a summary of the original set of intermediate, or low-lift locks and dams, along the Ohio River. Finally, the modernization effort which converted many low-lift locks into a lesser number of high-lift locks is also described in Section 2 of this appendix.

Information regarding pertinent prior studies, including the ORMSS Interim Report (approved in 2000), is summarized in Section 3 of this appendix. This section also provides an excellent review of how the ORMSS was initiated through studies of lock expansion at the former Uniontown Locks and Dam (renamed John T. Myers Locks and Dam in 1996).

Section 4 of this Engineering Appendix gives an overview of the existing configuration of the mainstem of the Ohio River navigation system. It includes a site-by-site description of each lock chamber including an aerial photograph of the project, as well plan view and site map. In addition, a brief overview of the existing condition of the structure and assessment of needs is provided for each site.

Probabilistic engineering reliability analysis is detailed in Section 5. This section covers the process by which the components requiring advanced modeling were determined through a two-phase ranking system. A detailed description of the finite element modeling and subsequent reliability analysis for miter gates and culvert valves is

provided in this section as well. Other modeled components (lock walls, mechanical systems, and electrical systems) are also detailed in this section. Finally, the expert elicitation for mass concrete deterioration at upper three Ohio River project, Emsworth, Dashields, and Montgomery (EDM), is described as well.

Section 6 of this appendix covers project specific cost and closure schedules for maintenance. This includes maintenance dewatering schedules and costs for the Pittsburgh, Huntington, and Louisville Districts as they relate to each project. The major differences between each district's costs and procedures are outlined.

The final section of the Engineering Appendix provides information regarding conceptual With Project designs and cost estimates for expansion of lock capacity at sites determined to be potential candidates for such improvement. Note that the With Project lock capacity expansion designs and cost estimates are conceptual in nature since the final ORMSS Report is not actually authorizing any project for large scale construction, therefore, traditional "feasibility-level" designs and costs are not applicable for this report. This is a change from the last ORMSS Report (Interim Report) in 2000, which was used to authorize lock capacity improvement construction at two high priority sites. If an individual site appears to have economic merit regarding potential lock capacity expansion, the individual district will need to secure funds to initiate feasibility-level designs, estimates, and go through the appropriate congressional approval process.

1.2 PRIOR STUDIES AND REPORTS RELATED TO ORMSS

In Fiscal Years 1990-91, funds were appropriated for an Interim Reconnaissance Report for Uniontown Lock and Dam (now John T. Myers Locks and Dam). The J.T. Myers project is located in the lower reaches of the Ohio River, about 30 miles downstream of Evansville, Indiana -- just upstream of the mouth of the Wabash River. The Uniontown Recon Study focused on only this one lock site, and in June 1991 a Recon Report was issued, which found positive benefits for traffic-capacity expansion at the Uniontown site. USACE Headquarters' review of this Reconnaissance Report, dated 14 February 92, stated:

> The Corps must take a "systems look" to properly address the level of investments needed to continue to provide a viable navigation system ***on the Ohio River Mainstem***. ... the entire Ohio River Mainstem navigation system should be carefully reviewed, but your primary emphasis for this study should concentrate on the lower portion of the river.

Table ED 1-1 summarizes documents pertinent to the ORMSS, particularly those relevant to the ORMSS Interim Report, which was completed and approved in FY 2000. The ORMSS Interim Report authorized two major navigation projects, the J.T. Myers Locks Improvements Project and the Greenup Auxiliary Lock Extension Project, as well as a Systematic Environmental Restoration Project. All of these were authorized with the Water Resources Development Act (WRDA) of 2000.

Table ED 1-1. List of Prior Studies and Related Reports

Document Title	Date	Produced by	Summary	Conference or Reference	Disposition / Status
Information Brochure for Periodic Inspection, Uniontown L&D	Jun-74	CELRL-ED	Reference data used for periodic inspections of the L&D facilities.	not applicable	Includes "as-built" drawings for Uniontown L&D (now Myers L&D). Constructed June 1965- Sept 1972.
Final Technical Report H-75-6 Navigation Conditions at Cannelton L&D, Ohio River	Apr-75	CEWES-HS	Pre-construction hydraulics model investigation for Cannelton L&D -- replaced old L&D's 43-45 w/1-1200 ft lock & 1-600 ft lock + 1365 ft of gated, non-navigable dam	not applicable	Uniontown L&D is 1 of 5 new L&D's (circa 1965) to replace 11 old navigation structures on the Ohio R.
Final Technical Report H-75-9 Navigation Conditions at Uniontown L&D, Ohio River	May-75	CEWES-HS	Pre-construction hydraulics model investigation for Uniontown L&D -- replaced old L&D's w/1-1200 ft lock & 1-600 ft lock + gated spillway and fixed overflow dam	not applicable	
Ohio River Mainstem Nav Study Interim Reconnaissance Study Uniontown Locks & Dam	1-Jun-91	CELRL-PDF	Evaluated large scale improvement alternatives	Recon Review Conference., Louisville 17 Sept 91	CECW-PE review memo of 14 Feb 92. Recon eventully certified per acceptance of P.S.P. in June 96.
Uniontown / ORMS LowCapitalCost Lock Alternatives (DACW27-92-D-0010)	29-Jan-93	HARZA Engrs, (Chicago, IL) for CELRL-ED-DS	Discussed alternatives for different lock components: 6 different walls, 6 gates, 5 empty-fill systems.	Plan Formulation / ED-D coordination. 1st step in low-cost alternatives' design.	Led to later delivery orders by HARZA for layouts at Uniontwn, Newburgh, Cannelton.
Uniontown Locks & Dam/ Ohio River Mainstem Study Initial Project Mgt Plan (IPMP)	1-May-93	CELRL-PDF	Outlined a $10M study, focusing on Uniontn, Newbrgh, & Cannltn Lks, to be complete in 1997.	CECW-P / ORD staffs meet, 10Dec93. IPMP apprvd 7Jun93 by ORL Proj. Mgt. Board.	CECW-PD draft review memo of 6 Jan 94, called for broader scope, includg: (1) itemize all Mainstem nav.costs (long-term); (2) detailed Risk assessmt.
ORMSS Design & Cost Screening of Lock Expansion Alternatives - Uniontown L&D (Final Report)	Jan-95	HARZA Engrs, (Chicago, IL) for CELRL-ED-DS	Evaluated low-cost lock expansion alternatives (including extending the 600-ft lock + low-cost methods to construct a new 1200-ft lock)	Final submittal, Delivery Order 0002, DACAW27-92-D-0010	Led to alternatives per later INCA contract.
Ohio River Mainstem Systems Study, Project Study Plan (PSP) [submittal # 1]	16-Jun-95	CELRD-wide team, edited: CELRL-PDF	Outlined $48M study of entire Main Stem, complete in 2002. Assumes full Feasibility detail for 9 sites.	ORD / CECW staffs, Aug95. Briefed Dir CW, Sep95. Certified 16Jun95, by ORD team leaders & Commanders.	CECW memo 13 Oct 95
ORMSS Design & Cost Screening of Lock Expansion Alternatives - Cannelton L&D (Final Report)	July-95	HARZA Engrs, (Chicago, IL) for CELRL-ED-DS	Evaluated low-cost lock expansion alternatives (including extending the 600-ft lock + a low-cost method to construct a new 1200-ft lock)	Final submittal, Delivery Order 0003, DACAW27-92-D-0010	Led to alternatives per later INCA contract.

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Table ED 1-1. List of Prior Studies and Related Reports (continued)

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Document Title	Date	Produced by	Summary	Conference or Reference	Disposition / Status
ORMSS Design & Cost Screening of Lock Expansion Alternatives - Uniontown L&D (Final Report)	July-95	HARZA Engrs, (Chicago, IL) for CELRL-ED-DS	Evaluated low-cost lock expansion alternatives (including extending the 600-ft lock + a low-cost method to construct a new 1200-ft lock)	Final submittal, Delivery Order 0004, DACAW27-92-D-0010	' '
ORMSS DRAFT Project Study Plan (PSP) [submittal # 2]	1-Feb-96	CELRD-wide team, edited: CELRL-PDF	Outlines $37M study, to be complete in 2000. Costs assume full Feasibility-detail at equivalent of 5 sites.	Fig.4-1 and study outline per discussion w/ CECW-P, 12Dec95 at LexingtonKY	More detail / organization: specific tasks and goals clearly shown. Differentiation between "early action" and other study efforts.
Revised June 96 Project Study Plan (PSP) [submittal # 3]	1-Jun-96	CELRL-PDF	Similar to Feb 96 PSP in terms of overall schedule and costs, but with "Lower River" early actions removed.	CEORD memo to Dir. of Civil Works, HQUSACE, 10Apr96	Lower River "early-action" initiatives removed--new innovative designs allow "in-water" construction with minimized traffic delays.
ORMSS Workshop Documentation, March 18-22 1996, DACW27-95-C-0126	11-Jun-96	INCA Engineers (Bellevue, WA) for CELRL-ED-DS	Results of week-long workshop. Includes PRELIM costs for various lock components.	ORMSS engineers' workshop, Bellevue, 18-22 Mar 96	"Jumpstart" to INCA-Corps collaboration on ORMSS designs
Ohio R. Navigation System Report, 1996 COMMERCE ON THE OHIO RIVER AND TRIBUTARIES	1996	CELRH-NC	The Biennial Report of Commerce and a system-wide inventory of facilities on the Ohio River and its tributaries	not applicable	This color., 20+ page brochure is updated every 2-3 years, with an annual stats update other years.
ORMSS Design Presentation for the 600 C-1 600-ft Lock Extension Alternative (DACW27-95-C-0126)	Mar-98	INCA Engineers (Bellevue, WA) for CELRL-ED-DS	Handout for presentation of to team engineers -- nine different empty-fill configurations	Document prepared for presentation to the ORMSS design/formulation teams at CELRL on 10-11 March 1998.	Handout for presentation of to team engineers -- nine different empty-fill configurations
ORMSS Workshop Documentation, Supp. #1: Alternative 600C Report August 29, 1996, DACW27-95-C-0126	Aug-96	INCA Engineers (Bellevue, WA) for CELRL-ED-DS	Plan 600C utilizes various elements: Float-in gate bay and lock wall monoliths, split lateral fill/empty system with outlet diffuser, floating approach walls	Supplement to workshop documentation for an additional Plan 600-C, developed following the workshop of Mar 96	
ORMSS Workshop Documentation, Supp #2: Alternative 600D Report September 27, 1996, DACW27-95-C-0126	Sep-96	INCA Engineers (Bellevue, WA) for CELRL-ED-DS	Plan 600D utilizes various elements: Float-in gate bay and lock wall monoliths, split lateral fill/empty system with outlet diffuser, floating approach walls	Workshop documentation for an additional alternative, 600-D, developed following the workshop of Mar 96	
ORMSS Alternative 600C Adaptation Report October 29, 1996	Oct-96	INCA Engineers (Bellevue, WA) for CELRL-ED-DS	Prelim. effort to adapt Alt 600-C for the Markland, Cannelton & Newburgh L&D sites -- site differences & costs.	not applicable	Useful for final ORMSS report -- Plan 3 adaptions to various sits

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.TABLE ED 1-1. LIST OF PRIOR STUDIES / REPORTS, ORMSS (continued)

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Document Title	Date	Produced by	Summary	Conference or Reference	Disposition / Status
Lock Closure Data Base for Louisville, Huntington & Pittsburgh Districts (Final Report, DACW69--93-D-0017, W.O. 004)	Apr-96	Jack Faucett Associates, Bethesda, MD., for CELRH-NC	Inventoried high-lift lock closures in the Ohio R. system exceeding 8 hrs duration, from 3 different sources of data, w/ statistical analysis, for O&M analyses.	Various Econ/Plan Formulation team members	partial input to Without-Project lock closures' assumptions
Report - ORMSS Prepare Conceptual Design for Emsworth L&D, Ohio R, 100% submittal (DACW57-D-0003, Del.O.# DV01)	Sep-97	INCA Engineers (Bellevue, WA) for CELRP-ED	Explains engr'g drawings (below) for concept level design for adding a 1200' lock at Emsworth L&D, Ohio R.	Various team and Oversight meetings -- first step towards upper Ohio L&D improvement costing.	Useful for final ORMSS report -- Emsworth is one of three old L&D facilities on the upper Ohio River.
Drawings - ORMSS Prepare Conceptual Design for Emsworth L&D, Ohio River, 100% submittal (DACW57-D-0003, Del.O.#DV01)	Sep-97	INCA Engineers (Bellevue, WA) for CELRP-ED	Drawings detail engr'g and concept level design for adding a 1200-ft lock at Emsworth L&D, Ohio R. (See companion report)	" "	" "
Report - ORMSS Prepare Conceptual Design for Montgomery L&D, Ohio River, 100% submittal (DACW57-D-0003, Del.O.# DV03)	Aug-97	INCA Engineers (Bellevue, WA) for CELRP-ED	Document details engr'g drawings for concept level design for adding a second 600-ft or a 1200-ft lock at Montgomery L&D, Ohio R.	" "	Useful for final ORMSS report -- Montgomery is one of 3 old L&D facilities on the upper Ohio River.
Drawings - ORMSS Prepare Conceptual Design for Montgomery L&D, Ohio River, 100% submittal (DACW57-D-0003, Del.O.#DV03)	Sep-97	INCA Engineers (Bellevue, WA) for CELRP-ED	Document details engr'g drawings for concept level design for adding a second 600-ft or a 1200-ft lock at Montgomery L&D, Ohio R.	" "	" "
Report - ORMSS Prepare Conceptual Design of Dashields L&D, Ohio River, 100% submittal (DACW57-D-0003, Del.O.#DV03)	Sep-97	INCA Engineers (Bellevue, WA) for CELRP-ED	Document details engr'g drawings for concept level design for adding a second 600-ft or a 1200-ft lock at Dashields L&D, Ohio R.	" "	Useful for final ORMSS report -- Dashields is one of 3 old L&D facilities on the upper Ohio River.
ORMSS Field Inspection Report of all L&D Facilities on the Ohio River (Pittsburgh, Huntington & Louisville Districts)	1996-1997	CELRP-EDD; inspections by a core group of LRP/ LRH/ LRL engineers.	Details visual inspection of facilities at each L&D plus interviews with Lockmasters & projects' O&M Leaders. Provides numerical ratings for various L&D components, and photos of conditions at each L&D.	Various team and Oversight meetings -- comparative data to begin reliability analyses.	A step in the process of evaluating risk & reliability for the L&D components and facilities throughout the Ohio R. Mainstem system.
OHIO RIVER NAVIGATION SYSTEM -- 1997 Statistical Supplement	1997	CELRH-NC	Intervening-year statistical update to the biennial Ohio R. Nav. System Report (1996)	The publication also references other Waterway Data Publications and their sources as well as a World Wide Web data access site.	Color., 20+ page Nav.Center brochure (see 1996 report listing above)
ORMSS Design Presentation for the 600 C-1 600-ft Lock Extension Alternative (DACW27-95-C-0126)	Mar-98	INCA Engineers (Bellevue, WA) for CELRL-ED-DS	An advanced presentation to team of 9 different empty-fill configurations (per next document below).	Document prepared for presentation to the ORMSS design/formulation teams at CELRL on 10-11 March 1998.	Discussions led to minor revisions in next document (below).

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Table ED 1-1. List of Prior Studies and Related Reports (end)

Document Title	Date	Produced by	Summary	Conference or Reference	Disposition / Status
ORMSS - 100% Submittal Constructibility and Cost Estimate (Analyses) for Prototype Alts. ***(DACW27-95-C-0126)***	May-98	INCA Engineers (Bellevue, WA) for CELRL-ED	Descriptions, drawings, constructn schedules, & cost estimates for 9 configuratns of F/E systems. Constructibility evaluations.	Report requested by Plan Formulation and ED teams, and incorporates comments received from 10-11 March and District reviews.	Essentially, evaluated sensitivity of layout costs to various empty-fill configuration for both 600 Aux. Extensions, and 3rd lock plans.
ORMSS -Engineering Appendix for Large-Scale Improvements (Prototype Designs) , ***DACW 27-95-C-0126***	Jun-98	INCA Engineers (Bellevue, WA) for CELRL-ED	Feasibility-level design (50% complete) based on J.T.Myers site, considered site adaptable to other Main Stem sites	INCA contract requirement: 50% point submittal	on-going development of Myers Engineering Technical Appendix for Interim Report
MANAGEMENT SUMMARY -- Cultural Resources Database Construction for ORMSS ***(DACA27-960C-0077)***	Aug-98	Gray & Pape, Cultural Resources Consultants, Richmond, VA for CELRL-PD-E	Summarizes efforts in creating 6 cultural resource database files for portions of 6 states along the Ohio R. mainstem nav. system (PA, WV, OH, KY, IN and IL), and tabulates findings.	Cultural Resources inventories for ORMSS.	Designed to work in coordination with a GIS database established by Gulf Engineers/Consultants (GEC)
REPORTS SPECIFIC to GREENUP LOCKS and DAM					
Greenup Locks and Dam, Ohio River, Design Memo #1, Huntington District, Corps of Engineers	Dec-53	CELRH-ED	General Design Memorandum -- overall layout and design assumptions	NA	Beginning of Post-Authorization design work
Navigation Conditions at Greenup Locks and Dam, Ohio River, Hydraulic Model Investigations, Technical Report #2-469	Jan-58	CEWES-HS for CELRH-ED			
Filling and Emptying System for Greenup and Markland Locks, Ohio River, Hydraulic Model Investigations, University of Minnesota	Jan-62	Univ. of Minnesota Hydraulics Lab for CELRH-ED			
Greenup Locks and Dam Periodic Inspection Report #1	Oct-68	CELRH-EC-DS	Reference data used for periodic inspections of the L&D facilities		Includes “as-built” drawings for Greenup L&D, constructed from 1955 to 1962
Meldahl L&D 600-ft Lock Extension Plan, Recon.Level Screening Study, Final submittal, ***DACW69-97-D-0012, D.O.# 0001***	Mar-98	Black & Veatch (Kansas City, MO) for CELRH-EC-DC	Evaluated low-cost lock expansion alternatives		Initial first look at alternatives and cost for a Meldahl 600-ft Lock Extension

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Section 2

OHIO RIVER NAVIGATION SYSTEM – HISTORICAL PERSPECTIVE AND CURRENT STATUS

2.1 HISTORY

2.1.1 Early Settlers and Steamboat Era

The first European explorers to visit the Ohio River Valley are believed to have arrived with De Soto's expedition in 1540. The first pioneers consisted of trappers, fur traders, and soldiers. Canoes provided the most common mode of transportation on the rivers. Over time, the French came to dominate the area with fur trading as their primary economic interest. The increased presence of Euro-American colonial traders by the mid eighteenth century prompted the French to build forts on the Allegheny River in an attempt to reclaim the Ohio River Valley. In 1753, Virginia militiamen, led by Major George Washington, attempted to construct a fort where the Allegheny and Monongahela Rivers combine to form the Ohio River. The French drove them away and built Fort Duquesne instead. In 1758, British forces regained control of the area and replaced Fort Duquesne with Fort Pitt. With the establishment of Fort Pitt, the City of Pittsburgh evolved in the surrounding areas. Because of its strategic location at the head of the Ohio River, Pittsburgh became a major port of embarkation for settlers and commodities traveling west. Flatboats and barges carried the trade of the country downstream. Since flatboats and barges could only travel downstream, the lumber making up these vessels was frequently sold at destination. Keelboats provided the first means for travel both upstream and downstream on the river. They provided regular passenger and freight service between Pittsburgh, Cincinnati, and Louisville. It typically took one month to complete the round trip between Pittsburgh and Cincinnati.

The steamboat era on the Ohio River began in 1811 when the New Orleans departed from Pittsburgh. Early steamboats had deep keels and were not suited for navigation on the shallow western rivers. The development of the first shallow draft steamboat in 1816 set a pattern for the river steamboats which followed. The presence of snags and sandbars, however, plagued navigation. Deadly snags could easily hole out and sink a steamboat without warning. Accidents and fatalities were commonplace. The success of the steamboat and its impact throughout the Ohio River Basin led to the first significant action by the Federal Government to improve navigation conditions.

2.1.2 Improvements to Navigation

When compared to overland routes, the Ohio River provided an easy mode of travel to the west. Travel on the river, however, had its fair share of hazards. In its

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original condition, the Ohio River was obstructed throughout its entire length by snags, rocks, and sand bars. Navigation was difficult and hazardous due to extreme variations in channel width and depth. During periods of low water, the depth could be as little as one foot over the worst shoals. This did not provide sufficient depth for vessels to safely navigate the river.

On 24 May 1824, the first Inland Waterways Improvement Act directed that experiments be conducted to determine the best method for dealing with the sandbars and snags that continued to obstruct navigation on the Ohio River. At this time, the primary function of the Army Engineers in the Ohio River Basin was to improve and develop waterway navigation for steamboat commerce.

One of the first obstacles to be addressed was the rapids near Louisville known as the "Falls of the Ohio". The rapids dropped nearly 26 feet and extended for two miles. Navigation over the falls was impossible except during periods of high water. The Louisville and Portland Canal was completed in 1830 allowing river traffic to bypass the falls. The canal was 1.9 miles long and had three successive locks measuring 50 feet by 185 feet. Since completion of the canal, continuous improvements have been made to the project which is now known as McAlpine Locks and Dam.

The development of the double hulled snag boat by Captain Shreve greatly reduced the snag hazard. Snags were large and numerous with some weighing over one hundred tons. Removal of rock in the channel near Grand Chain commenced in 1830. The use of cutoff dams on back channels and wing dikes to concentrate flow in the main channel improved the navigable depth in most areas to a minimum channel depth of three feet. In 1825, the first wing dike was built at Henderson Bar. Dikes were constructed at Scuffletown and Sisters Islands in 1831 and at French and Cumberland Islands in 1832. Improvements upstream of Louisville were limited to snag removal until 1836 when the dams at Brown Island were built. The success of this project led to the construction of many wing dikes and back channel dams between Pittsburgh and Cincinnati. Improvements to navigation continued on a regular basis through 1844. Contrasting political leadership and the Civil War essentially ended all work from 1845 to 1866.

2.1.3 Canalization

In 1835, Lieutenant George Dutton first expressed his view that the construction of locks and dams was necessary to provide adequate navigation conditions for year round use of the Ohio River. The idea was overlooked at first due to the magnitude of the engineering problems to be dealt with and objections of the river users who believed that dams would be a hindrance to navigation. This attitude began to change during the mid nineteenth century when one way flatboats used to transport coal to downstream destination points were gradually replaced by steamboats towing fleets of coal barges downriver and returning with the empty barges for reuse. It soon became apparent that a system of locks and dams was needed to accommodate the growing coal fleets. Construction of thirteen locks and movable dams between Pittsburgh and Wheeling was proposed by Major W. E. Merrill in 1874. The proposed system was an essential part of the plan to provide a 6-foot navigable depth on the upper Ohio River.

The concept of a movable dam was adopted to meet the needs of coal boat operators. The dam could be raised during low flows to maintain a harbor pool and lowered during high water to allow passage of the coal boat fleets without lockage. The

movable wicket dam invented in 1852 by Chief Jacques Chanoine of the French Corps of Engineers was adapted to meet the needs of the Ohio River. The wickets consisted of a set of timbers that were bolted together. During high water they lay flat against a masonry foundation leaving an open channel for navigation. At low water, the wickets were raised on end to form a dam.

The River and Harbor Act of 1875 provided funds for the construction of a movable dam 4.7 miles downstream of Pittsburgh at Davis Island. The original goal of the project was to provide a pool at Pittsburgh for assembling of coal boats and formation of tows suitable for the downstream run when a "coal boat rise" occurred on the river. Work began in 1877 and the structure was opened to traffic on 7 October 1885. Since it was the first canalization project on the Ohio River, the Davis Island Dam became known as Dam 1.

The Davis Island Dam was 1223 feet long with a Chanoine wicket pass of 559 feet and three Chanoine weir sections. The back channel of the Ohio River was closed with a non-navigable stone-filled timber-crib dam. Because of ice conditions typically experienced on the Ohio River, the wickets in the navigable pass were raised and lowered with a maneuver boat. A service bridge was used to raise and lower the weir wickets. Damage to the bridge by barges and debris led to the use of a maneuver boat for raising and lowering all of the wickets. A drift gap was also added in 1889 to pass floating logs and other debris. Fortunately, the difficult task of raising and lowering the wickets occurred at infrequent intervals during very low or high water.

The 110 foot wide by 600 foot long lock at Davis Island was designed to meet the needs of the coal boat fleets. These dimensions became standard for the initial canalization of the entire Ohio River. The lock chamber was closed via rolling gates mounted on wheels. A recess in the landward lock wall provided storage for the gates.

A consecutive numbering scheme was used to denote the next four dams that were constructed downstream of Davis Island Dam (Dam 1). Appropriations for these projects were made by various River and Harbor Acts starting in 1890. Dam 2 was located 9.0 miles downstream of Pittsburgh and was constructed between 1898 and 1906. Construction of Dam 3, located 10.9 miles from Pittsburgh, occurred between 1899 and 1907. Dams 4, 5, and 6 were built between 1892 and 1908 at miles 18.6, 24.1, and 29.3, respectively.

The board of Engineer officers designated by the River and Harbor Act of 1902 recommended that the navigable depth in the upper Ohio River be increased from six to nine feet. Appropriations for modifications to Dams 2-6 came from the River and Harbor Act of 1905. By 1906, a proposal for a nine foot navigation depth for the entire Ohio River was approved for implementation. The formal authorization for the nine foot depth was provided by the River and Harbor Act of 1910. The original plan called for a total of 54 locks and dams. The projects were divided among four Engineer Districts: Pittsburgh (Dams 1-10), Wheeling (Dams 11-28), Cincinnati (Dams 29-40), and Louisville (Dams 41-54). Of the fifty four dams originally envisioned, only fifty one were included in the final plan. Dams 40, 42, and 54 were eliminated by modifying other projects. The dams had a navigable pass that could be used during high water and a single 110- by 600-foot lock chamber that could be used the remainder of the time.

Upon completion of a reexamination study of the Ohio River in 1916, it was recommended that fixed dams replace the movable wicket dams. The Emsworth Locks and Dams at mile 6.2 replaced Dams 1 and 2. This was the first time that the concept of

movable wicket dams was abandoned in favor of a non-navigable concrete dam. To avoid traffic delays caused by lock closure, two locks were built at the site. The main lock was 110- by 600-feet and the auxiliary lock was 56- by 360-feet. Upon its completion in 1921, the project provided the first non-navigable dam and first twin locks on the Ohio River. In addition, the non-navigable Dashields Locks and Dam was built as a replacement for Dam 3 at mile 13.3. The configuration of Dashields was similar to that of Emsworth. Initial canalization of the Ohio River was finally completed in 1929. Of the fifty lock and dam structures, all but two had a navigable pass.

2.1.4 Intermediate Projects

Following canalization of the Ohio River, several intermediate projects were constructed to enhance navigation conditions. These projects were built prior to the modernization era which began in 1953.

The 56- by 360-foot auxiliary lock chamber at Locks and Dam 41 was completed in 1930. The additional lock substantially increased the capacity of the project. The Emsworth Dams were reconstructed between 1935 and 1938 with gated crests. The upstream pool was raised by seven feet and two lock and dam structures were eliminated.

The storage of water in Tygart Lake, completed in 1938, provided sufficient flows for navigation on the upper Ohio River during dry periods. The project is also part of the comprehensive Ohio River flood control system and provides for water supply and pollution control.

Two new navigation projects were also constructed during this period: Montgomery Locks and Dam in 1936, and Gallipolis Locks and Dam in 1937. Montgomery Locks and Dam, located at mile 31.7, replaced Dams 4, 5, and 6. With a lift of 17.5 feet, it was the first high lift project completed on the Ohio River. The project had two locks measuring 110- by 600-feet and 56- by 360- feet. The Gallipolis Locks and Dam at mile 279.2 replaced three dams on the Ohio River and three on the Kanawha River. It was the most modern lock and dam project of its time. Both locks were 110 feet wide with lock lengths of 600 feet and 360 feet. The original purpose of the Gallipolis project was to improve navigation conditions on the Kanawha River; however, it is operated as part of the Ohio River system. By replacing six existing locks and dams, the Gallipolis Locks and Dam reduced operation and maintenance costs. In addition, the movement of river traffic was expedited as a result of fewer lockages. After completion of the Gallipolis project, there were forty one movable wicket dams and five non-navigable dams on the Ohio River.

2.1.5 Modernization

River traffic on the Ohio River declined during the Great Depression but resumed its climb soon afterward. The original system of locks and dams, designed to transport 13 million tons annually, was moving nearly 38 million tons by 1942. Traffic had increased dramatically and tow lengths of 1000 feet had come into widespread use. The 600-foot lock chambers became obsolete in the early 1950s and, in some cases, became an impediment to the navigation they were designed to enhance. It became evident that a smaller number of high lift locks and dams with longer navigation pools would be needed to improve the system. A full scale modernization program began in 1953. The program

provided for the progressive replacement of low lift navigable structures with a smaller number of non-navigable structures with higher lifts. The nine foot navigation channel depth continued as the standard, but lock chamber sizes were increased to accommodate the larger tows. According to river users, a 110- by 1200-foot lock could accommodate the largest tows that could be efficiently operated on the Ohio River. The Corps adopted these dimensions for the main lock chambers at all new projects. In addition, a 110- by 600-foot auxiliary lock chamber was to be provided to improve dependability, flexibility, and capacity.

Construction priority for the new projects was based on the traffic demands of the time. The first modernization project, New Cumberland Locks and Dam, was completed in 1959. Structures at Greenup, Meldahl, and Markland soon followed. By 1979, a total of thirteen new high lift structures had been built to replace thirty nine low lift locks and dams. The new projects had lifts from 16 to 35 feet and pools with an average length of 59 miles. This was a significant improvement over the old structures which had lifts of 5 to 11 feet and pool lengths less than 20 miles. All of the new projects had a 110- by 1200-foot main lock chamber and a 110- by 600-foot auxiliary lock chamber. The only exception is Smithland Locks and Dam which had twin 110- by 1200-foot lock chambers. In addition to the new construction, a 1200 foot lock was built at McAlpine in 1967 to meet the demands of increased traffic. The existing locks at Gallipolis Locks and Dam (renamed R. C. Byrd Locks and Dam) were replaced with a 110- by 1200-foot main lock and a 110- by 600-foot auxiliary lock in 1993. An additional 1200-foot lock chamber is now under construction at McAlpine to replace the inadequate 600-foot auxiliary lock. Only two of the original locks and dams (52 and 53) remain today. They are scheduled to be retired when the last replacement project of the modernization program, Olmsted Locks and Dam, is completed. The Olmsted project will have twin 110- by 1200-foot lock chambers. The dam will also incorporate movable steel wickets that will allow free movement of traffic during periods of moderate to high flows.

2.2 EXISTING LOCK HYDRAULICS CHARACTERISTICS

Table ED 2-1 was developed to provide basic information about the existing eighteen locks and dams on the Ohio River and the Olmsted Locks and Dam presently under construction to replace Locks 52 and 53. Note that the authorization of auxiliary lock chamber extensions at John T. Myers and Greenup will change those project configurations once construction is completed. Both projects are currently undergoing final design and initial construction of support facilities has started on J.T. Myers at the time of this report.

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Table ED 2-1. Ohio River Project Characteristics

	EMSWORTH	DASHIELDS (Dead Man's Island)	MONTGOMERY	NEW CUMBERLAND	PIKE ISLAND	HANNIBAL	WILLOW ISLAND
GENERAL							
River Mile	6.2	13.3	31.7	54.4	84.2	126.4	161.7
District	Pittsburgh	Pittsburgh	Pittsburgh	Pittsburgh	Pittsburgh	Pittsburgh	Huntington
In-Service Date	1921	1929	1936	1959	1963	1972	1975
Upper Pool Elevation	710	692	682	664.5	644	623	602
Lower Pool Elevation	692	682	664.5	644	623	602	582
Lift (ft)	18	10	17.5	20.5	21	21	20
Top/Lock Elevation	718	704.6	692	674	656	633	616
Lock/Out Elevation	714	701	688	670.1	651.1	629	611
LOCK SIZES							
Main Lock	600' x 110'	600' x 110'	600' x 110'	1200' x 110'	1200' x 110'	1200' x 110'	1200' x 110'
Auxiliary Lock	360' x 56'	360' x 56'	360' x 56'	600' x 110'	600' x 110'	600' x 110'	600' x 110'
FILLING/EMPTYING SYSTEM							
Main Lock Type	Multivalve-Direct	Side Port	Side Port	Side Port	Side Port	Side Port	Side Port
Culvert Size	N/A	11' x 14'-7"	11' x 14'-7"	15'-6" x 15'-6"	15'-6" x 15'-6"	15' x 16'	16' x 18'
Operating Valves	5'4"Butterfly (13)	Butterfly	Butterfly	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter
Discharge Locatn	River - Direct	Lower Approach	Lower Approach	Lower App+River	River - Direct	River - Direct	River - Direct
Depth Over Sill	17.0' U - 12.9'L	13.4'U - 18.5'L	16.0'U - 14.6'L	12.5'U - 14.8'L	17.0'U - 14.8'L	35.8'U - 14.8'L	27.4'U - 15.0'L
Aux Lock Type	Multivalve-Direct	Side Port (R Wall)	Side Port (R Wall)	Bottom Lateral	Bottom Lateral	Bottom Lateral	Bottom Lateral
Culvert Size	N/A	10' x 12'	10' x 12'	15'-6" x 15'-6"	15'-6" x 15'-6"	15' x 16'	16' x 18'
Operating Valves	5'-4" Butterfly (6)	Butterfly	Butterfly	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter
Discharge Locatn	River - Direct	River + Low App	River + Low App	Lower Approach	River - Direct	River - Direct	River - Direct
Depth Over Sill	15.5'U - 12.9'L	13.4'U - 18.5'L	16.0'U - 14.6'L	12.5'U - 14.8'L	17.0'U - 14.8'L	17.0'U - 14.8'L	27.4'U - 15.0'L
APPROACH WALLS							
Main Lock - Upper Wall							
Type	Guide	Guide	Guide	Guard (Ported)	Guard (Ported)	Guard (Ported)	Guard (Ported)
Length (Useable)	525'	490'	489'	1082'	1074'	1200'	1201'
- Lower Wall							
Type	Guard	Guide	Guide	Guard (Solid)	Guard (Solid)	Guard (Solid)	Guard (Solid)
Length (Useable)	577'	491'	490'	1057'	1054'	1440'	1091'
Aux Lock - Upper Wall							
Type	Guard (Ported)	Guard (Ported)	Guard (Ported)	Guide	Guide	Guide	Guide
Length (Useable)	145'	163'	110'	352'	444'	398'	364'
- Lower Wall							
Type	Guard (Solid)	Guard (Ported)	Guard (Solid)	Guard	Guard	Guard	Guard
Length (Useable)	199'	111'	161'	462'	465'	204'	398'
NAVIGABLE WEIRS							
Type	None	None	None	None	None	None	None
Length	N/A	N/A	N/A	N/A	N/A	N/A	N/A
REMARKS							

NOTES: "Useable" Length of approach walls means that length of wall available to an approaching tow for landing.
"Depth over sill" means depth over highest feature in the approach, usually a bulkhead sill

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Table ED 2-1. Ohio River Project Characteristics (continued)

	BELLEVILLE	RACINE	R C BYRD	GREENUP	MELDAHL	MARKLAND
GENERAL			(Gallipolis)		(New Richmond)	
River Mile	203.9	237.5	279.2	341	436.2	531.5
District	Huntington	Huntington	Huntington	Huntington	Huntington	Louisville
In-Service Date	1965	1967	1993	1959	1962	1959
Upper Pool Elevation	582	560	538	515	485	455
Lower Pool Elevation	560	538	515	485	455	420
Lift (ft)	22	22	23	30	30	35
Top/Lock Elevation	596	580	560	537	505	466
Lock/Out Elevation	591	575		531	499	463
LOCK SIZES						
Main Lock	1200' x 110'	1200' x 110'	1200' x 110'	1200' x 110'	1200' x 110'	1200' x 110'
Auxiliary Lock	600' x 110'	600' x 110'	600' x 110'	600' x 110'	600' x 110'	600' x 110'
FILLING/EMPTYING SYSTEM						
Main Lock Type	Split Lateral	Side Port	Side Port	Split Lateral	Split Lateral	Split Lateral
Culvert Size	15' x 16'	15'x16'(15'x18'@Ports)	16' x 18'	16' x 18'	16' x 18'	16' x 18'
Operating Valves	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter
Discharge Location	River - Direct	River - Direct	River - Direct	River - Direct	River - Direct	River - Direct
Depth Over Sill	20.0'U - 15.0'L	18.0'U - 15.0'L	18.0'U - 18.0'L	18.0'U - 15.0'L	18.0'U - 15.0'L	25.0'U - 15.0'L
Aux Lock Type	Bottom Lateral	Bottom Lateral	Bottom Lateral	Bottom Lateral	Bottom Lateral	Bottom Lateral
Culvert Size	15' x 16'	15' x 16'	16' x 18'	16' x 18'	16' x 18'	16' x 18'
Operating Valves	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter
Discharge Location	River - Direct	River - Direct	River - Direct	River - Direct	River - Direct	River - Direct
Depth Over Sill	20.0'U - 15.0'L	18.0'U - 15.0'L	28.0'U - 18.0'L	18.0'U - 15.0'L	18.0'U - 15.0'L	25.0'U - 15.0'L
APPROACH WALLS			(Upper Approach in Canal)			
Main Lock - Upper Wall						
Type	Guard (Ported)	Guard (Ported)	Guard	Guard (Ported)	Guard (Ported)	Guard (Ported)
Length (Useable)	1168'	1200'	1200'	1200'	1200'	1197'
- Lower Wall						
Type	Guard (Solid)	Guard (Solid)	Guard	Guard (Solid)	Guard (Solid)	Guard (Solid)
Length (Useable)	1091'	1090'	1000'	1050'	1090'	1050'
Aux Lock - Upper Wall						
Type	Guide	Guide	Guard	Guide	Guide	Guide
Length (Useable)	316'	370'	262'	382'	382'	379'
- Lower Wall						
Type	Guard	Guard	Guard	Guard	Guard	Guard
Length (Useable)	440'	371'	490'	380'	340'	380'
NAVIGABLE WEIRS						
Type	None	None	None	None	None	None
Length	N/A	N/A	N/A	N/A	N/A	N/A
REMARKS						

NOTES: "Useable" Length of approach walls means that length of wall available to an approaching tow for landing.
"Depth over sill" means depth over highest feature in the approach, usually a bulkhead sill

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Table ED 2-1. Ohio River Project Characteristics (continued)

	McALPINE	CANNELTON	NEWBURGH	J T MYERS	SMITHLAND	OLMSTED
GENERAL	(L/D 41)			(Uniontown)	(Dog Island)	(Under Construction)
River Mile	606.8	720.7	776.1	846	918.5	964.4
District	Louisville	Louisville	Louisville	Louisville	Louisville	Louisville
In-Service Date	1961-2003	1971	1975	1975	1979	2008 (Scheduled)
Upper Pool Elevation	420	383	358	342	324	295-301
Lower Pool Elevation	383	358	342	324	302	Uncontrolled
Lift (ft)	37	25	16	18	22	21 (Nominal)
Top/Lock Elevation	443	402	380	362	344	310
Lock/Out Elevation	440	399	377	359	341	295-301
LOCK SIZES						
Main Lock	1200' x 110'	1200' x 110'	1200' x 110'	1200' x 110'	1200' x 110'	1200' x 110'
Auxiliary Lock	1200' x110' (2003)	600' x 110'	600' x 110'	600' x 110'	1200' x 110'	1200' x 110'
FILLING/EMPTYING SYSTEM						
Main Lock Type	Split Lateral (Existing)	Side Port	Side Port	Side Port	Side Port	Side Port
Culvert Size	16' x 18'	16' x 18'	14' x 16'	14' x 16'	14' x 18'	14' x 18'
Operating Valves	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter
Discharge Location	River - Direct	River - Direct	River - Direct	River - Direct	River - Direct	River - Direct
Depth Over Sill	18.0'U - 12.0'L	15.0'U - 15.0'L	18.0'U - 16.0'L	20.0'U - 16.0'L	34.0'U - 15.0'L	34' to 40'U - 18'L
Aux Lock Type	Central Culverts (UC)	Bottom Lateral	Bottom Lateral	Bottom Lateral	Side Port	Side Port
Culvert Size	16' x 18'	16' x 18'	14' x 16'	14' x 16'	14' x 18'	14' x 18'
Operating Valves	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter	Reverse Tainter
Discharge Location	Lower Approach	River - Direct	River - Direct	River - Direct	River - Direct	River - Direct
Depth Over Sill	18.0'U - 16.0'L	15.0'U - 15.0'L	18.0'U - 16.0'L	20.0'U - 16.0'L	34.0'U - 15.0'L	34' to 40'U - 18'L
APPROACH WALLS	(Upper Approach in Canal)					
Main Lock - Upper Wall						
Type	Guard (Ported)	Guard (Ported)	Guard (Ported)	Guard (Ported)	Guard (Ported)	Guard (Floating)
Length (Useable)	1010'	1188'	1190'	1198'	900'	900'
- Lower Wall						
Type	Guard (Ported)	Guard (Solid)	Guard (Solid)	Guard (Solid)	Guard (Solid)	Guard (Floating w/ Curtains)
Length (Useable)	1094'	1002'	1009'	998'	1050'	852'
Aux Lock - Upper Wall						
Type	Guide	Guide	Guide	Guide	Guard (Ported)	Guard (Floating)
Length (Useable)	390'	430'	310'	310'	600'	767'
- Lower Wall						
Type	Guide	Guide	Guard	Guard	Guide	Guide (Fixed)
Length (Useable)	600'	439'	426'	448'	450'	359'
NAVIGABLE WEIRS						
Type	None	None	1300'	2100'	1572'	1400'
Length	N/A	N/A	Fixed	Fixed	Fixed	Boat Operated Wickets
REMARKS						

NOTES: "Useable" Length of approach walls means that length of wall available to an approaching tow for landing.
"Depth over sill" means depth over highest feature in the approach, usually a bulkhead sill
"Aux Lock" refers to the landward 1200' lock at the McAlpine, Smithland and Olmsted projects.

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Section 3

OHIO RIVER HYDROLOGY AND HYDRAULICS

The Ohio River flows through three districts (Pittsburgh, Huntington and Louisville) of the Great Lakes and Ohio River Division. There exists in the three district offices much hydrology information that is useful to the Ohio River Mainstem Systems Study (ORMSS). The data are collected and retained in different formats depending on the capabilities of the satellite, number of DCP's, computer systems, etc. Also the length of record, time intervals of the data, and presentation will vary from district to district. New technology, such as the Internet, world wide web and home pages have made hydrology information readily available to other Corps of Engineers districts, federal and state agencies, architect-engineers, and the general public. The information, tables and plates presented in the following paragraphs highlight types of available data. Except for a table of the lake projects in the Ohio River Basin, only samples of available data will be presented in this part of the ORMSS report. The lakes in each district will show only the drainage area and the year its operation began because they are two of the main pieces of information needed to evaluate how a historical flood profile would be affected by existing conditions. If a full period of record data is required for a project, it will be in the volume titled, "(Study Project) Lock & Dam Site Engineering Appendix.

3.1 BASIN CHARACTERISTICS

The Ohio River is unique in that the stream mileage is measured from its headwater location in Pittsburgh, where the Allegheny and the Monongahela Rivers meet to form the Ohio River downstream approximately 981 miles until it empties into the Mississippi River near Cairo, IL. The total drainage area of the Ohio River Basin is 203,943 square miles.

The Pittsburgh District, known as the Headwaters District is comprised of the Ohio River drainage basin above New Martinsville, WV. The downstream limit of the Pittsburgh District is at river mile 127.2. The District covers an area of approximately 26,000 square miles (67,000 square km), including portions of Pennsylvania, West Virginia, Ohio, New York and Maryland. Major river systems within the District include the upper Ohio, the Allegheny, the Monongahela and the Beaver Rivers. The District manages 16 flood control and multipurpose reservoirs with a combined capacity of over 3 million acre-feet (3.8 billion cubic meters) and 23 navigation locks and dams on 330 miles (530 kilometers) of navigable waterways. Six of the locks and dams are on the Ohio River.

The Huntington District lies downstream on the Ohio River from the Pittsburgh District and the reach stretches from stream mile 127.2 to 438.0. The Louisville District has the longest reach of the Ohio River from mile 438.0 at the Huntington District line to its mouth (mile 981.0) at the Mississippi River.

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3.1.1 General Topography

The topography of the Ohio River Valley varies greatly from its origin in Pittsburgh, PA where the Allegheny and Monongahela Rivers meet to form the headwaters of the Ohio River to its mouth at the Mississippi River. The main stem of the Ohio River flows in a general southwesterly direction, falling 429 feet in its 981-mile course from Pittsburgh to Cairo. The flood plain is rather narrow, owing largely to the river's creation at the southern edge of Ice Age glacial action.

In the Pittsburgh District, the valley floor averages about 0.8 miles in width and the natural gradient of the streambed is about 1.0 feet per mile. Present stream banks generally average 20-25 feet in height except in the Emsworth pool where they average 10-15 feet high. Several islands are found in the Ohio River and the highly industrialized Neville Island is located in the Emsworth and Dashields pools.

The flood plain width averages more than a mile between Cincinnati and Louisville. At Louisville, the Ohio River floodplain widens to approximately four miles and then contracts to a mile below the Salt River. However, a floodwall around Jefferson County and the city of Louisville in Kentucky along with New Albany and Jeffersonville, Indiana floodwalls, limits the width to about a mile. Near the mouth, the Ohio River floodplain again widens to about six to eight miles. Elevations vary from 100 to 600 feet below the plateaus surrounding the valley. The only falls are at Louisville, where a 26-feet difference in water surface between the upper and lower pools existed prior to canalization. Numerous islands have been formed in the river over the centuries. Large bends or oxbows in the river give the stream a picturesque look. However in some areas like the Kentucky Peninsula across the stream from Evansville, Indiana, floodwaters have caused erosion problems and threaten to cut through the oxbow from the continuous flooding of the land.

3.1.2 Major Tributaries

Tributaries in the Ohio River Basin vary from very steep mountain streams with cascades and rapids to sluggish, meandering, marsh-like areas. Slopes of major tributaries vary from more than 100 feet per mile in the headwaters to less than two-tenths of a foot per mile in the flat areas near the main stem. In general, the streams are considerably steeper in the headwaters, becoming relatively flat near the mouth. Post-glacial changes in stream patterns, local layers of hard rock and distribution of tributaries may cause local modifications in profiles.

Table ED 3-1entitled "Ohio River & Tributaries Drainage Areas", has been developed which shows the river mile and total drainage area at major communities, former dam locations, and at the present locks and dams. Also provided are the river miles of major tributaries, which shows the contributing drainage area to the Ohio River at that point. As shown in Table 3.1.2-1, the Pittsburgh District has information on the lengths and average slopes of the main tributaries.

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Table ED 3-1. Ohio River & Tributaries Drainage Areas

RIVER MILE	SITE	BANK	DRAINAGE AREA (SQ. MI.)	LENGTH (MILES)	AVERAGE SLOPE (FEET/MILE)	OHIO RIVER DRAINAGE AREA (SQ. MI.)
	Allegheny River					**11,748**
	Monongahela River					**7,384**
	Head of the Ohio River					**19,132**
0.7	Saw Mill Run	Left	19.4	9.6	47.0	
2.6	Chartiers Creek	Left	277.0	52.0	11.0	
6.2	**Emsworth Locks & Dam**					**19,428**
6.2	Lowries Run	Right	17.0	8.3	55.0	
9.4	Montour Run	Left	36.6	11.5	43.0	
11.8	**Sewickley, PA**					**19,500**
13.3	**Dashields Locks & Dam**					**19,522**
15.4	Big Sewickley Creek	Right	30.2	10.5	40.0	
22.2	Crows Run	Right	13.8	7.4	55.0	
25.4	Beaver River	Right	3153.0	87.5	3.4	
29.6	Raccoon Creek	Left	184.0	45.0	12.0	
31.7	**Montgomery Locks & Dam**					**22,969**
39.5	Little Beaver Creek	Right	503.0	15.9	12.1	
40.1	Mill Creek	Left	15.5	6.3	73.0	
47.1	Little Yellow Creek	Right	22.7	10.4	43.6	
50.4	Yellow Creek	Right	239.0	32.1	10.1	
54.4	**New Cumberland Locks & Dam**					**23,870**
60.1	Kings Creek	Left	49.6	14.2	36.3	
61.7	Island Creek	Right	26.4	9.3	57.3	
66.7	Harmon Creek	Left	39.0	16.3	37.3	
71.6	Indian Cross Creek	Right	128.0	30.5	19.8	
71.6	Virginia Cross Creek	Left	79.9	23.2	26.0	
74.7	Buffalo Creek	Left	163.0	39.8	13.5	
81.4	Indian Short Creek	Right	148.0	24.4	23.4	
81.5	Virginia Short Creek	Left	24.4	10.1	56.4	
84.2	**Pike Island Locks & Dam**					**24,639**
90.2	Wheeling Creek, OH	Right	108.0	31.0	18.0	
85-93	**Wheeling, WV**					**24,800**
90.7	Wheeling Creek, WV	Right	298.0	29.35	7.9	
94.7	McMahon Creek	Right	91.0	27.9	20.4	
102.4	Grave Creek	Left	74.8	22.2	29.1	
109.6	Captina Creek	Right	180.0	25.9	10.2	
113.8	Fish Creek	Left	229.0	26.85	7.1	
118.0	Sunfish Creek	Right	114.0	31.4	16.3	
119.8	Opossum Creek	Right	25.4	13.0	47.3	
122.3	Proctor Creek	Left	22.0	8.9	53.7	
126.4	**Hannibal Pool Locks & Dam**					**25,960**
127.2	**Pittsburgh-Huntington District Line**					**25,966**

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Table ED 3-1. Ohio River & Tributaries Drainage Areas

RIVER MILE	SITE	BANK	DRAINAGE AREA (SQ. MI.)	LENGTH (MILES)	AVERAGE SLOPE (FEET/MILE)	OHIO RIVER DRAINAGE AREA (SQ. MI.)
155.0	**St. Marys, WV**					**26,850**
161.7	**Willow Island Locks and Dam**					**26,900**
172.2	Muskingum River	Right	8040			
184.4	**Parkersburg, WV**					**35.600**
184.6	Little Kanawha River	Left	2320			
199.3	Hocking River	Right	1190			
203.9	**Belleville Locks and Dam**					**39,302**
237.5	**Racine Locks and Dam**					**40,130**
265.3	**Pomeroy, OH**					**40,500**
265.7	Kanawha River	Left	12,200			
265.8	**Point Pleasant**					**52,760**
279.2	**R.C. Byrd (Gallipolis) Locks and Dam**					**53,300**
305.2	Guyandotte River	Left	1670			
311.6	**Huntington, WV**					**55,900**
317.1	Big Sandy River	Left	4294			
322.5	**Ashland, KY**					**60,750**
341.0	**Greenup Locks and Dam**					**62,000**
356.5	Scioto River	Right	6510			
408.6	**Maysville, KY**					**70,130**
436.2	**Meldahl Locks and Dam**					**70,808**
438.0	**Huntington-Louisville District Line**					**70,820**
464.1	Little Miami River	Right	1760			
470.2	Licking River	Left	3707			
470.5	**Cincinnati, OH**					**76,580**
491.1	Great Miami River	Right	5400			
531.5	**Markland Locks and Dam**					**83,170**
545.7	**above Kentucky River**					**83,320**
545.8	Kentucky River	Left	6966			
557.7						**90,580**
607.3	**McAlpine Locks and Dam**					**91,170**
627.1	**Kosmosdale**					**91,440**
629.9	Salt River	Left	2920			
633.2	**Dam 43**					**94,440**
663.2	**Dam 44**					**95,685**
703.0	**Dam 45**					**96,260**
720.7	**Cannelton Locks and Dam**					**97,000**
727.8	**Tell City**					**96,750**
757.3	**Dam 46**					**97,180**
755-757	**Owensboro, KY**					**97,200**

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Table ED 3-1. Ohio River & Tributaries Drainage Areas

RIVER MILE	SITE	BANK	DRAINAGE AREA (SQ. MI.)	LENGTH (MILES)	AVERAGE SLOPE (FEET/MILE)	OHIO RIVER DRAINAGE AREA (SQ. MI.)
776.1	**Newburgh Locks and Dam**					**97,690**
777.7	**Dam 47**					**97,690**
784.2	Green River	Left	9230			
792.4	**Evansville**					**107,000**
803.9	**Henderson, KY**					**107,600**
809.6	**Dam 48**					**107,600**
829.2	**Mt. Vernon, IN**					**107,700**
845.0	**Dam 49**					**107,965**
846.0	**J.T. Myers Locks and Dam (Uniontown)**					**108,000**
848.0	Wabash River	Right	33,100			
867.3	Saline River	Right	1170			
873.4	Tradewater River	Left	1000			
876.8	**Dam 50**					**143,400**
903.1	**Dam 51 (Golconda, IL)**					**143,900**
918.5	**Smithland Locks and Dam**					**144,000**
920.4	Cumberland River	Left	17,920			
934.5	Tennessee River	Left	40,910			
934.8	**Paducah**					**202,800**
938.9	**Dam 52**					**202,830**
943.6	**Metropolis, IL**					**203,000**
962.6	**Dam 53 (near Grand Chain, IL)**					**203,100**
964.4	**Olmsted Locks and Dam (Under Const.)**					**203,100**
974.2	**Mound City, IL**					
981.0	**Mouth of the Ohio River**					**203,943**

3.2 HYDROLOGY

3.2.1 Upstream Reservoir and Flood Protection Projects

The January 1937 basin-wide flood and the increase in industry tow traffic made a major impact on the water facilities in the three districts. Although a few flood control and multipurpose lakes were completed or were under construction in 1937, many more dams and lakes were built after this flood so that at present there are 72 lake projects. This does not include projects in the Nashville District, which affect the Ohio River below the Cumberland and Tennessee Rivers. These rivers enter in the lower reach of the Ohio River where two 1200' locks already exist at Smithland Locks & Dam and where construction is underway on two 1200' locks at Olmsted Lock & Dam (total project

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completion date is 2008). A list of reservoirs with their drainage areas and approximate date of completion are shown on Table ED 3-2.

There are no Corps of Engineers local flood protection projects consisting of floodwalls, levees or dikes along the main stem Ohio River in the Pittsburgh District. However, there are numerous local protection projects in the Huntington and Louisville Districts. These local protection projects will not be affected by expanded and added lock projects since pool levels would not be changed.

3.2.2 Stream Gauging Stations and Records

The records of flooding in the Pittsburgh area were obtained at Fort Duquesne at the junction of the Allegheny and Monongahela Rivers as early as 1765. Later, when navigation became a more dominant factor in colonial activity, gages were established on the Monongahela River wharf and records are found from this source.

The collection of systematic hydrologic records on the Ohio River dates back to the flood heights recorded at Pittsburgh in 1806. At first, only significant hydrologic events were recorded. These events usually consisted of floods of unusual magnitude, extent or duration. It was not until 1855, when the U.S. Army Signal Corps made regular daily observations, later replaced by the U.S. Weather Bureau in 1878, that continuous records became available. However, continuous record collection on the Ohio River began at Pittsburgh in 1847, Cincinnati in 1858, and Louisville in 1866. Each district maintains a database of hydrologic information for their respected reach. Continuous hydrologic records are kept at locks and dams on the Ohio River. In addition, many communities and flood control projects have gages that provide a continuous record. Records of stage are most readily available with stream flow records being less common.

Corps of Engineers (COE) Pittsburgh District staff gages are located on the upper and lower lock walls at Emsworth, Dashields, Montgomery, New Cumberland, Pike Island and Hannibal Locks and Dams. Auxiliary staff gages are installed above the lock walls to measure high water events. Staff gage measurements are taken by lock personnel and have been recorded since the time of construction in three-hour increments and hourly during high water events. Each dam has a critical river height at which these hourly readings are recorded and this procedure continues until the river recedes.

Digital automatic stage records are available for the Ohio River at Pittsburgh's "Point" gage, the upper and lower pools at Emsworth Locks and Dam, New Cumberland Locks and Dam, Pike Island Locks and Dam and Hannibal Locks and Dam. The measurement equipment includes chart recorders and remote transmitters. The digital readouts are located within the projects for the purpose of continuous monitoring.

Data Collection Platform (DCP) gages are located on the Ohio River at Emsworth Locks and Dam, East Liverpool, New Cumberland Locks and Dam, Pike Island Locks and Dam, Wheeling, Dilles Bottom, and Hannibal Locks and Dam. The stage readings are automatically recorded and transmitted to the Pittsburgh District's data storage system using satellite telemetry. They have been in operation since the early 1980's.

River stage readings have been recorded at the USGS gauging station, Ohio River at Sewickley, Pennsylvania since October 1933. Currently, an automatic continuous recording DCP gage with satellite telemetry is located on the upstream side of Dashields Locks and Dam. This station has a fixed-crest dam control, which merits it with a good stage-discharge relationship.

TABLE ED 3-2 LAKE PROJECTS IN THE OHIO RIVER BASIN

RIVER BASIN	LAKE PROJECT	DRAINAGE AREA	IN OPERATION DATE PLACED
	PITTSBURGH DISTRICT		
Allegheny River, Pennsylvania	Kinzua Dam and Allegheny Reservoir	2,180 sq. mi.	1967
	Tionesta Lake	478 sq. mi.	1940
	Union City Dam	222 sq. mi.	1971
	Woodcock Creek Lake	45.7 sq. mi.	1974
	East Branch Clarion River Lake	72.4 sq. mi.	1952
	Mahoning Creek Lake	340 sq. mi.	1941
	Crooked Creek Lake	277 sq. mi.	1940
	Conemaugh River Lake	1,351 sq. mi.	1952
	Loyalhanna Lake	290 sq. mi.	1942
Monongahela River, West Virginia	Stonewall Jackson Lake	102 sq. mi.	
	Tygart Lake	1,184 sq. mi.	1938
Monongahela River, Maryland	Youghiogheny River	434 sq. mi.	1948
Beaver River, Ohio	M. J. Kirwan Dam and Reservoir	80.5 sq. mi.	1967
	Berlin Lake	249 sq. mi.	1943
	Mosquito Creek Lake	97.4 sq. mi.	1944
Beaver River, Pennsylvania	Shenanro River Lake	589 sq. mi.	1967
	HUNTINGTON DISTRICT		
Muskingum River, Ohio	Atwood Lake	70 sq. mi.	1937
	Beach City Lake	300 sq. mi.	1937
	Bolivar Lake	502 sq. mi.	1938
	Charles Mill Lake	215 sq. mi.	1936
	Clendening Lake	69 sq. mi.	1937
	Dillon Lake	742 sq. mi.	1961
	Dover	1,397 sq. mi.	1938
	Leesville Lake	48 sq. mi.	1937
	Mohawk Lake	1,504 sq. mi.	1937
	Mohicanville Lake	271 sq. mi.	1937
	North Branch of Kokosing Lake	44.5 sq. mi.	1971

TABLE ED 3-2. LAKE PROJECTS IN THE OHIO RIVER BASIN (continued)

RIVER BASIN	LAKE PROJECT	DRAINAGE AREA	IN OPERATION DATE PLACED
Miami River, Ohio	Clarence J. Brown Dam and Reservoir	82 sq. mi.	January 1974
Whitewater River, Indiana	Brookville Lake	379 sq. mi.	January 1974
Kentucky River, Kentucky	Carr Creek Lake	58 sq. mi.	January 1976
	Buckhorn Lake	408 sq. mi.	December1961
Salt River, Kentucky	Taylorsville Lake	353 sq. mi.	January 1983
Green River, Kentucky	Green River Lake	682 sq. mi.	June 1969
	Nolin River Lake	703 sq. mi.	March 1963
	Barren River Lake	940 sq. mi.	October 1964
	Rough River Lake	454 sq. mi.	September 1959
Wabash River, Indiana	J. Edward Roush Lake	707 sq. mi.	October 1968
	Salamonie Lake	553 sq. mi.	September 1966
	Mississinewa Lake	809 sq. mi.	October 1967
	Cecil M. Harden Lake	216 sq. mi.	July 1960
	Cagles Mill Lake	295 sq. mi.	June 19553
	Monroe Lake	441 sq. mi.	February 1965
	Patoka Lake	168 sq. mi.	August 1980
	NASHVILLE DISTRICT		
Cumberland River, Kentucky	Martin's Fork Lake	55.7 sq. mi.	1978
	Laurel River Lake	282 sq. mi.	1977
	Lake Cumberland	5,789 sq. mi.	1950
Cumberland River, Tennessee	Dale Hollow Lake	935 sq. mi.	1943
	Cordell Hull Lake	8,096 sq. mi.	1973
	Center Hill Lake	2,174 sq. mi.	1948
	Old Hickory Lake	11,674 sq. mi.	1957
	J.Percy Priest Lake	892 sq. mi.	1967
	Cheatham Lake	14,160 sq. mi.	1959
Cumberland River, Kentucky	Lake Barkley	17,598 sq. mi.	1966

Table ED 3-3. Pittsburgh District Historical Minimum and Maximum Flow Rates at Various Gauging Stations (Flow in cfs)

Station	Drainage Area	Period of Record	Minimum Flow	Minimum Date	Maximum Flow	Maximum Date
Ohio River						
Sewickley, PA	19,522	1933-date	1800	9/57	574,000	3/36
New Cumberland L/D	23,873	1959-date	----	----	386,000	6/72
Wheeling, WV	24,666	1838-date	----	----	373,000	6/72

Over the years flow measurements have been made to develop rating curves at gage locations to show the relationship between stage and flow. The stage data that is obtained provides instantaneous information and together with highwater marks form the basis of the historical flood profiles.

The locations of various stream flow gages in the Huntington and Louisville Districts, together with other pertinent data, are contained in Table ED 3-4 and ED 3-5, respectively. Although not discussed in detail as for the Pittsburgh District above, the Huntington and Louisville Districts have staff gages, digital automatic stage recorders, DCP gages with satellite telemetry to provide instantaneous and continuous recording of data.

Data is available from the files of Table ED 3-5 in the Louisville District so that annual peaks and all peaks above a specified elevation can be provided both chronologically and in order of magnitude for the period of record. An example for the J. T. Myers upper gage is provided in Table ED 3-6.

Table ED 3-4. Huntington District Ohio River Stream Flow Gaging Stations

Station Locations	River Mile	Drainage Area (square miles)	Period of Record	Maximum Stage (ft)	Gage Datum (ft)
Saint Marys, WV	155.0	26,850	1913-1972	54.20	577.30 (1)
Marietta, OH	174.3	35,600	1968-Present	38.52	567.12 (1)
Pomeroy, OH	251.3	40,520	1913-1968	55.00	514.10 (1)
Point Pleasant, WV	265.2	52,760	1940-Present	55.00	514.00 (1)
Huntington, WV	308.3	55,900	1935-Present	61.60	490.26 (1)
Ashland, KY	322.5	60,750	1884-Present	73.60	483.10 (1)
Greenup L&D	341.0	62,000	1968-Present	50.96	472.97 (2)
Maysville, KY	408.6	70,130	1937-Present	75.30	451.50 (1)

(1.) Denotes Sandy Hook Datum.
(2.)Denotes 1929 Datum.

Table ED 3-5. Louisville District Ohio River Stations

CODE	STATION	RIVER-MILE**	ORD DATUM	PERIOD
001	EVANSVILLE	792.3	329.2	1930-1999
100	MT VERNON	829.2	318.9	1930-1991
300	TELL CITY (COMPOSITE)	727.7	347.6	1930-1991
390	MARKLAND (CLG)	531.9	408.0	1930-1999
391	MARKLAND (UPR)	531.2	443.0	1963-1999
392	MARKLAND (LWR)	531.9	408.0	1963-1999
393	LOCK 39 (LWG)	531.7	411.0	1930-1936
401	J.T.MYERS (UPR)	845.8	330.0	1970-1999
402	J.T.MYERS (LWR)	846.2	312.0	1970-1999
410	MCALPINE (CLG)	606.8	374.0	1976-1982
411	MCALPINE (UPR)	607.3	408.0**	1875-1999
412	MCALPINE (LWR)	606.8	374.0	1875-1999
415	MCALPINE (WWG)	606.8		1961-1970
420	KOSMOSDALE	627.1	374.0	1972-1999
510	GOLCONDA + LD51 (CLG)	903.2	293.0	1930-1980
511	GOLCONDA + LD51 (UPR)	902.9	294.6	1930-1989
515	PADUCAH	934.6	286.3	1965-1999
520	BROOKPORT LK52 (CLG)	938.7	281.0	1930-1995
521	BROOKPORT LK52 (UPR)	939.1	283.3	1930-1999
522	BROOKPORT LK52 (LWR)	938.7	281.0	1930-1999
530	LOCK 53 (CLG)	962.4	273.1	1930-1995
531	LOCK 53 (UPR)	962.8	273.1	1930-1999
532	LOCK 53 (LWR)	962.4	273.1	1930-1999
534	GRAND CHAIN RECORDING	962.1	276.6	1930-1969
555	SMITHLAND(UPR)	918.8	312.0	1981-1999
556	SMITHLAND(LWR)	918.3	290.0	1981-1999
601	CANNELTON(UPR)	720.5	374.0	1971-1999
602	CANNELTON(LWR)	720.9	348.0	1968-1999
701	NEWBURGH(UPR)	775.9	348.0	1971-1999
702	NEWBURGH(LWR)	776.3	330.0	1971-1999
800	CAIRO	979.5	270.9	1930-1999
802	MELDAHL(LWR)	436.7	443.0	1965-1999
900	CINCINNATI	470.5	429.6	1930-1999
901	CINCINNATI(ADJ)	470.5	429.6	1950-1990

* RIVER MILEAGE ADJUSTED FROM HIGHWATER PROFILES
** STAGE VALUES BEFORE JAN 1965 HAVE BEEN ADJUSTED FOR NEW DATUM

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Table ED 3-5

OHIO RIVER AT J.T.MYERS(UPR)
RIVER ELEVATION FREQUENCY TABLE
(FOR PERIOD SEP 1975 - OCT 1998)

ANNUAL PEAKS (BY WATER YEAR)

YEAR	PEAK	DATE
1976	355.30	27 FEB 1976
1977	351.60	13 APR 1977
1978	358.70	23 MAR 1978
1979	362.50	08 MAR 1979
1980	352.50	29 MAR 1980
1981	350.80	14 JUN 1981
1982	355.40	26 MAR 1982
1983	360.90	10 MAY 1983
1984	354.20	15 MAY 1984
1985	354.70	05 MAR 1985
1986	356.00	07 DEC 1985
1987	349.70	18 APR 1987
1988	350.90	10 FEB 1988
1989	357.40	24 FEB 1989
1990	356.90	20 FEB 1990
1991	364.00	09 JAN 1991
1992	346.80	09 DEC 1991
1993	353.60	13 MAR 1993
1994	357.20	23 APR 1994
1995	358.80	26 MAY 1995
1996	360.00	15 MAY 1996
1997	366.00	11 MAR 1997
1998	353.90	27 APR 1998

PEAKS IN PERIOD (BY ORDER OF OCCURANCE)

PEAK	DATE
351.10	9 JAN 1976
355.30	27 FEB 1976
351.60	13 APR 1977
351.00	3 FEB 1978
358.70	23 MAR 1978
359.00	18 DEC 1978
352.40	9 JAN 1979
352.50	29 JAN 1979
362.50	8 MAR 1979
354.20	18 APR 1979
352.50	29 MAR 1980
350.80	14 JUN 1981
351.20	29 JAN 1982
351.00	9 FEB 1982
355.40	26 MAR 1982
360.90	11 MAY 1983
353.40	23 MAY 1983
353.50	5 APR 1984
354.10	30 APR 1984
354.20	15 MAY 1984
354.70	5 MAR 1985
351.90	7 APR 1985
356.00	7 DEC 1985
353.00	14 FEB 1986
350.90	10 FEB 1988
357.40	24 FEB 1989
352.20	14 MAR 1989
355.50	9 APR 1989
356.90	21 FEB 1990
351.90	23 MAY 1990
351.00	3 JUN 1990
364.00	9 JAN 1991
354.30	31 MAR 1991
353.60	13 MAR 1993
352.40	4 APR 1993
356.70	6 FEB 1994
352.20	3 MAR 1994
354.10	18 MAR 1994
357.20	23 APR 1994
358.80	26 MAY 1995
357.20	31 JAN 1996
360.00	16 MAY 1996
366.00	13 MAR 1997
353.90	27 APR 1998
352.10	12 MAY 1998

PEAKS IN PERIOD (BY ORDER OF MAGNITUDE)

PEAK	DATE
366.00	13 MAR 1997
364.00	09 JAN 1991
362.50	08 MAR 1979
360.90	11 MAY 1983
360.00	16 MAY 1996
359.00	18 DEC 1978
358.80	26 MAY 1995
358.70	23 MAR 1978
357.40	24 FEB 1989
357.20	23 APR 1994
357.20	31 JAN 1996
356.90	21 FEB 1990
356.70	06 FEB 1994
356.00	07 DEC 1985
355.50	09 APR 1989
355.40	26 MAR 1982
355.30	27 FEB 1976
354.70	05 MAR 1985
354.30	31 MAR 1991
354.20	18 APR 1979
354.20	15 MAY 1984
354.10	30 APR 1984
354.10	18 MAR 1994
353.90	27 APR 1998
353.60	13 MAR 1993
353.50	05 APR 1984
353.40	23 MAY 1983
353.00	14 FEB 1986
352.50	29 JAN 1979
352.50	29 MAR 1980
352.40	09 JAN 1979
352.40	04 APR 1993
352.20	14 MAR 1989
352.20	03 MAR 1994
352.10	12 MAY 1998
351.90	07 APR 1985
351.90	23 MAY 1990
351.60	13 APR 1977
351.20	29 JAN 1982
351.10	09 JAN 1976
351.00	03 FEB 1978
351.00	09 FEB 1982
351.00	03 JUN 1990
350.90	10 FEB 1988
350.80	14 JUN 1981

3.2.3 Historical and Recorded Floods

Storm patterns and the length of the Ohio River can produce record floods occurring in one district with little or no flooding in the other districts. The exception is the January 1937 flood, which was the modern day major flood in the basin.

In the Pittsburgh District, the highest known floods prior to the construction of flood control projects occurred March 15, 1907 with a peak of 732.7 feet above National Geodetic Vertical Datum (NGVD), January 9, 1763 with a peak of 735.1 (NGVD) and March 18, 1936 with a peak of 740.2 feet above NGVD at the Pittsburgh "Point". Since the 1936 flood, twelve flood control reservoirs have been built in the Allegheny and Monongahela River basins which provide flood protection on the Ohio River from Pittsburgh on downstream. In addition, four reservoirs in the Beaver River basin (built 1943-1967) effect reductions in flood stages in the Montgomery pool and downstream.

The March 1936 (St. Patrick's Day) Flood occurred prior to the construction of any Corps of Engineers' flood control dams. The base flow for the Ohio River on March 9 was 50,100 cfs. Water content of the snow in the district was 2" to more than 4" in the mountains. Melting snow and about 0.65 inches of precipitation caused a rise on the 12th-13th at which time the "Point" gage reached 25.8 feet and was above flood stage for 21 hours. Essentially all snow was melted at this time. Although the flow receded to 99,300 cfs on the 16th, anywhere from 2.5" to 5" of rain fell on the 16th and 17th, with the heaviest in the Lower Allegheny basin. This sent the Ohio River at Pittsburgh to a crest of 46 feet (740.2 feet above NGVD and 557,000 cfs), the river remained above flood stage for 84 hours. It would have been reduced by 10.7 feet with the present reservoir system. A third rise occurred on the 25th-26th during which the river was above flood stage for 32 hours, cresting at 30.6 feet. Total runoff for the month of March 1936 was 8.74 inches at Pittsburgh.

The June 23, 1972 Flood, a result of Tropical Storm Agnes, produced the highest stage at the Pittsburgh "Point" using the current reservoir system. The Ohio River flow on June 20th was 23,700 cfs at the "Point". From the 20th through the 26th, the Allegheny Basin received from 4" to 12" of rainfall and the Monongahela Basin from less than 3" to over 12". The Ohio River crested at Pittsburgh at 35.85 feet (730.0 feet above NGVD and 380,000 cfs), remaining above flood stage for 86 hours. It would have been 12.1 feet higher without the current reservoir system. The runoff during the flood at Pittsburgh was 4.65 inches for the period June 21-July 15, 1972.

Table ED 3-6 presents peak water surface elevations for historic high water events, including the March 1936 and June 1972 floods at the Pittsburgh "Point" and Wheeling, WV.

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Table ED 3-6. Historical Peak Elevation Events on the Ohio River in the Pittsburgh District

	Pittsburgh (Point), Pennsylvania	Wheeling, West Virginia
	Elevations in feet above NGVD	
March 18, 1936	740.2	666.0
December 31, 1942	730.8	662.3
June 24, 1972	730.0	657.4
April 27, 1937	729.3	656.7
January 20, 1996	728.8	654.2

Historical profiles and the way they are presented may vary from district to district. Various other information such as communities, major roads, major tributaries, etc are also shown. The historical flood profile elevations would be reduced, but to a varying degree by the new reservoirs constructed after the occurrence of the flood. All three districts have plots of historical and frequency profiles in their office files.

In the Louisville District, the April 1976 discharges for the Ohio River were the basis of the frequency profiles that were developed for the Ohio River. The factors used to develop the HEC-2 model were verified by the reproduction of historical flood profiles utilizing the April 1976 ORD stage and discharge frequency curves.

3.2.4 Natural and Existing Flood Flows

Stage data that is obtained at the recording locations do not provide a homogeneous set of data. The operation of the flood control dams upstream results in a set of data that is existing at that particular time. To obtain a natural condition, water stored for a selected time interval in each reservoir must be routed downstream and added to the appropriate gage. This would have the effect of raising the gage heights and making flood profiles higher. To obtain the present condition at a particular gage, the opposite process is required. All reservoirs that were not built or operated differently must have flows adjusted at the dam by its normal operation. The water that would have been stored for a selected time period is routed downstream and subtracted from the appropriate gage. This has the effect of lowering stages and lowering the flood profile.

Flood flows are difficult to determine for a stream the length of the Ohio River. If another reservoir project is built or an operation is changed, the modified condition will change (probably minimally). The Lakes and River Division, known as the Ohio River Division at the time of the study, using the methodology described above for all of the reservoirs in the Ohio River Basin developed discharge frequency flow curves for a number of locations. The data was labeled “19__ modified conditions. However, the division used only the annual peak at each gage in developing frequency flow data. This has little effect on floods occurring less than once in ten years. However, these curves did not include partial, multiple yearly peaks in the statistical analysis.

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3.2.5 Ordinary High Water

Ordinary High Water (OHW) is a line on the bank of a river or other body of water that marks the boundary of those lands subject to navigational servitude. The public has the right to navigate freely over lands subject to navigational servitude. Also, physical facilities intended to support navigation may be placed and maintained on such lands.

The line of ordinary high water, as applied to rivers, that separates what properly belongs to the riverbed from that which belongs to the owner of adjacent land is determined by normal conditions, not by reference to unusual floods. Ordinary high water is the point on the bank where the waters are so continuous as to leave a distinct mark either by erosion, destruction or terrestrial vegetation, or other easily recognized characteristics. The most common method of identifying OHW marks is to find that elevation on the bank below which terrestrial (dry land) vegetation does not exist. Other indicators are: (1) absence of commercial agriculture, (2) drift or debris lines, (3) changes in soil characteristics, (4) benching and shelving of the bank, (5) absence of all vegetation, and (6) absence of commercial human activity.

The ordinary highwater elevation not only has an effect on the adjacent environment but also is critical on the Ohio River with relation to water supply inlets, storm and sanitary sewer outlets, permanent and floating docks, and adjacent industrial, residential and recreational facilities. The extension of present locks or the addition of a third lock would not have an effect on the ordinary highwater profile. Therefore this is of little concern in the Huntington and Louisville Districts in this study. Ordinary highwater profiles for the Ohio River are available in both districts.

There is a possibility that a study of replacing the upper three locks and dams near Pittsburgh with two locks and dams would need evaluation. This would change the ordinary highwater profile in these reaches. The Pittsburgh District is currently reevaluating Ordinary High Water for their District's six navigational pools. The 0.7 year frequency profile is estimated to be the District's Ordinary High Water for the Ohio River. Ongoing field investigations will better define the District's current Ordinary High Water line. This updated profile together with the standard project flood, the 100-year flood, the streambed, and the normal pool level resulting from the Ohio River dams, are available from the Pittsburgh district.

3.2.6 Low Flow Conditions

Low flow conditions will normally be an asset during lock expansion construction. The months when low flows can be expected are available through the gage's history or from continuous gage records. As an example, in the Pittsburgh District, the most sustained and severe period of low flow in the Ohio River occurred during the summer and autumn of 1930. The actual average flow at Pittsburgh in October 1930 dropped to 1,206 cfs. It is estimated that the October flow would have been even lower, about 900 cfs, if Lake Lynn on the Cheat River had not released water reserved for power generation. Low flow augmentation by existing reservoirs would have greatly improved these conditions. Table ED 3-7 shows the mean monthly actual, natural and augmented 1930 drought flows on the Ohio River at Pittsburgh, Pennsylvania. Also included in the table are the mean monthly flows from the more

recent droughts of 1988 and 1991 obtained from the U.S. Geological Survey Water Resources Data publication for the Ohio River at Sewickley, Pennsylvania.

Table ED 3-7. Monthly Mean Flows of the Ohio River at Pittsburgh, Pennsylvania
(Flow in cfs)

	Jul	Aug	Sep	Oct	Nov	Dec
1930 Drought						
Actual	3,979	1,284	1,273	1,206	1,563	6,643
Natural *	3,951	1,241	1,000	903	1,394	6,737
Augmented - Existing	5,708	4,205	4,186	4,156	3,740	6,712
1988 Drought	6,308	5,076	9,241	18,470	19,830	51,490
1991 Drought	6,263	4,953	5,132	49,600	31,670	74,740

***** Without Lake Lynn Drawdown

The seven days, ten year frequency flow (Q7-10) is defined as a mean low flow for seven consecutive days that will recur, on the average, once in ten years. The Q7-10 flows were developed for the Ohio River based on 31 years of record for the period 1949 to 1979. Table ED 3-8 shows the Ohio River at selected points in the Pittsburgh District of the Q7-10 flows which were based on regulated conditions by the upstream reservoirs.

Table ED 3-8. Seven Day – Ten Year Flow (Q7 – 10)

Ohio River Location	Flow in cfs
Dashields Locks and Dam	4,800
Montgomery Locks and Dam	5,700
New Cumberland Locks and Dam	5,750
Pike Island Locks and Dam	5,830
Hannibal Locks and Dam	5,850

3.3 LOCK HYDRAULICS (TYPICAL FOR OHIO RIVER)

3.3.1 Approach Conditions

Before a vessel can successfully enter the lock chamber, it must first approach the lock over open water. The approach conditions are typically evaluated with physical hydraulic models to be sure that adverse currents do not occur. In some cases, it may be necessary to construct underwater dikes to modify the currents to provide for safe

approach conditions. Approach conditions can also be made difficult by wind conditions, particularly for tows with empty barges as they sit higher in the water. Final approach to the lock chamber is aided by the presence of lock approach walls both upstream and downstream of the locks. Vessels arriving at the lock will use the approach wall to align themselves properly for entry into the lock. In terms of safety and processing time, the approach characteristics of a lock are one of the most important features of the navigation projects on the Ohio River.

Approach Walls

Vessels entering or exiting a lock at low speed lack maneuverability and steerageway and are susceptible to adverse currents. Approach walls are used to safely guide vessels and tows into or out of the lock chamber. They also provide a mooring location for long tows that require multiple lockages. An additional benefit provided by some of the walls is protection from hazardous areas and adverse currents.

Typical Arrangement

For navigation projects on the Ohio River, the two typical types of approach walls are the guide and guard walls. The distinguishing feature between the two types is their position with respect to the dam. Guard walls are located between the locks and the discharging portion of the dam. The wall situated on the landward side of the lock approach is defined as the guide wall. Approach walls are further subdivided based on their location either upstream (upper) of downstream (lower) of the dam axis. Of the twenty active locks and dam on the Ohio River, thirteen have approach wall configurations as provided in Figure ED 3-1.

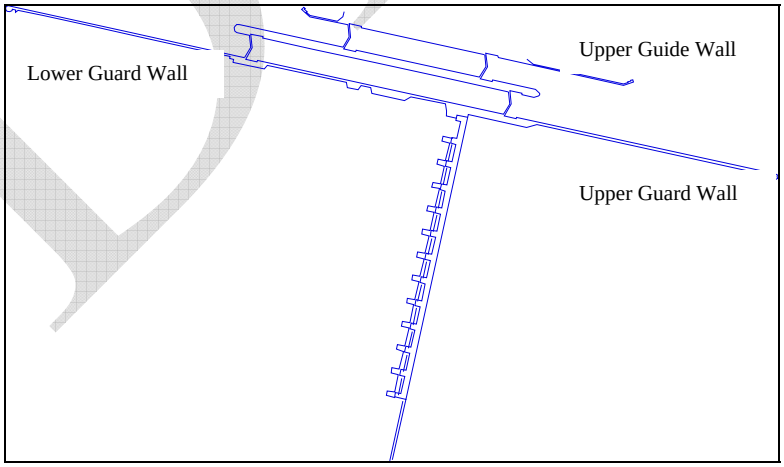

Figure ED 3-1. Typical Approach Wall Configurations

Upper Guard Wall

Downbound tows aligning for entry into the lock chamber utilize this wall. The ports typically found in this wall allow currents in the upstream approach to pass under the wall and flow towards the dam. These currents tend to hold tows against the wall, thus facilitating safe entry into the lock. Without the ports, lateral currents across the upper approach would tend to push tows towards the bullnose. The wall is configured so that the largest tows can safely align themselves for entry into the lock chamber.

Upper Guide Wall

This wall is typically used as an alignment wall for the auxiliary lock chamber. Because most of the auxiliary locks are only 600 feet long, the length of these walls is typically less than the upper guard wall. In general, vessels and tows using this wall are not adversely affected by river currents. Tows that are longer than the wall, however, may have difficulty with alignment due to the currents in the upper approach.

Lower Guard Wall

Upbound tows align for entry into the main lock chamber using this wall. It also protects against adverse currents caused by discharges from the dam. Since currents introduced through this wall would tend to push tows away from the wall, they are not ported. Downstream of the lock approach, the wall induces a slackwater "shadow" that facilitates a safer entry into the lock.

Lower Guide Wall

The typical lock configuration on the Ohio River provides a relatively short landward wall downstream of the auxiliary lock. This wall can be used to align for entry into the auxiliary lock. The middle wall serves as a landing area for upbound vessels.

Unique Approach Conditions

Several of the locks and dams on the Ohio River have approach conditions that warrant a separate discussion.

Smithland and Olmsted

A safe approach wall configuration for twin 1200 feet by 110 feet locks was developed using the physical hydraulic model tests of Smithland. The system consists of a relatively long ported guard wall and a ported middle wall. The middle wall serves as a landing surface and an alignment mechanism for downbound tows. The lower approach walls consist of a non-ported guard wall and a relatively short guide wall. This configuration allows for safe and efficient use of both lock chambers. The approach walls at Olmsted will have the same arrangement.

Emsworth, Dashields, and Montgomery

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Since the main lock at each of these projects is only 600 feet long, a standard size Ohio River tow requires multiple lockages. With auxiliary locks measuring 360 feet by 56 feet, significant delays are experienced when the main lock is closed for maintenance purposes.

McAlpine

There are several unique conditions associated with the McAlpine approaches that are not experienced elsewhere in the navigation system. The approach to the canal is very close the downtown Louisville, KY area and leave little room for error. A relatively new vane dike has improved these entry conditions. In addition to the entry conditions, the presence of a railroad bridge with minimal vertical and horizontal clearances make this approach one of the most challenging in the system. In the lower approach, the guard wall is ported to alleviate adverse currents around the bullnose. Occasionally this presents a problem to upbound tows that may be pushed away from the wall. The most serious concern in the lower approach is related to the proposed discharge facilities for the new 1200 foot lock. The lock will discharge directly into the lower approach. As a result, traffic in the lower approach will be severely restricted during periods of discharge.

The action of filling the locks with water from the canal tends to induce long period surges. The period of the surges is typically thirty minutes with a magnitude of one foot. The surges and currents that they generate are such that they can interfere with the operation of the main lock. Filling operations must be performed with great caution to minimize the impact of these surges.

R.C. Byrd

The project consists of a 1200 foot main lock and a 600 foot auxiliary lock. Similar to McAlpine, the approach to the locks is via a canal. Since the lock intakes are located in an embayment off of the river, the surges experienced at McAlpine are not a problem here. The unique footprint of the locks means that site specific plans must be developed for any capacity enhancement project.

Approach Time

The interval between the time a tow passes the lock arrival point and the time the two is prepared to enter the lock chamber is defined as the approach time. Traffic between the arrival point and the lock chamber is typically limited to one tow. This provides pilots with the maximum flexibility to maneuver and ensures safe utilization of the lock. The approach time can vary depending on the conditions at the lock with the average falling between thirty and forty minutes.

3.3.2 Culvert Valves

Each culvert in a filling and emptying system has two valves. The filling valve is located between the upper pool and the lock chamber and the emptying valve is located between the lock chamber and the lower pool. The valves are always the same size and

are only operated together during flushing operations. The two filling (or emptying) valves must be synchronized in F/E systems that utilize two culverts. All of the locks constructed since the opening of New Cumberland in 1959 use reverse tainter valves. Some of the locks on the upper reach of the river use butterfly valves. The stoney valve has been used on tributary streams.

Reverse Tainter Valves

The most common valve type in use at Ohio River Navigation Projects is the reverse tainter valve. The valve is a circular arc that is supported by two strut arms that are attached to anchorages via hinges. The valve requires a significant amount of space and is usually placed in an open pit within the lock wall. This pit serves as a surge tank during filling and emptying operations. The valves can be operated by cables connected to horizontal hydraulic cylinders, but the most common mechanism consists of a strut arm connected to a hydraulic cylinder through a bell crank assembly. The typical configuration is shown in Figure ED 3-2. For clarity sake, the bulkhead slots are not shown in the figure, they are located just upstream and downstream of the culvert valve pit as indicated by the arrows in the figure. The geometry of the operating mechanism results in a nonlinear relationship between hydraulic cylinder movement and valve opening. This characteristic proves to be beneficial during the early stages of filling or emptying when the discharge rate is changing rapidly.

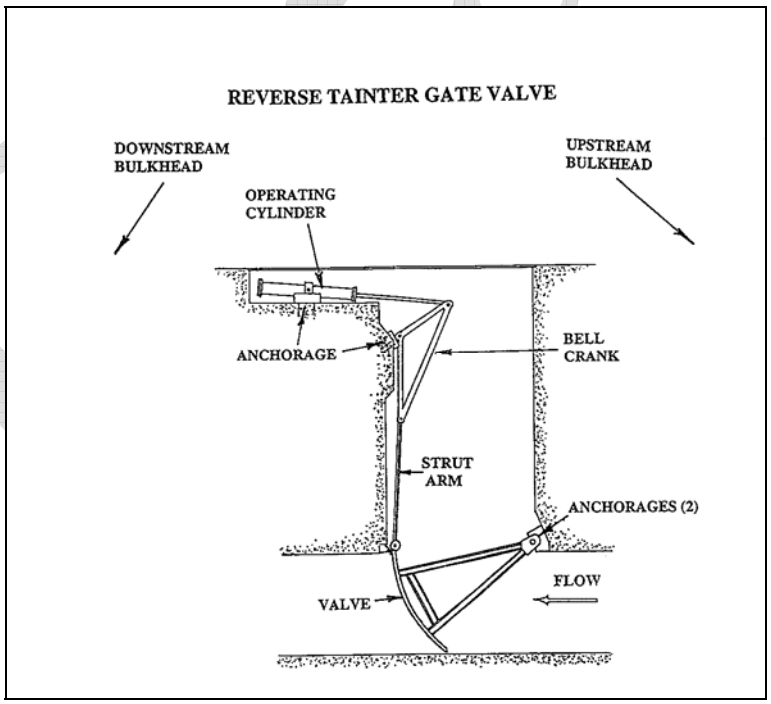

Figure ED 3-2. Typical F/E Valve for Ohio River Locks

Butterfly Valves

When combined with a central culvert filling and emptying system, the butterfly valve provides a cost effective means of flow control. The major disadvantage of this valve is associated with anticipated maintenance difficulties. A diagram of this type of valve is provided in Figure ED 3-3.

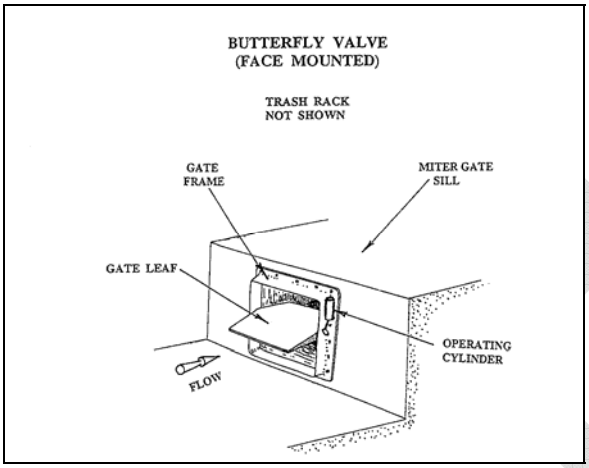

Figure ED 3-3. Butterfly Valve

Stoney Gate Valves

These vertical lift gates can be operated by hydraulic cylinders or hoists. Rollers on either side of the valve run in vertical raceways to reduce frictional forces. Ease of maintenance is achieved by locating the operating mechanism on the top of the lock wall. Another significant advantage is the smaller footprint that is required for the valve. The valve requires less space and the monolith required to support this type of valve is smaller. The operating scheme usually results in a linear valve opening. Careful consideration must be given to any design that incorporates this type of valve with a reverse tainter valve. A typical stoney valve is shown in Figure ED 3-4.

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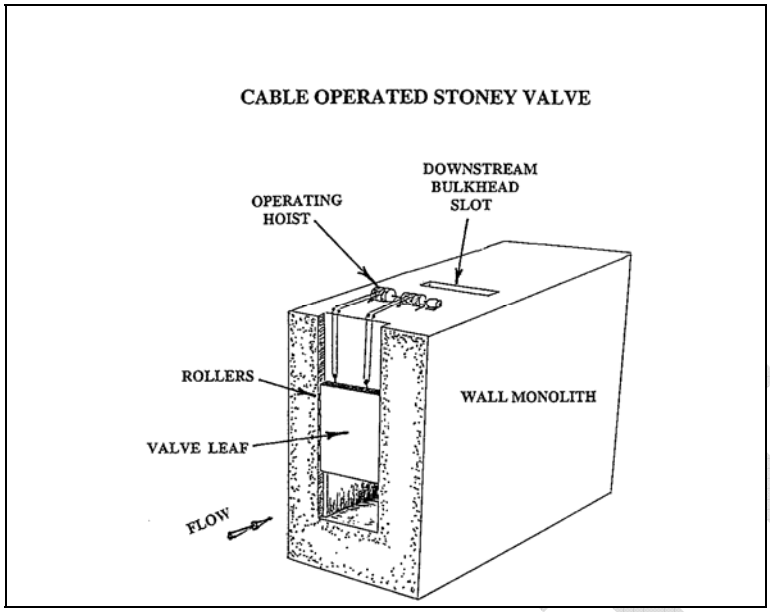

Figure ED 3-4. Stoney Gate Valve

3.3.3 Discharge Systems

Velocities near lock discharges are relatively high and the water surface tends to be violent. The outfalls are usually located riverward of the lock chamber so that the turbulent discharges do not interfere with navigation. The lower guard wall protects vessels and tows from the adverse currents and high velocities that are generated during lock discharges. Some of the locks in the inland waterways system have F/E systems that discharge into the lower approach area immediately downstream of the lock. This type of design places restrictions on tow movements in the lower approach, especially when the lock is discharging.

3.3.4 Hawser Force

When filling or emptying a lock chamber, small oscillations develop in the water surface within the lock chamber. The oscillations will tend to induce motion in a tow within the lock chamber. As a result, the tow must be moored with hawser lines to prevent it from striking the miter gates. These lines must be able to resist the forces generated by the moving tow. The resisting forces generated in the line are defined as hawser forces. These forces are usually evaluated with physical hydraulic models. Experience has indicated that limiting the hawser forces in a model to less than five tons will provide satisfactory prototype performance. Recent advances in numerical modeling techniques have provided additional methods for evaluating hawser forces. The numerical techniques provide satisfactory results for screening of alternatives, but final design should be based on the results of physical hydraulic model tests.

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In traditional F/E systems, the filling cycle will generate greater hawser forces than the emptying cycle. In addition, the most significant factor influencing the oscillations in the lock chamber is the rate of change of discharge (dq/dt). These factors produce the greatest hawser forces during the early part of the filling cycle while the valve is opening.

3.3.5 Chamber Empty / Fill Time

The system of intakes, culverts, valves, ports, and manifolds that is used to raise or lower the water level in the lock chamber is known as the lock filling and emptying (F/E) system. The design of these systems must optimize the solution of two mutually exclusive objectives. The lock must be filled or emptied as rapidly as possible without creating adverse oscillations in the lock chamber.

Typical F/E Systems

The three typical F/E systems used on the Ohio River are: side port, split lateral, and bottom lateral. These designs have been developed to accommodate various combinations of lock size and lift.

Side Port System

This system is commonly found in locks with lifts less than twenty five feet. The configuration features a large culvert in each of the lock walls. Intake manifolds are located in the face of the approach walls at a point upstream of the miter gates. Large valves located near the miter gate pintle control flow from the upper pool into the culverts. The culverts are connected to the lock chamber through a series of ports in along the face of the lock chamber wall. The valves that control emptying of the lock chamber are` located downstream of the ports. The discharge section of the culvert leads from these emptying valves to the lower pool.

Split Lateral System

Projects with lifts in excess of thirty feet feature this type of F/E system. This configuration is similar to the side port system in that a large culvert is located in each lock wall. The filling valves are also typically located near the miter gate pintle. Instead of ports, each culvert is connected to the lock chamber through a series of lateral culverts. One culvert supplies the lateral field in the upper portion of the chamber and the other culvert supplies the lateral field in the lower portion. These lateral culverts extend from the main culvert across the lock chamber floor to the opposite lock wall. Each of the lateral culverts has a series of ports that allow flow to enter or exit the lock chamber. The valves that control emptying of the lock chamber are located downstream of the lateral culverts. The discharge section leads form the valve to the lower pool.

Bottom Lateral System

The 600-foot auxiliary locks on the Ohio River utilize this system. It is similar to the split lateral system except that there is only one culvert instead of two. Consequently, there is only one lateral field extending across the middle portion of the lock chamber. Since the culvert is the same size as the culverts for the main chamber, the valves and bulkheads are interchangeable. The discharge portion of the auxiliary lock passes underneath the main lock chamber so that it can discharge in the lower pool area away from the approach.

Central Culvert F/E System

Traditional F/E systems incorporate large culverts within the lock walls. New lock designs that incorporate roller compacted concrete and other construction materials and techniques cannot accommodate the culverts within the lock walls. As a result, the traditional F/E systems must be adapted to these new designs. The central culvert F/E system has twin culverts situated on the floor of the lock chamber away from the walls, but the culverts themselves are located in the lock walls for maintenance access.

3.4 DAM OPERATION

3.4.1 Stair Step

The locks and dams on the Ohio River were designed and operated on the "stair step" principle. The target elevation of the upstream pool is such that a minimum navigation depth of nine feet is provided at all times. The height of the dam gates has been set to meet this requirement. The lower miter gate sills of the locks are set to match the target elevation of the next downstream dam. During periods of low flow, the navigation pools are almost flat. This conditions results in the "stair step" profile as shown in Figure ED 4-1.

The dam gates of a project are operated such that the target elevation of the upper pool is maintained at the upstream face of the dam. This insures a minimum navigation depth of nine feet upstream of the project. During periods of moderate to high flow, the water surface upstream of each dam will develop a sloping profile starting at the upstream face of the dam and extending upstream to the next dam. As a result, a typical lock and dam on the Ohio River will have a relatively steady upper pool elevation and a fluctuating tailwater elevation.

If flows in the river increase substantially during a flood, the dam gates can be raised as needed until they are in the fully opened position. Under these conditions, the gates are clear of the water and the upper pool elevation can no longer be controlled. The natural flow of the river then becomes the controlling factor. If the level of the water continues to rise, it is due to the flow in the river and not the existence or operation of the project. A slight increase in pool elevation upstream of the dam may be observed due to

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the project. This increase is similar to that which would be caused by bridge piers and does not have a significant impact on the water surface or flows in the river.

3.4.2 Hinged Pool Operation

A hinged pool operation differs from a stair step operation in that the target pool elevation is maintained at a location upstream of the dam. As the flow increases, the water surface at the upstream end of the pool rises and the water surface near the upstream face of the dam lowers. At the present time, the only hinge pool now in operation on the Ohio River navigation system is at Emsworth L/D. A two foot reduction of the upper pool elevation is used to reduce the duration of high water conditions at Pittsburgh's Golden Triangle. The Olmsted Dam, now under construction, will be operated in accordance with a complex hinged pool plan with four target locations upstream of the project. The most significant target point is located fifty two miles upstream of the dam site.

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Section 4

EXISTING OHIO RIVER NAVIGATION PROJECT CONDITION AND CONFIGURATION

4.1 GENERAL BACKGROUND INFORMATION

There are currently a total of 20 active lock and dam projects on the 981-mile reach of the mainstem Ohio River. Six of these projects in the upper reach are under the jurisdiction of the Pittsburgh District, six projects in the middle Ohio River are within the boundaries of the Huntington District, and the remaining eight on the lower end are controlled by the Louisville District. The vast majority of the projects have high lift, gated dams, although the type of dam gate varies by project. The only exceptions to this are Lock and Dams 52 and 53 on the extreme lower Ohio River and Dashields in the upper Ohio River. Dashields is a fixed crest concrete dam. The dams at 52/53 are controlled by boat-operated wickets. Lock and Dams 52/53 will be replaced once Olmsted Locks and Dam, currently under construction, is completed around 2014. For the purposes of ORMSS, it is assumed Olmsted will be active in 2014 and 52/53 are deactivated. Therefore, the Louisville District will have seven projects under their jurisdiction when that occurs. A plan and profile view of the projects on the Ohio River is depicted in Figure ED 4-1.

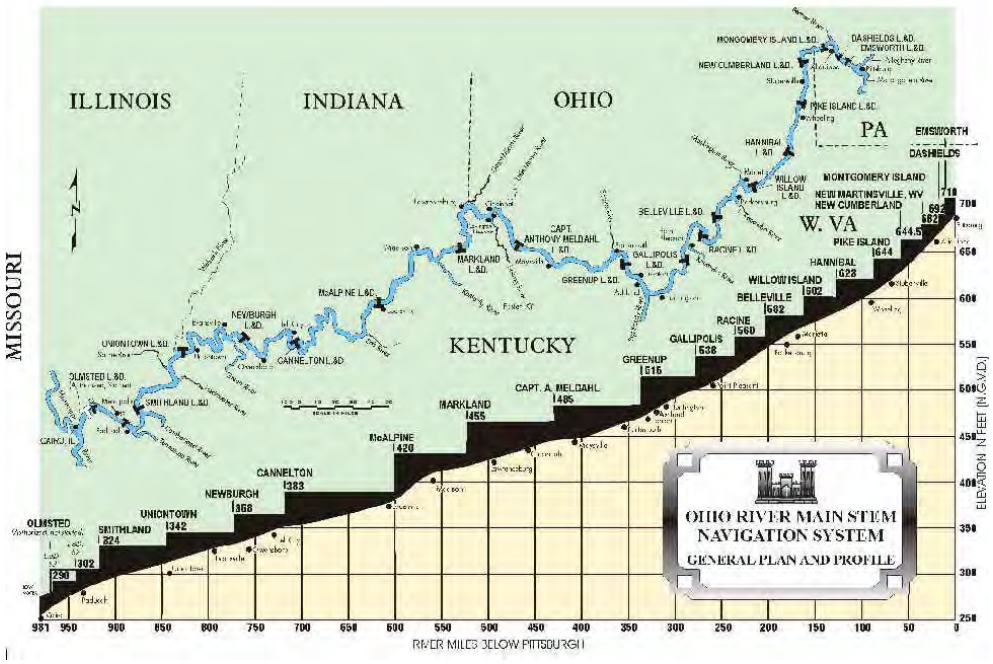


Figure ED 4-1. Plan and Profile View of the Ohio River Navigation Projects

The majority of the projects are configured with side-by-side 110’ x 1200’ main and 110’ x 600’ auxiliary lock chambers. There are a few exceptions to this typical configuration. These include the upper three projects (Emsworth, Dashields, and Montgomery) which have a 110’ x 600’ main chamber and 56’ x 360’ auxiliary chamber. There are a few projects on the lower Ohio River where traffic levels warrant more lock capacity. For example, the Smithland project has twin 110’ x 1200’ lock chambers. The Olmsted project will also have twin 110’ x 1200’ lock chambers once completed. Finally, a new 110’ x 1200’ lock chamber at McAlpine is currently under construction to replace the dilapidated 110’ x 600’ auxiliary chamber, so when completed McAlpine will also have twin 1200-ft lock chambers. The new lock at McAlpine is currently scheduled for completion around 2008.

4.2 GENERAL ASSESSMENT OF THE LONG-TERM NEEDS FOR THE OHIO RIVER NAVIGATION SYSTEM

There are two related major concerns associated with many of the navigation projects on the Ohio River. The first concern is the general long-term condition of many of the Ohio River projects given their age and high level of historical usage. Excluding the three lock chambers currently under construction (two at Olmsted and one at McAlpine) and L/D 52 and 53 which will be decommissioned, there are 35 lock chambers on the mainstem of the Ohio River. The average age of these lock chambers is 43 years. The service life of a lock and dam varies according to many factors including its operating environment, level of use, quality of original construction, but typically they are designed for a 50-year life without requiring increasing levels of maintenance to keep them operational. It should be noted that the Ohio River operates year round without seasonality, therefore, maintenance and large-scale repairs during the “off season” or “winter shutdown” period is not a viable option for this river system. Repairs need to be made while traffic continues to transit the system, therefore, extended lock closures are a major concern from an economic standpoint. The likelihood of more frequent, lengthy lock closures to make repairs increases as the projects age. This is evidenced by recent history on many Ohio River locks. The Ohio River navigation system is an extremely high usage system (both commercial and recreational usage) with roughly 270 million tons moving through the system annually. Some of the busiest locks in the world in terms of annual tonnage transit through Ohio River locks. Therefore, it is of great concern that roughly 54% of the existing lock chambers and dams on the Ohio River will exceed their original 50-year design life within the next 10 years. Several are already past their original design life.

The increasing usage and aging of the infrastructure is coupled with the second major concern, which is the existing capacity of the smaller auxiliary lock chambers relative to current and projected future traffic levels. At several sites, the existing traffic levels are near or exceed the capacity of the existing auxiliary chamber. Most tows are configured to lock through the longer, 1200-ft main chamber in order to maximize shipping efficiency. However, maintenance is required in order to keep these high use locks operating safely. The maintenance closure frequencies and durations vary by district according to their repair fleet operations, manpower availability, and number of projects requiring repairs by the fleet. The closures of the main chamber require the longer tows to lock through the shorter auxiliary chamber, which is typically 600-ft in

length at most Ohio River projects. In order to lock through the shorter auxiliary lock chamber, the tow must be reconfigured into two shorter segments to process through the auxiliary lock. This process is called "double-cutting" since it takes two cuts for most tows to process through the lock. This causes a large queue of tows waiting to process through the facility since it dramatically slows the transit process. Typically, the transit time (approach, locking, and departure) through an Ohio River project takes approximately an hour when both the main and auxiliary lock chambers are open. When the main chamber is closed for lengthy periods, the delay for some tows can reach several days depending upon the individual characteristics of the closure. This causes millions of dollars in navigation delay to the towing industry and thus, the general population depending upon the commodity that is shipped.

Figure ED 4-2 depicts an October 2001 aerial photograph of the queue of tows waiting to process through the John T. Myers Locks and Dam while the main chamber is dewatered for maintenance. Note the accumulation of tows waiting immediately at the facility, three at the lock, one waiting on the downstream bank, and 5 waiting upstream in of the project. In addition, tows tie up both upstream and downstream on the bank line of the project for several miles during these delays stirring up the bank line that causes adverse environmental effects. Tows can sometimes be delayed up to several days during main chamber outages depending upon the project site, main chamber outage duration, and towing industry reaction to the closure. Note that tow costs are approximately $450 per hour and 15-20 may transit through a facility during non-closure periods. Therefore, delay costs add up quickly under this scenario.

It should also be noted that these delays described above are encountered for "planned" maintenance closures where the towing industry is given a significant lead time indicating when lock chambers are planned for closures so they can make appropriate shipping modifications as necessary. Unexpected closures are anticipated in the future as individual project reliability degrades as major structures age and see more usage cycles. There are several Ohio River projects where the reliability of major components (lock gates, filling/emptying valves, mass concrete, etc…) is a major concern as several projects are presently approaching their original design life. In addition, the ORMSS is investigating the long-term performance through 2060 in which many projects will be near or over 100 years in age with high usage. Therefore, the reduced auxiliary chamber capacity coupled with reduced reliability of major components plays a major part in the overall economic analysis of the ORMSS.

Figure ED 4-2. Recent J.T. Myers Main Chamber Dewatering with Tow Queue

4.3 EMSWORTH LOCKS AND DAM

4.3.1 Project Information - Emsworth

Emsworth Locks and Dam (L&D) was authorized by the Secretary of the Army on 18 July 1918 under the authority of Section 6 of the River and Harbor Act approved 3 March 1909, as replacement for Ohio River Locks and Dams No. 1 (Davis Island Lock and Dam), built 1877-1885 and Lock and Dam 2, built 1898-1906. The project was constructed from 1919-1922, and placed in operation in September 1921. Emsworth L&D is under the jurisdiction of the Pittsburgh District.

Emsworth L&D is located 6.2 and 6.8 river miles downstream of Pittsburgh, Pennsylvania (main and back channel dams). It is 7.1 miles upstream of Dashields L&D. The navigation locks are located on the right bank of the Ohio River (main channel). The pool extends from the Emsworth Dam to the Braddock L&D, located at river mile 11.2 on the Monongahela River, and to L&D 2, located on the Allegheny River. The length of the Emsworth pool is 17.4 river miles (Monongahela River side), and 12.9 river miles (Allegheny River side). The port of Pittsburgh lies along the Emsworth pool. A profile of the navigational pools of the Ohio River is presented in Figure ED 4-1 to provide orientation with other Ohio River navigation Pools relative to the Emsworth project. Emsworth L&D provides an 18.0 ft. lift, from the Dashields pool (normal pool elevation 692.0) to the Emsworth pool (normal pool elevation 710.0 Emsworth L&D replaced L&D 1 (Davis Island L&D) at river mile 4.7. Davis Island L&D was built 1877-1885, and was the first moveable dam (wickets) in the United States. The main and back

channel dams were originally constructed in 1919-1922 as fixed crest structures. The dams were reconstructed in 1935-1938 to provide gated crests, thereby raising the Emsworth pool by 7.0 feet, and allowing for elimination of L&D 1, Allegheny River, built 1894-1902, and L&D 1 Monongahela River, reconstructed 1909-1915.

4.3.2 Project Layout - Emsworth

The Emsworth project features two lock chambers with a non-navigable, gated dam on both the main and back channels of the Ohio River. The Emsworth Dam is composed of 8 gate bays (main channel) and 6 gate bays (back channel). The main channel dam contains a short fixed weir, located adjacent to the river wall. Thirteen of the fourteen gates on the Emsworth dams are vertical lift. One gate bay (No. 9, or the first gate bay on the back channel dam) utilizes a Sidney gate, which is a "hybrid" gate (cross between a vertical lift and a tainter gate). Emsworth does not have a hydroelectric plant. A recent aerial photograph is shown in Figure ED 4-3 and a site plan/vicinity map is shown in Figure ED 4-4 to give the reader a better feel of the project's characteristics.

Figure ED 4-3. Aerial View of the Emsworth L&D Project

Two adjacent parallel locks are located on the right bank of the Ohio River. The main lock chamber has clear dimensions of 110' x 600' and the auxiliary lock 56' x 360'. The auxiliary lock is located riverward of the main lock. Filling and emptying systems are designed to fill and empty the locks in six to eleven minutes for each of these operations. The main lock is filled and emptied through a series of butterfly valves in the upper and lower middle wall. The auxiliary lock fills and empties thru a series of

butterfly valves in the upper and lower river wall. Both chambers can be dewatered by use of poiree (needle) dams, located immediately upstream or downstream of the miter gates in each chamber. An esplanade is along the landward lock. Other primary components of the locks are the miter gates, culvert valves, electrical system, mechanical system, miter gate sill, lock wall monolith, lock chamber monolith, and miter gate monolith.

The dams were originally constructed as non-navigable fixed-crest structures. Both main and back channel dams were later reconstructed to provide gated-crests and raise Emsworth pool by 7.0 feet. The overall length of the dams are 967.42 feet (main channel) and 750.0 feet (back channel). The main channel dam consists of 8 gated bays, each 100 feet in length, with a concrete weir adjacent to the river wall. The back channel dam consists of 6 gated bays, each 100 feet in length. Thirteen of the fourteen gated bays utilize vertical lift gates. Only one gate bay (No. 9), the first bay on the back channel dam utilizes a Sidney gate. All fourteen gates are non-submersible.

Both main and back channel dams contain service bridges, which supports both a bulkhead crane (below) and a maintenance crane (on top). The bulkhead cranes run along a crane runway, attached to the underside of the service bridges, transferring bulkheads from the storage pits at the ends of the dams, to any of the gate bays, as needed. Three bulkheads are stored at each dam and are fabricated to "stack" on top of each other to provide closure for one gate bay.

Normal upper pool (Emsworth pool) is elevation 710.0 mean sea level. Normal lower pool (Dashields pool) is elevation 692.0 mean sea level. Thus, the lift is 18 feet at normal pool levels.

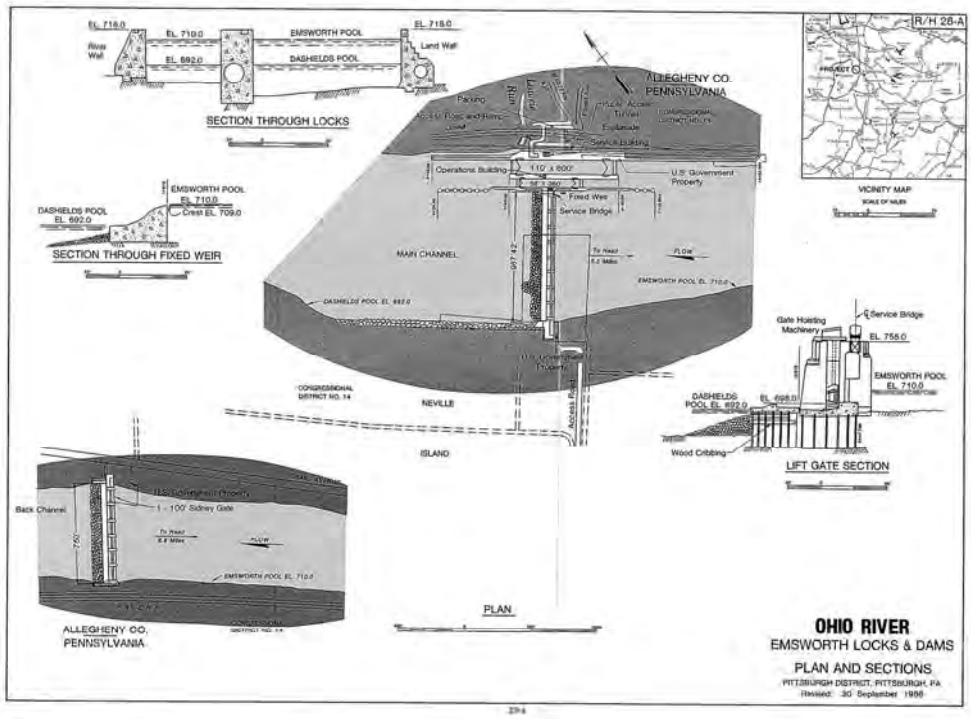


Figure ED 4-4. Plan View and Vicinity Map of the Emsworth L&D Project

4.3.3 Assessment of Concerns and Needs - Emsworth

The Emsworth lock and dam project plays a major role in the economy of the Pittsburgh region, since the Emsworth dams create and control the pool which flows adjacent to the city of Pittsburgh and it's adjoining communities. An issue of concern is the structural deficiencies of the vertical-lift dam gates, which limits the capacity of the dam to control pool elevations under extreme flow conditions. The facilities are situated in a highly industrialized area with many of the industrial plants relying heavily on water transportation for the receiving of raw materials and the shipping of finished products. Should the lift gates of the dam and/or lifting machinery fail, the resulting loss of pool would be catastrophic with the above mentioned industrial complex's dependence on water transportation. In addition, power plants and industrial and municipal water intakes which rely on relatively stable pools would be adversely affected. Two of the 14 dam gates have become inoperable due to reported deficiencies. One of these gates and machinery (gate bay No. 6) have been removed and replaced in 2002. The new gate is raised and lowered with hydraulic-operated cylinders. To date, performance of the new gate and machinery has been extremely reliable. The Pittsburgh District has prepared a Rehabilitation Evaluation Report, addressing the reliability and needs of the Emsworth Main Channel and Back Channel Dams. This RER performs an economic justification of a major rehabilitation of the Emsworth Dam, showing that anticipated federal construction costs are justified. The project was approved in 2002, but remained unfunded until start-up funds were initiated due to the concern about the condition of the dam. Refer to the Emsworth Dam Rehab Report, dated July 2001 and Addendum to the Emsworth Dam Rehab Report, dated December 2001. The Addendum addresses the issue of scour and accompanying problems and needs. The major rehab project of the dam is currently in construction and should be completed within the next few years.

Internal cracking in concrete lock wall monoliths is another significant concern and need at Emsworth. Numerous randomly-located cracks are prevalent throughout most concrete monoliths, throughout the land wall, middle wall, river wall, guide walls and guard walls. This cracking is known as a result of numerous cores drilled throughout the walls, as well as visual inspections throughout the horizontal and vertical surfaces as well as throughout the recesses and galleries. Cracking tends to propagate if left unchecked. Internal stresses created by freeze-thaw cycles is a major driver in crack growth. Cracking can eventually propagate through entire wall sections and lead to separation and significant movements of varying-sized monolith sections. A diagram graphically showing failure potential failure scenarios is shown in Figure ED 4-5.

The main causes of concrete deterioration for the locks and dams are from weathering and freeze-thaw action. Due to the fact that the locks and dams were constructed before the advent of air-entrainment in concrete, the concrete has been particularly susceptible to weathering and freeze-thaw damage. Construction practices in the 1920's and 1930's were rather poor compared to the quality control tolerances which are required for a similar project constructed today. Some construction seasons extended into the winter months, with little or no protection of the newly placed concrete from the elements. Prior to the major rehabilitation effort in the mid 1980's, horizontal and vertical surfaces of the lock walls were in advanced stages of deterioration. At Emsworth, the vertical and horizontal extent of concrete deterioration measured from the top and chamber face of the lock walls was up to 4.5 and 1.5 feet, respectively. The

major rehabilitation projects detailed varying levels of horizontal and vertical wall repairs. As stated previously, these repairs were performed in order to extend the useful life of the projects for another 25 years. These horizontal concrete overlays and vertical refacing of the lock chamber walls are considered cosmetic in nature and do not address the underlying problems associated with the deteriorated state of the existing concrete. The overlays and refacing only superficially delay the advent of further concrete deterioration.

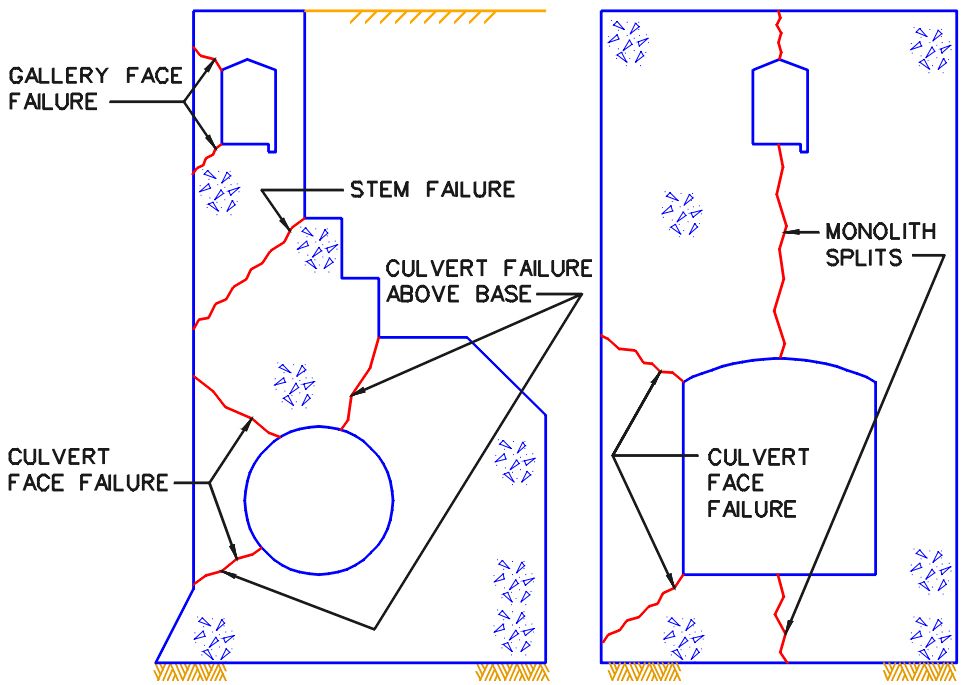


Figure ED 4-5. Internal Cracking in Lockwall Monoliths Typical for Emsworth, Dashields and Montgomery L/D's

4.3.4 Major Rehabilitation Project - Emsworth

Emsworth L&D has undergone major rehabilitation during the early1980's. These major rehabilitation efforts were designed to extend the useful life of the structure and maintain a safe navigation system for commercial and recreational users. Both 50 year and 25 year plans were considered. For all three rehabilitation efforts the 25-year plan was chosen for the following reasons; (1) feasibility to perform the required work in terms of construction time and adaptability to existing lock walls. The 25-year plan would require a significantly shorter construction period with less impact to the navigation industry. Furthermore, utilizing the existing "footprints" of the lock walls would not be conducive to retrofitting components, designed to conform to modern criteria, to extend the life of the structure for 50-years. (2) the lower cost needed to perform the 25-year plan versus the 50-year plan, and (3) the 25-year plan was a stop gap measure intended to allow safe operation of the project until replacement of the lock structures would be programmed sometime near the end of this period. With these

factors in mind, this condition report outlines the condition of the major features of the locks and dams, noting that the 25-year time period from the end of the major rehabilitation projects for Emsworth, Dashields, and Montgomery would occur at years 2010, 2015 and 2014, respectively.

4.4 DASHIELDS LOCKS AND DAM

4.4.1 Project Information - Dashields

Dashields Locks and Dam (L&D) was authorized by the Secretary of the Army on 18 July 1918 under the authority of Section 6 of the River and Harbor Act approved 3 March 1909. The project was constructed from 1927-1929, and placed in operation in August 1929. Dashields L&D is under the jurisdiction of the Pittsburgh District.

Dashields Locks and Dam is located 13.3 miles downstream of Pittsburgh, Pennsylvania . It is 7.1 miles downstream of Emsworth L&D. The towns of Edgeworth, Sewickley, Osborne, Coraopolis, Haysville, Glenfield, Dixmont and Emsworth lie along the Dashields pool. A profile of the navigational pools of the Ohio River is presented in Figure ED 4-1 to provide orientation with other Ohio River navigation Pools relative to the Dashields project. Dashields L&D provides a 10.0 ft. lift, from the Montgomery pool (normal pool elevation 682.0) to the Dashields pool (normal pool elevation 692.0).

4.4.2 Project Layout - Dashields

The Dashields project features two lock chambers with a non-navigable, fixed-crest dam. The Dashields Dam is composed of 8 gate bays (main channel) and 6 gate bays (back channel). The main channel dam contains a short fixed weir, located adjacent to the river wall. Thirteen of the fourteen gates on the Emsworth dams are vertical lift. One gate bay (No. 9, or the first gate bay on the back channel dam) utilizes a Sidney gate, which is a “hybrid” gate (cross between a vertical lift and a tainter gate). Dashields does not have a hydroelectric plant. A recent aerial photograph is shown in Figure ED 4-6 and a site plan/vicinity map is shown in Figure ED 4-7 to give the reader a better feel of the project’s characteristics.

Two adjacent parallel locks are located on the right bank of the Ohio River. The main lock chamber has clear dimensions of 110’ x 600’ and the auxiliary lock 56’ x 360’. The auxiliary lock is located riverward of the main lock. Filling and emptying systems are designed to fill and empty the locks in six to eleven minutes for each of these operations. The main lock is filled and emptied with one 13 ft. by 14 ft-10 in. butterfly valve located both in the upper and lower land and middle walls. The auxiliary lock fills and empties with one 10 ft. by 12 ft. butterfly valve, located in the upper end (filling) and lower end (emptying) of the river wall. Both chambers can be dewatered by use of poiree (needle) dams, located immediately upstream or downstream of the miter gates in each chamber. An esplanade is along the landward lock. Other primary components of the locks are the miter gates, culvert valves, electrical system, mechanical system, miter gate sill, lock wall monolith, lock chamber monolith, and miter gate monolith.

Figure ED 4-6. Aerial View of the Dashields L&D Project

The dam is the only fixed crest (uncontrolled flow) structure built along the entire Ohio River. The dam is unreinforced concrete founded on rock and provided with a shear key into rock near the upstream face. The overall length of the dam is 1,585 ft. and crest elevation is 692.0. The fixed crest dam section extends from the river wall to the abutment (on the right bank) and contains no gated sections, service bridge, bulkhead or maintenance cranes.

Normal upper pool (Dashields pool) is elevation 692.0 mean sea level. Normal lower pool (Montgomery pool) is elevation 682.0 mean sea level. Thus, the lift is 10 feet at normal pool levels.

4.4.3 Assessment of Concerns and Needs - Dashields

Unstable guide walls coupled with heavily cracked lockwall concrete contribute to serious condition concerns at Dashields. Analysis of upper and lower guide wall stability has confirmed that the walls are unstable. Survey monitoring has revealed movement in both walls. Failure of the guide wall monoliths could block the approaches to the land chamber and disrupt river traffic. An unscheduled outage of the main chamber would force all traffic, including double cut tows, to lock thru the auxiliary chamber, resulting in significant delays, even with the use of helper boats. Concrete cracking is extremely prevalent throughout the monoliths on the land, middle and river walls, and can be easily seen throughout the pipe galleries. Figures ED 4-8 and ED 4-9 show some the extent of some of the concrete damage to the approach walls at Dashields.

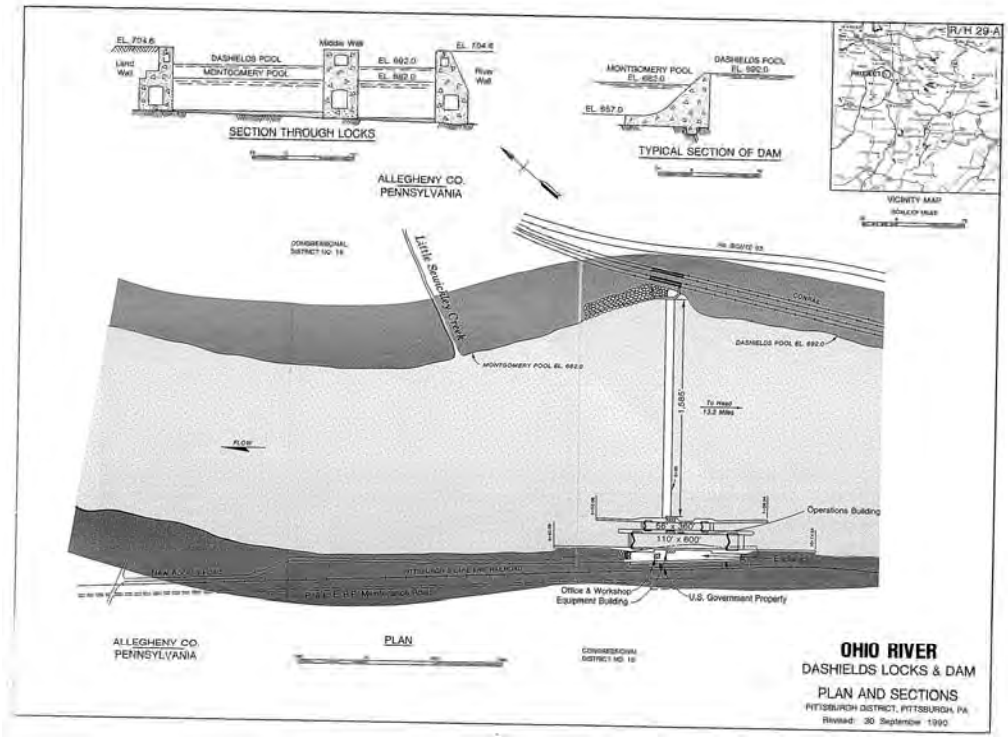


Figure ED 4-7. Plan View and Vicinity Map of the Dashields L&D Project

Figure ED 4-8. Lower Guide Wall – Downstream End as Seen From the River Wall

Figure ED 4-9. Upstream Guide Wall, Crack in Land Side Face of Wall

The main causes of concrete deterioration for the locks and dams are from weathering and freeze-thaw action. Due to the fact that the locks and dams were constructed prior to 1950, before the advent of air-entrainment in concrete, the concrete has been particularly susceptible to weathering and freeze-thaw damage. Construction practices in the 1920's and 1930's were rather poor compared to the quality control tolerances which are required for a similar project constructed today. Prior to the major rehabilitation effort for the upper Ohio projects completed 15 to 20 years ago, horizontal and vertical surfaces of the lock walls were in advanced stages of deterioration. The major rehabilitation projects detailed varying levels of horizontal and vertical wall repairs. These horizontal concrete overlays and vertical refacing of the lock chamber walls are considered cosmetic in nature and do not address the underlying problems associated with the deteriorated state of the existing concrete. The overlays and refacing only superficially delay the advent of further concrete deterioration.

Prior to the rehabilitation projects, the concrete at Dashields was the worse condition both from a deterioration standpoint as well as experiencing numerous cracking of a structural nature. Both Dashields and Montgomery locks utilize integral filling and emptying culverts and pipe galleries in all three walls. These features result in thin-walled sections with numerous reentrant corners, susceptible to stress concentrations, causing cracking and crack propagation. These details coupled with the lack of concrete reinforcing, which would be provided in modern structures, encourage conditions susceptible to cracking. Progressive riverward movement of the upper and lower guide walls continue to be monitored. A recent stability report recommended anchoring to retard the riverward movement.

The lock structure continues to be plagued by interior cracking, located at numerous random positions along the monoliths, but prevalent throughout the filling and emptying valve recesses, bulkhead recesses and miter gate machinery recesses. Several structural repairs were performed during the major rehabilitation project. Recently a structural crack has been identified at the downstream land wall culvert valve recess propagating through to the valve bulkhead recess. Due to the age of the underlying

original concrete, typical for all three locks and dams, freeze-thaw cycles have caused cracking and deterioration along weather-susceptible surfaces, such as recesses which are covered with aluminum grating. In some cases, such as cracking in the miter gate anchorage areas, fatigue appears to have contributed to the deficiencies. Typical concrete damage photos of the lock structure at Dashields are shown in Figures ED 4-10 and ED 4-11.

Figure ED 4-10. Cracking in River Wall Gallery at Monolith R-20

Figure ED 4-11. Cracking in Middle Wall Gallery

Dashields underwent major rehabilitation during the late 1980's. These major rehabilitation efforts were designed to extend the useful life of the structure and maintain a safe navigation system for commercial and recreational users. The 25-year

rehabilitation plan was chosen for the same reasons as those outlined for the Emsworth rehabilitation. This 25 year design plan extended the life expectancy from 1989 to 2014 at Dashields.

There are no significant navigation problems; however, industry considers the lock approaches to be difficult to maneuver with larger tows, due largely to the location of ports along the upper and lower guard walls, which has a tendency during filling or emptying to create turbulence in the approach areas. Dashields has an extensive history of tow damage to the miter gates, further indicating a less than desirable approach condition in part due to the ported design.

The Dashields project is one of the older projects on the Ohio River, along with Emsworth, Montgomery, and McAlpine, built prior to World War II. The Dashields project began lockages in 1929.

The lock chamber sizes, 110' x 600' and 56' x 360' were once optimum for the size and configuration of Ohio River tows, but are now well below the size required to accommodate larger more powerful modern tows. The double lockage requirement consumes both time and additional operational wear and tear on both the lock structure and operating machinery. Also, the inadequate chamber sizes of these three locks deter economic activity vital to the region.

The Dashields dam has been plagued by scour problems over the years; hence, is another area of concern. Downstream scour holes and undermining of the dam apron have been detected. Annual dive inspections monitor these downstream conditions. A model study by ERDC was conducted prior to the rehab, to determine a method to eliminate the scour. As part of the major rehabilitation effort, tremie concrete and grout-filled bags were placed along the toe of the apron to impede the recurring scour along the base of the toe. Periodic dive inspections provide information that allows the District to monitor the adequacy of this repair.

4.5 MONTGOMERY LOCKS AND DAM

4.5.1 Project Information - Montgomery

Montgomery Locks and Dam is located 31.7 river miles downstream of Pittsburgh, Pennsylvania. It is 18.4 miles downstream of Dashields L&D. The pool extends 18.4 miles, from the Montgomery Dam, at river mile 31.7 to the Dashields dam, at river mile 13.3. A profile of the navigational pools of the Ohio River is presented in Figure ED 4-1 to provide orientation with other Ohio River navigation Pools relative to the Montgomery project. Montgomery L&D provides a 17.5 ft. lift, from the New Cumberland pool (normal pool elevation 664.5) to the Montgomery pool (normal pool elevation 682.0).

4.5.2 Project Layout - Montogmery

The Montgomery project features two lock chambers with a non-navigable, gated dam on the Ohio River. The Montgomery Dam is composed of 10 gate bays. Two fixed weirs, on either end, were constructed as a part of the Montgomery dam. Each of the 10 gates are vertical lift. Montgomery does not have a hydroelectric plant. A recent aerial

photograph is shown in Figure ED 4-12 and a site plan/vicinity map is shown in Figure ED 4-13 to give the reader a better feel of the project's characteristics.

Two adjacent parallel locks are located on the left bank of the Ohio River. The main lock chamber has clear dimensions of 110' x 600' and the auxiliary lock 56' x 360'. The auxiliary lock is located riverward of the main lock. Filling and emptying systems are designed to fill and empty the locks in six to eleven minutes for each of these operations. The main lock is filled and emptied through a butterfly valve in the upper and lower middle wall. The auxiliary lock fills and empties thru a butterfly valve in the upper and lower river wall. Both chambers can be dewatered by use of poiree (needle) dams, located immediately upstream or downstream of the miter gates in each chamber. An esplanade is along the landward lock. Other primary components of the locks are the miter gates, culvert valves, electrical system, mechanical system, miter gate sill, lock wall monolith, lock chamber monolith, and miter gate monolith.

The dam consists of 10 gated bays, each 100 feet in length, with two concrete weir sections, one adjacent to the river wall and the other adjacent to the abutment. The overall length of the dam, river wall to abutment, is 1,378.75 ft. Each of the 10 gate bays utilize vertical lift gates. All dam gates are non-submersible.

Figure ED 4-12. Aerial View of the Montgomery L&D Project

The dam was constructed with a service bridge, which supports both a bulkhead crane (below) and a maintenance crane (on top). The bulkhead crane runs along a crane runway, attached to the underside of the service bridge, transferring bulkheads from the storage pit at the ends of the dam, to any of the gate bays, as needed. Three bulkheads are stored at each dam and are fabricated to "stack" on top of each other to provide closure for one gate bay.

Normal upper pool (Montgomery pool) is elevation 682.0 mean sea level. Normal lower pool (New Cumberland pool) is elevation 664.5 mean sea level. Thus, the lift is 17.5 feet at normal pool levels.

4.5.3 Assessment of Concerns and Needs - Montgomery

Montgomery locks and dams is one of the oldest operating structures in the Pittsburgh District and has several concerns. Heavily cracked lockwall concrete and dam gate hoist problems are among the most severe. Concrete cracking is extremely prevalent throughout the monoliths on the land, middle and river walls, and is readily visible throughout the pipe galleries and within recesses (gate, valve, bulkhead, and ladder ways). Figures ED 4-14 and ED 4-15 depict typical concrete damage noted at Montgomery.

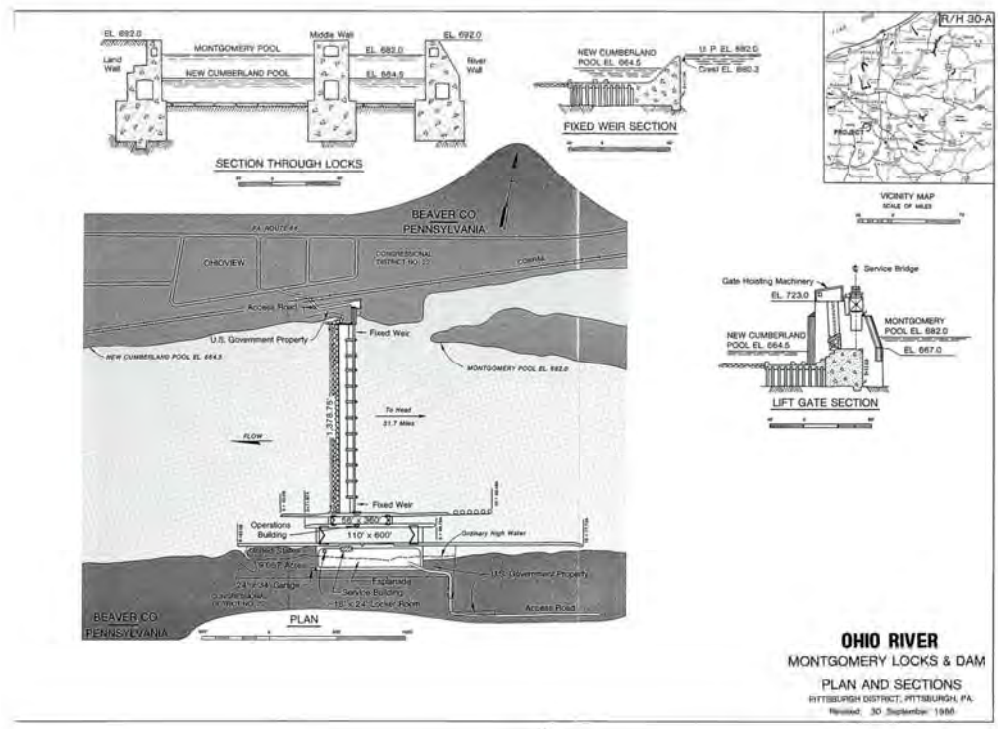


Figure ED 4-13. Plan View & Vicinity Map of the Montgomery L&D Project

The main causes of concrete deterioration for the locks and dams are from weathering and freeze-thaw action. Due to the fact that the locks and dams were constructed prior to 1950, before the advent of air-entrainment in concrete, the concrete has been particularly susceptible to weathering and freeze-thaw damage. Prior to the major rehabilitation effort, horizontal and vertical surfaces of the lock walls were in advanced stages of deterioration. The major rehabilitation projects detailed varying levels of horizontal and vertical wall repairs. As stated previously, these repairs were performed in order to extend the useful life of the projects for another 25 years. These horizontal concrete overlays and vertical refacing of the lock chamber walls are considered cosmetic in nature and do not address the underlying problems associated

with the deteriorated state of the existing concrete. The overlays and refacing only superficially delay the advent of further concrete deterioration. Furthermore, the overlays and refacing , which these feature of work were completed in 1987 , have experienced numerous cracking, therefore, consequently not providing the level of protection anticipated to achieve the 25 year design life expectancy. The lockwalls contain numerous cracks at numerous random locations, some of which begin at gate, valve and bulkhead recess corners and extend laterally or longitudinally throughout the entire monolith, and beyond. Many of these cracks have propagated downward into the pipe galleries, and likely are growing further toward the culverts. Pipe galleries in the land, middle and river walls are full of cracks, many with heavy efflorescence, indicating water penetration from above surfaces. Maintenance has regularly resealed cracks to prevent seepage, but is short lived. Under-reinforced monoliths (relative to today's standards) coupled with thin wall sections and lack of fillets along the gallery corners has been susceptible to torsion effects of wall loadings from pool fluctuations and dewaterings. Results are severe cracking throughout. Core samples have been taken in high-stress and other key areas to survey the extent of the problem. Many cores contain numerous cracks, at various elevations. Monoliths are at risk for this cracking to extend to exterior surfaces, causing separation of wall segments.

Montgomery L&D also has undergone a 25-year major rehabilitation during the mid 1980's. These major rehabilitation efforts were designed to extend the useful life of the structure and maintain a safe navigation system for commercial and recreational users. The same reasons for rehab and selection of the 25-year plan as was described for Emsworth and Dashields were applicable for Montgomery.

The gate hoists on the dam are a serious concern at Montgomery. The condition of the chains, and gate position indicators and two drive motors, one on each pier, creates a serious situation. The dam gate hoist chains tend to kink and are showing other signs of wear and lack of internal lubrication. The gate position indicators are driven by the hoist machinery and do not directly read the position of the gate. If a hoist chain were to kink or foul, the position indicator would not yield an accurate reading. Maintaining a level gate position is critical to safe dam operation. If a dam gate were to become jammed, part of the hoist machinery could fail and drop or jam the gate. The use of two drive motors in lifting the gate can create a large force. Due to these conditions, the dam is rarely operated remotely, even though programmable logic controllers (PLC's) were installed during the major rehabilitation. A more detailed evaluation of the dam gate hoist chains and sprockets should be made. Also, a more positive and reliable method of determining the gate position should be evaluated. Until the condition of the dam gate hoist machinery can be ascertained all mote operations of the dam gates should be discontinued.

Figure ED 4-14. Typical Cracking, Efflorescence Throughout the Galleries

Figure ED 4-15. Typical Cracking, Efflorescence Throughout the Galleries

Stability analysis on the Montgomery lock walls, prior to the rehab, revealed that, in general the lock wall monoliths failed to meet criteria standards. The geometry of several major features of the locks, such as the upper guide wall and miter sill, whose configuration are of an unconventional nature, contribute to their structural inadequacies. Pre-stressed tensioning anchors, which are much more desirable than passive anchors, for enhancing stability of the monoliths, were not chosen due to various concerns from the Ohio River Division office. Statements were made from Division, commenting on the District's June 1980 Rehabilitation Report, indicating reluctance in using tensioned

anchors. "The entire anchoring scheme needs to be more fully developed and carefully reviewed to insure that the structure can withstand the loads that will be imposed by the anchors and that the anchors would be practical to construct." "In general, it is felt that the moderately large tendon anchors are not well suited to the anchorages proposed. They are located near the face of concrete and in thin concrete sections. They will be difficult to install and will overstress the concrete in tension in some areas and in compression in others. It may be necessary to use passive or lightly prestressed cement grouted prestressing bars (singularly or in bundles)". Consequently, passive anchors were installed in lieu of tensioned anchors, even though passive anchors contribute to the structural integrity of a monolith only after movement has occurred. Use of passive anchors is not recommended by current guidance within ETL 1110-2-310, "Stability Criteria for Existing Concrete Navigation Structures on Rock Foundations". Paragraph 8. States that "Non-prestressed anchors shall not be used if other options are feasible. The effectiveness of this system is questionable and undependable due to the movement required to activate the anchor force. Therefore, the system; should not be considered as effective in improving the safety factor for the structure's stability. They may be used as a last resort to prevent any possibility of catastrophic failure. In designing the passive anchors, uplift forces within the foundation were assumed to be reduced by the anchor force provided; however, the anchor force was recognized as not being fully active until sufficient movement between the foundation and the wall had occurred. The simplistic assumption that the anchors were active avoided a more complex analysis whereby the movement to mobilize the anchors would redistribute the uplift forces within the foundation. The incorrectness within the analysis probably would necessitate an adjustment whereby additional anchors would be provided and would further support the contention made that the installed passive anchors can not be depended on to provide the required factors of safety.

Montgomery dams have had a history of scour related problems exposing the downstream face of the dam, cribbing foundation, and wood piles and at times undermining the stilling basin. When the dam was being constructed a cofferdam washout occurred prompting the need to place stone fill along approximately 173 feet of the main channel dam. The stone and concrete blocks that were placed at the time of the washout also washed downstream in the following years. To stabilize the downstream face of the dam, stone filled barges were sunk along the downstream face and stone protection placed between them and the downstream face of the stilling basin in the summer of 1925. Placement of additional scour protection below the dam has been an ongoing maintenance concern. Additional placement of scour protection was performed during the major rehabilitation project. Subsequent to that effort, additional scour has occurred prompting the need to perform further measures to retard this adverse effect.

4.6 NEW CUMBERLAND LOCKS AND DAM

4.6.1 Project Information – New Cumberland

The project is located on the Ohio River, 54.4 river miles downstream from Pittsburgh, PA. The locks are at Stratton, Ohio, and the dam abutment is approximately 2.5 miles north of New Cumberland, West Virginia. It is the fourth navigation facility

from the head of the River at Pittsburgh. Tail water is controlled by Pike Island Lock and Dam, located at river mile 84.2.

4.6.2 Project Layout – New Cumberland

The dam is 1315 feet long with eleven gated bays of 110 feet each, and 12 piers. Flow is controlled with six non-submergible tainter gates and five submergible tainter gates. Target pool is elevation 664.5, and at this pool creates a lift of 20.5 feet from the tailwater created by Pike Island Locks and Dam, at mile 84.2. The New Cumberland pool extends 22.7 miles upstream to Montgomery Locks and Dam. The dam is founded on rock varying from gray siltstone to gray and brown sandstone. The stilling basin is founded on steel H-piles and there is a steel sheetpile cutoff under the end sill. A plate girder service bridge spans the distance from the land wall pier to the abutment pier. The span over the landward lock chamber is a lift span designed to be raised 10.5 feet to provide a clear distance of 68 feet above normal upper pool.

Two parallel lock chambers are located along the right bank of the river. There is a 110-foot by 600-foot landward chamber and a 110-foot by 1200-foot riverward chamber. Each lock has two sets of hydraulically operated steel miter gates opening into recesses in the walls. Each lock wall has a filling and emptying culvert controlled by hydraulically operated reverse tainter valves. Each wall has a set of eight intake and eight discharge ports. The land chamber is filled and emptied through six laterals that extend form the land wall culvert across the land wall floor. The river chamber is filled and emptied by the middle and river wall culverts through ports located in the walls. The lock walls are concrete gravity walls founded on rock. The guard walls and guide walls are built on pile foundations of varying types.

The dam tainter gates are operated by bar-link type hoisting chains driven by a sprocket wheel and electric motor-driven hoist mechanism. Each sprocket is driven by a large gear reduction unit through a spur gear and pinion. The operating machinery for each of the lock miter gates consists of a sector arm and strut, sector gear, and rack in a single horizontal plane. A hydraulic cylinder actuates the rack. The operating machinery for each reverse tainter valve consists of a connecting rod, rocker, and strut oriented in a vertical plane. The connecting rod is attached to a piston rod and piston actuated by a hydraulic cylinder. Three constant delivery type hydraulic fluid pumps and one pressure holding pump located in the operations building on the middle wall power the hydraulic system. There are separate pipe systems for each lock with interconnection at the pumps. Other machinery includes a locomotive crane, traveling bulkhead hoist, lift-span hoisting machinery, emergency generator, and air compressor.

A set of four interchangeable truss-type emergency bulkheads, each nine feet high, are stacked to provide the required heights for closure of the dam gate bays or lock chambers. Units are raised, lowered, and transported by a traveling hoist equipped with a lifting beam. Poiree dams are used for downstream maintenance closure of the lock chambers

A recent aerial photograph is shown in Figure ED 4-16 and a site plan/vicinity map is shown in Figure ED 4-17 to give the reader a better feel of the project's characteristics.

Figure ED 4-16. Aerial View of the New Cumberland L&D Project

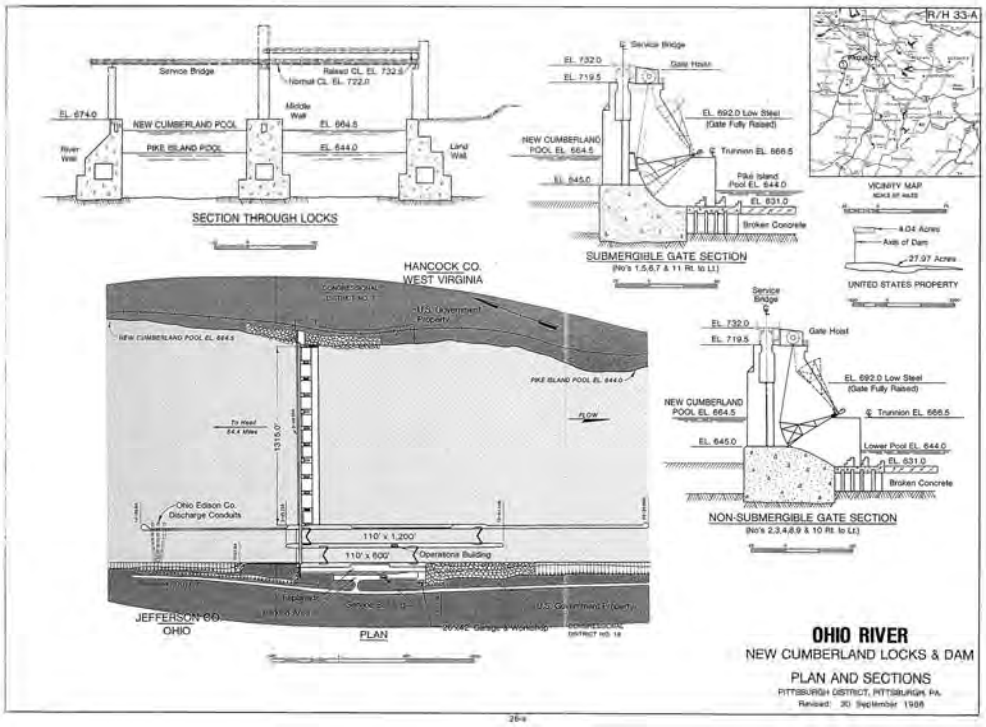


Figure ED 4-17. Plan View and Vicinity Map of the New Cumberland L&D Project

4.6.3 Assessment of Concerns and Needs – New Cumberland

Concerns with the lockwalls are related to cracking and relative movements. The river wall has an alignment problem. Some river wall monoliths have moved and/or rotated Survey monitoring pins have been installed on all river wall monoliths and are routinely being monitored by survey crews. Additional foundation drilling and testing needs to be performed to obtain actual strength parameters for purposes of reanalyzing lockwall stability. Cracking is a problem in the lockwall monoliths. This is true in all walls; however the middle wall appears most severe. Cracks have appeared in each monolith below the downstream auxiliary chamber miter gates. These cracks generally run longitudinally across the top surfaces of the monoliths, and extend downward to the galleries, and in some cases to the culvert. Crack surveys have been partially performed but need to be completed throughout all lockwalls and galleries. Exterior horizontal surfaces need to have cracks routed and sealed to prevent water intrusion and arrest crack growth, perpetuated from freeze-thaw cycles. Movement of the end monoliths on the guard walls (upper and lower bullnoses) have occurred such that the monolith joints have "opened" both vertically and horizontally. The most severe is the upper bullnose, exhibiting a horizontal opening of one inch down to the water line. Alignment pins have been installed and survey crews provide routine monitoring.

Concerns with the dam relate mostly to relative movements of piers and a significant crack in the abutment wingwall. Alignment pins have been installed along the top of the dam and are routinely monitored. Some pier movements have been recorded at 0.4". The upstream abutment wingwall contains a significant crack and is also being monitored.

Auxiliary chamber miter gates have heavy corrosion on many members and heavy leakage at the quoin and miter blocks. These gates are original and have been in service for approximately 45 years. Miter gates in the main 1200-ft chamber were replaced in 2002 due to the heavy damage to these miter gates through continued use and corrosion..

4.7 PIKE ISLAND LOCKS AND DAM

4.7.1 Project Information – Pike Island

Pike Island Locks and Dam is located on the Ohio River about 12 miles north of Wheeling, West Virginia, at river mile 84.2. The locks are located in Ohio County, West Virginia, and the abutment is in Belmont County, Ohio. It is the fifth navigation facility from the head of the Ohio River. Its upper pool extends 30 miles upstream to New Cumberland Locks and Dam.

4.7.2 Project Layout – Pike Island

The dam is a combination gated and fixed crest weir concrete structure with an overall length of 1,306 feet. The dam consists of eight intermediate piers, nine broad crested gated weirs, two end piers, and a fixed weir on the right abutment end. Flow is controlled by five submergible gates and four non-submergible gates, each 110-feet wide.

Normal upper pool elevation is 644.0 feet, 21 feet above the normal lower pool elevation of 623.0 feet, created by Hannibal Locks and Dam, downstream. The dam and the piers are founded on rock. The reinforced concrete stilling basin contains one row of baffles, and terminates at the end of the piers with a four-foot high end sill. The stilling basin apron is founded on steel bearing piles driven to rock with a concrete cutoff wall to rock at the downstream edge. A post-tensioned concrete box girder bridge extends across the dam and both lock chambers and carries a concrete deck, walkways, and a traveling hoist for placement of the bulkheads. An auxiliary crane for maintenance is carried on the hoist frame.

Two adjacent and parallel lock chambers are located on the left bank. The landward chamber is 110 feet by 600 feet and the riverward chamber is 110 feet by 1200 feet. The tops of the lock walls are at elevation 656.0. Each lock has two sets of hydraulically operated steel miter gates opening into recesses in the walls. Each lock wall contains a filling and emptying culvert through which flow is controlled by hydraulically operated reverse tainter valves. The land (600-foot) chamber is filled and emptied through six laterals extending across the floor from the land wall culvert. The river (1200-foot) chamber is filled and emptied by the middle and river wall culverts through ports located in the walls. The main lock walls are concrete gravity sections founded on rock. The upper guide wall is unreinforced concrete founded on steel bearing piles. Both the upper and lower guard walls are concrete caps over sheet pile cells enclosing steel bearing piles. The upstream emergency closures are steel bulkheads placed by a movable crane on an overhead bridge. Downstream closure is accomplished using poiree dams.

The dam tainter gates are operated by means of wire ropes and electric powered hoists. Each gate is operated by means of a drive-end unit and a driven-end unit, spaced and attached to the service bridge framing across the gate opening. The operating machinery for the lock miter gates consists of a sector arm and strut, sector gear, and rack in a single horizontal plane. The rack is connected to the piston rod of a hydraulically actuated cylinder. The operating machinery for each reverse tainter valve consists of a connecting rod, rocker and strut oriented in a vertical plane. The connecting rod is attached to the piston rod of a hydraulically actuated cylinder. The hydraulic system is powered by three constant delivery type service hydraulic oil pumps and one pressure holding oil pump located in the operation building on the middle wall. There are separate pipe systems for each lock with interconnection at the pumps. Other machinery includes a bulkhead hoist and crane with an auxiliary locomotive crane, emergency generator, air compressor, jib cranes, and an elevator.

A recent aerial photograph is shown of the Pike Island project is shown in Figure ED 4-18.

Figure ED 4-18. Aerial View of the Pike Island L&D Project

4.7.3 Assessment of Concerns and Needs – Pike Island

Concerns with the dam relate to heavy corrosion and deterioration of the service bridge crane rail and securing devices/fasteners. Corrosion is prevalent throughout but the most severe is approximately above the two gates at the center of the service bridge. These gates are operated most frequently, and a theory is that increased gate movements result in increased water spray across the top of the dam. Given freeze-thaw cycles, this wet environment has apparently led to extreme damage to the crane rails. Grout pads supporting the rails are heavily spalled and damaged. Further spalling could lead to loss in bearing support for the crane and hence a safety problem. One abutment wingwall has cracked and spalled and is also being monitored. Heavy corrosion of dam gates has been an ongoing problem at Pike Island. Several contracts have been awarded to procure painting/metalizing services. Two dam gates (No. 4 and 9) remain unpainted but are on the remedial measures list. Both of these gates are overflow or submersible gates and desperately require cleaning and painting. Seepage is occurring thru a lift joint in the fixed weir.

4.8 HANNIBAL LOCKS AND DAM

4.8.1 Project Information - Hannibal

Hannibal Locks and Dam is located on the Ohio River at river mile 126.4. The locks are in Monroe County, Ohio, and the abutment is in Wetzel County, West Virginia, at the town of New Martinsville. It is the sixth navigation facility from the head of the Ohio River. Its upper pool extends 42.2 miles upstream to Pike Island Locks and Dam.

4.8.2 Project Layout - Hannibal

The dam is 1067 feet long, from the river face of the river wall to the river face of the hydropower plant, with eight gated bays, each 110 feet long, and a fixed crest weir, 79 feet long. There are seven intermediate piers and two end piers. The fixed weir is located between the gated portion of the dam and the hydropower plant. Eight non-submersible fixed trunnion radial lift tainter gates control flow. Normal upper pool elevation is 623.0 feet, 21 feet above the normal lower pool of 602.0 feet, created by Willow Island Locks and Dam, downstream. The dam is founded on rock. The reinforced concrete stilling basin extends 41 feet downstream from the ends of the piers, contains one row of baffles, and terminates with a four-foot high end sill. A concrete girder service bridge spans from a pier on the land wall to the pier adjacent to the fixed weir. The span over the landward lock chamber is designed to provide a navigation clearance of 68 feet above normal pool.

Two side-by-side lock chambers are located along the right bank of the river. The landward chamber is 110 feet by 600 feet and the riverward chamber is 110 feet by 1200 feet. Each lock gate has two sets of hydraulically operated steel miter gates opening into recesses in the walls. Each lock wall contains a filling and emptying culvert through which flow is controlled by hydraulically operated reverse tainter valves. The land (600-foot) chamber is filled and emptied through nine laterals extending across the floor from the land wall culvert. The river (1200-foot) chamber is filled and emptied by the middle and river wall culverts through ports located in the walls. The main lock walls are concrete gravity walls founded on rock. The guard walls and guide walls are built on pile foundations of varying types.

The dam tainter gates are operated by means of wire ropes and electric powered hoists. Each gate is operated by means of a drive-end unit and a driven-end unit, spaced and attached to the service bridge framing across the gate opening. The operating machinery for the lock miter gates consists of a sector arm and strut, sector gear, and rack in a single horizontal plane. The rack is connected to the piston rod of a hydraulically actuated cylinder. The operating machinery for each reverse tainter valve consists of a connecting rod, rocker and strut oriented in a vertical plane. The connecting rod is attached to the piston rod of a hydraulically actuated cylinder. The hydraulic system is powered by three constant delivery type service hydraulic oil pumps and one pressure holding oil pump located in the operation building on the middle wall. There are separate pipe systems for each lock with interconnection at the pumps. Other machinery includes a bulkhead hoist, generator, air compressor, jib cranes, and an elevator.

A set of three interchangeable bulkhead units, each ten feet high, are stacked to provide the height needed as a bulkhead in the dam gate bays upstream of the tainter gates; as an overflow weir for passage of ice and debris from the upstream approach; as a maintenance or emergency bulkhead at the upstream end of a lock. The bulkhead units are raised, lowered, and transported by a traveling hoist equipped with a lifting beam.

Five bulkhead units, each six feet high, are used in conjunction with the emergency bulkheads in dewatering each tainter gate bay for inspection, repair, or maintenance purposes. These six-foot high bulkhead units are also used downstream of the lower miter gates for maintenance closures and upstream of the emergency dam sill for access to the in-place emergency bulkhead. The six-foot high bulkhead units are installed and removed by a floating crane.

More detailed information on the configuration of Hannibal Locks and Dam as well as selected as-built drawings can be found in Appendix X of the Hannibal Locks and Dam, First Periodic Inspection Report.

The New Martinsville Hydroelectric Project is located on the left bank of the Ohio River and is integral with Hannibal Dam, abutting the fixed crest overflow weir section of the dam. Provisions were made during design of the dam for add-on hydropower by including four permanent sheetpile cells adjacent to the fixed crest weir, with the idea that these cells could be easily removed for construction of a powerhouse. Two of these sheetpile cells were removed along with one of the three fixed crest monoliths. The license for the hydroelectric project was issued in June 1984 to the City of New Martinsville, West Virginia. Burgess and Niple, Limited, of Columbus, Ohio provided engineering services for the City of New Martinsville. The primary contractor was Bechtel International with Canonie Construction Company. Features of the project include: a 365-foot long, approximately 125-foot wide approach channel; a cast-in-place reinforced concrete powerhouse equipped with two identical 17.86 MW horizontal Kaplan pit bulb turbines; a 495-foot long tailrace channel varying in width from 115 to 165 feet; and a 138 KV, 3 phase transmission line between the switchyard and the Monongahela Power substation, located approximately 1500 feet east of the site. A recent aerial photograph is shown in Figure ED 4-19 to give the reader a better feel of the project's characteristics.

Figure ED 4-19. Aerial View of the Hannibal L&D Project

4.8.3 Assessment of Concerns and Needs - Hannibal

The Hannibal project was placed in operation in 1972 and is a modern lock and dam, generally in good condition with no significant problems.

One of the precast girders supporting the service bridge contains a crack on span No. 2, both upstream and downstream faces, and is regularly monitored during cyclic bridge safety inspections as well as by project personnel. Deterioration of expansion joint faces is prevalent along the bridge. Some joints are severe in that concrete chunks have broken off, causing concern that longitudinal expansion can freely take place without interference. Bridge bearings supporting the spans over the lock chambers have rotated to an angle which appears abnormal. This may be related to the thermal-induced superstructure expansion and contraction. Random tight cracks exist on the pier hammerheads. The fixed weir has a minor seepage problem across the top lift joint, adjacent to the hydropower plant.

Some operational issues require attention. The bulkhead latching devices use an air pressure latching system and often have problems latching, especially in winter months. The miter gates appear to have an alignment problem, possibly created by undo wear in the sector gear pin and bushings. The strut arms frequently require tightening. All gates in the 1200' chamber has a problem with the sector arms which have often rubbed the racks in the near open position. Clearances between the arms and the ribs on top of the racks may be the problem. The maintenance crane on the service bridge is functional; however, does not possess telescoping capability to make picks which creates difficulty for operators. Tainter gates are functional, structurally sound, and sealing satisfactorily; however, contain significant corrosion, mostly along the tailwater side along the splash zones.

4.9 WILLOW ISLAND LOCKS AND DAM

4.9.1 Project Information – Willow Island

Willow Island Locks and Dam (L&D) was authorized by the Secretary of the Army under the authority of Section 6 of the River and Harbor Act approved 3 March 1909, as a replacement for Ohio River Locks and Dams No. 15, 16, and 17. The lock construction contract was awarded in 1968 and navigation traffic began using the facility in 1972 during construction of the dam. Construction of the dam was completed in 1976. The pool was raised to full height in September 1975. It is under the jurisdiction of the Huntington District.

Willow Island L&D is located 161.7 river miles downstream of Pittsburgh, Pennsylvania. It is also 3.4 miles upstream of Waverly, West Virginia. The navigation locks are located on the North bank, or the Ohio side of the river. The pool extends from the dam upstream for a distance of 35.3 miles to Hannibal Dam, located at river mile 126.4. A profile of the navigational pools of the Ohio River is presented in Figure ED 4-

1 to provide orientation with other Ohio River navigation pools relative to the Willow Island project.

4.9.2 Project Layout – Willow Island

The Willow Island project features two parallel lock chambers with a non-navigable, gated dam. The dam includes a 111' fixed weir with an 84' open crest. A recent aerial photograph is shown in Figure ED 4-20 and a site plan/vicinity map is shown in Figure ED 4-21 to give the reader a better feel of the project's characteristics.

Figure ED 4-20. Aerial view of the Willow Island L&D Project

Two adjacent parallel locks are located on the Ohio bank, the main lock chamber has clear dimensions of 110' x 1,200' and the auxiliary lock of 110' x 600'. The main lock is located riverward of the auxiliary lock. Filling and emptying systems are designed to fill and empty the locks in about eight minutes for each of these operations. The main lock is filled or emptied through longitudinal culverts in both walls; the auxiliary locks' culverts are in the land wall only. Flow is then distributed in the main lock using ports along the monoliths and in the auxiliary lock using a lateral system that extends from the culverts across the lock floor. Emergency gates are located immediately upstream of the upstream miter gates. These gates are vertical lift gates. An esplanade is along the landward lock. Other primary components of the locks are the miter gates, culvert valves, electrical system, mechanical system, miter gate sills, lock wall monoliths, lock chamber monoliths, and miter gate monoliths.

The dam is a non-navigable, high-lift, gated dam, top length 1,128' including a 111' fixed weir with 84' open crest. It consists of 8 tainter gates with each gate having a clear span of 110' between piers, a damming height of 26' above the sills, and a clearance above the maximum high water level of approximately 5' when fully raised.

Normal upper pool is elevation 602.0 mean sea level and the normal upper pool surface area is 6,400 acres. Normal lower pool is elevation is 582.0 mean sea level. The lift at normal pool levels is 20'.

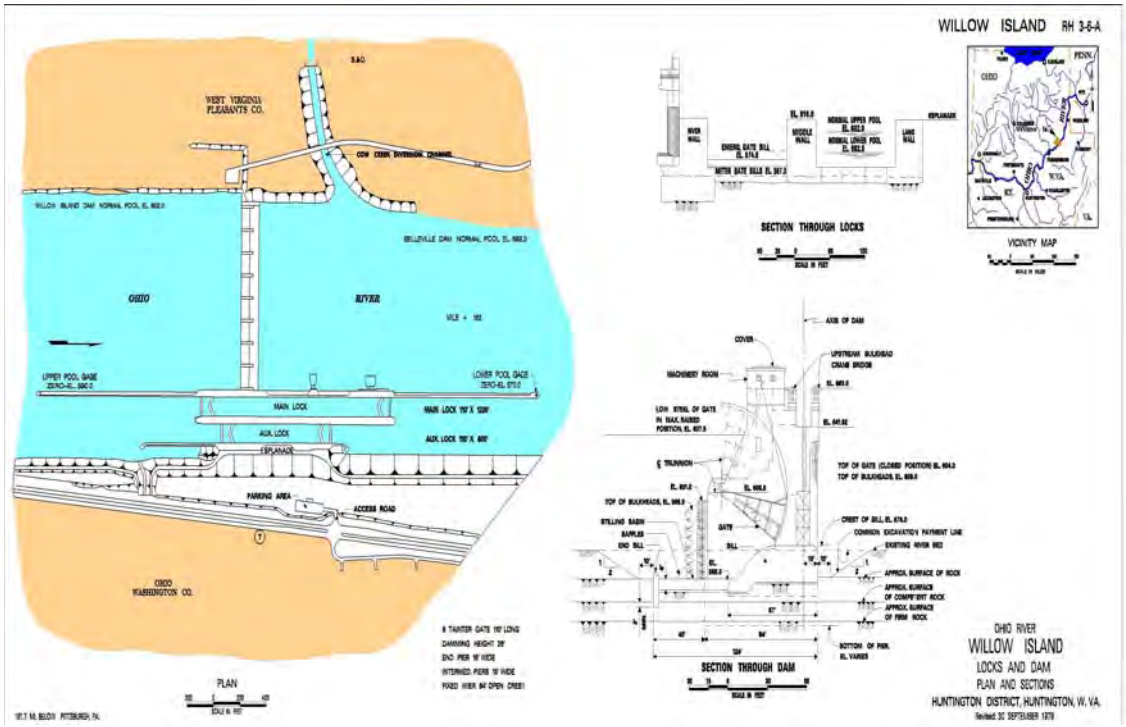


Figure ED 4-21. Plan View and Vicinity Map of the Willow Island L&D Project

4.9.3 Assessment of Concerns and Needs – Willow Island

There has not been any major deterioration or any significant deficiencies noted during recent inspections. This includes a dewatered inspection of the main chamber conducted in July 1999. The dewatered inspection did not include a thorough cleaning to remove all zebra mussels and debris prior to inspection. Therefore, as is discussed under the assessment of concerns and needs for Meldahl L&D, corrosion of the miter gate girder webs may not have been apparent although present.

Monoliths R-89 and R-90 (Upper Guard Wall) have moved causing an open joint between the two monoliths, mainly in the upper ¼ of the monoliths. Presently, this joint is being monitored through visual inspections and periodic diver inspections, but does not present a structural concern.

4.10 BELLEVILLE LOCKS AND DAM

4.10.1 Project Information - Belleville

Belleville Locks and Dam (L&D) was authorized by the Secretary of the Army under the authority of the River and Harbor Act approved 3 March 1909, as a replacement for Ohio River Locks and Dams Nos. 17, 18, 19, and 20, Dam No. 1 on the Little Kanawha River, and Dam No. 1 on the Muskingum River. Construction of the locks was initiated in June 1963 and they were placed in operation 12 October 1965. Construction of the dam was started in September 1964 and the pool was raised to full height 1 November 1968. It is under the jurisdiction of the Huntington District.

Belleville L&D is located 203.9 river miles downstream of Pittsburgh, Pennsylvania. It is also 0.5 miles downstream of Belleville, West Virginia. The navigation locks are located on the west bank, or the Ohio side. The pool extends from the dam upstream for a distance of 42.2 miles to Willow Island L&D, located at river mile 161.7. A profile of the navigational pools of the Ohio River is presented in Figure ED 4-1 to provide orientation with other Ohio River navigation pools relative to the Belleville project.

4.10.2 Project Layout - Belleville

The Belleville project features two parallel lock chambers with a non-navigable, high-lift, gated dam. The dam includes a 189' fixed weir with a 130' open crest. A recent aerial photograph is shown in Figure ED 4-22 and a site plan/vicinity map is shown in Figure ED 4-23 to give the reader a better feel of the project's characteristics.

Figure ED 4-22. Aerial View of the Belleville Locks and Dam

Two adjacent parallel locks are located on the Ohio bank, the main lock chamber has clear dimensions of 110' x 1,200' and the auxiliary lock of 110' x 600'. The main lock is located riverward of the auxiliary lock. Filling and emptying systems are

designed to fill and empty the locks in about eight minutes for each of these operations. The lock chambers are filled or emptied through a system of gated culverts in the interior of the lock walls and sets of transverse laterals along the floors of the lock chambers. Emergency closure is made by utilizing the dam gate bay emergency bulkheads which are placed immediately upstream of the miter gates in both the main and auxiliary locks. The bulkheads can be raised and lowered under flowing conditions using the bulkhead crane from the crane bridge which extends continuously over both locks and the dam. An esplanade is along the landward lock. Other primary components of the locks are the miter gates, culvert valves, electrical system, mechanical system, miter gate sills, lock wall monoliths, lock chamber monoliths, and miter gate monoliths.

The dam is non-navigable, high lift, gated dam, top length 1,206’ including a 189’ fixed weir with a 130’ open crest. It consists of 8 tainter gates with each gate having a clear span of 110’ between piers, a damming height of 32’ above the sills, and a clearance above the maximum high water level of approximately 5’ when fully raised.

Normal upper pool is elevation 582.0 mean sea level and the normal upper pool surface area is 8,900 acres. Normal lower pool is elevation 560.0 mean sea level. The lift at normal pool levels is 22’.

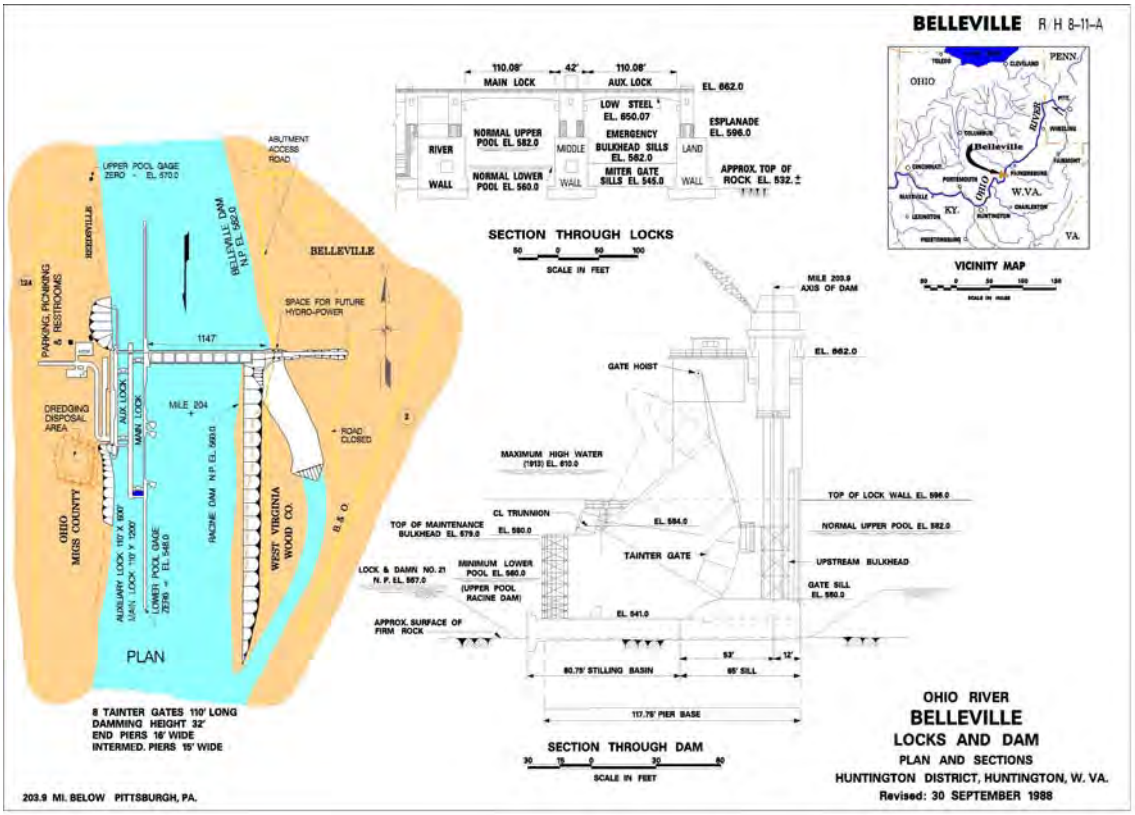


Figure ED 4-23. Plan View and Vicinity Map of the Belleville L&D Project

4.10.3 Assessment of Concerns and Needs - Belleville

There has not been any major deterioration or any significant deficiencies noted

during recent inspections. These inspections did not include a thorough cleaning to remove all debris from miter gates prior to inspection. Inspections identified minor spalling of concrete along lock walls, leakage around the miter gates, and minor leakage of miter gate machinery. None of these deficiencies present apparent structural or operational concerns.

4.11 RACINE LOCKS AND DAM

4.11.1 Project Information - Racine

Racine Locks and Dam (L&D) was authorized by the Secretary of the Army under the authority of the River and Harbor Act approved 3 March 1909, as a replacement for Ohio River Locks and Dams Nos. 21, 22, and 23. Construction of the locks was initiated in April 1965 and they were placed in operation 16 December 1967. Construction of the dam was started in August 1967 and the pool was raised to full height 24 August 1971. It is under the jurisdiction of the Huntington District.

Racine L&D is located 237.5 river miles downstream of Pittsburgh, Pennsylvania. It is also about 1.5 miles downstream of Letart Falls, Ohio. The navigation locks are located on the Northwest bank, or the West Virginia side. The pool extends from the dam upstream for a distance of 33.6 miles to Belleville Dam located at river mile 203.9. A profile of the navigational pools of the Ohio River is presented in Figure ED 4-1 to provide orientation with other Ohio River navigation pools relative to the Racine project.

4.11.2 Project Layout - Racine

The Racine project features two parallel lock chambers with a non-navigable, high-lift, gated dam. Instead of the typical fixed weir adjacent to the dam, Racine has a hydroelectric plant operated by the American Electric Power Company. A recent aerial photograph is shown in Figure ED 4-24 and a site plan/vicinity map is shown in Figure ED 4-25 to give the reader a better feel of the project's characteristics.

Figure ED 4-24. Aerial View of the Racine Locks and Dam

Two adjacent parallel locks are located on the West Virginia bank, the main lock chamber has clear dimensions of 110’ x 1,200’ and the auxiliary lock of 110’ x 600’. The main lock is located riverward of the auxiliary lock. Filling and emptying systems are designed to fill and empty the locks in about eight minutes for each of these operations. The main lock is filled or emptied through a system of gated culverts along the interior of the lock walls. These culverts are connected to sets of transverse laterals, with openings on the floor of the auxiliary lock chamber and port openings in the walls of the main lock chamber. Emergency closure of the locks is accomplished by two sets of vertical lift gates upstream of the upper miter gates. The downstream leaf of each emergency gate can be raised in flowing water. An esplanade is along the landward lock. Other primary components of the locks are the miter gates, culvert valves, electrical system, mechanical system, miter gate sills, lock wall monoliths, lock chamber monoliths, and miter gate monoliths.

The dam is non-navigable, high lift, gated dam, top length 1,160’ including the hydroelectric turbine building. It consists of 8 tainter gates with each gate having a clear span of 110’ between piers, a damming height of 32’ above the sills, and a clearance above the maximum high water level of approximately 5’ when fully raised.

Normal upper pool is elevation 560.0 mean sea level and the normal upper pool surface area is 5,300 acres. Normal lower pool is elevation 538.0 mean sea level. The lift at normal pool levels is 22’.

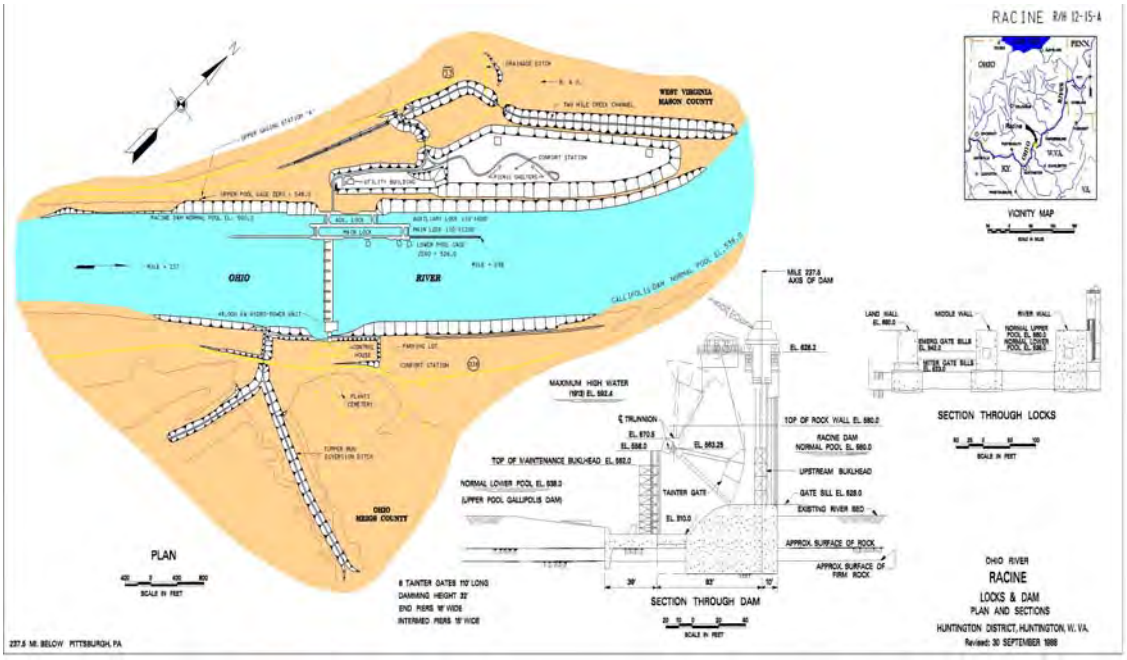


Figure ED 4-25. Plan View and Vicinity Map of the Racine L&D Project

4.11.3 Assessment of Concerns and Needs - Racine

There has not been any major deterioration or any significant deficiencies noted during recent inspections. These inspections did not include a thorough cleaning to remove all debris from miter gates prior to inspection. Inspections identified minor spalling of concrete along lock walls, significant leakage around the miter gates, and minor leakage of miter gate machinery. None of these deficiencies present apparent structural or operational concerns.

4.12 ROBERT C. BYRD LOCKS AND DAM

4.12.1 Project Information – Robert C. Byrd

Robert C. Byrd Locks and Dam was authorized by the Secretary of the Army under the authority of the River and Harbor Act approved 30 August 1935, as a replacement for Ohio River Locks and Dams Nos. 24, 25, and 26 on the Ohio River and Locks and Dams Nos. 9, 10, and 11 on the Kanawha River. The original Gallipolis locks were placed in operation on 25 August 1937. Construction of the dam was started in January 1935 and the dam was placed into operation in August 1937. Replacement of the original Gallipolis locks and rehabilitation of the original dam was authorized in the Supplemental Appropriation Act of 1985 and the Water Resources Development Act of 1986. Construction of the new Robert C. Byrd locks was started in October 1987 and completed in January 1993. It is under the jurisdiction of the Huntington District.

Robert C. Byrd L&D is located 279.2 river miles downstream of Pittsburgh, Pennsylvania. It is also 9.0 miles downstream of the City of Gallipolis, Ohio. The new navigation locks are located on the East bank, or the West Virginia side. The pool extends from the dam upstream for a distance of 41.7 miles to Racine Dam located at river mile 237.5 on the Ohio River and upstream for a distance of 44.6 miles to Winfield Dam located at river mile 31.1 on the Kanawha River. A profile of the navigational pools of the Ohio River is presented in Figure ED 4-1 to provide orientation with other Ohio River navigation pools relative to the Robert C. Byrd project.

4.12.2 Project Layout - Robert C. Byrd

The Robert C. Byrd project features two parallel lock chambers with a non-navigable, high-lift, gated dam. A recent aerial photograph is shown in Figure ED 4-26 and a site plan/vicinity map is shown in Figure ED 4-27 to give the reader a better feel of the project's characteristics.

Two adjacent parallel locks are located on the West Virginia bank, the main lock chamber has clear dimensions of 110' x 1,200' and the auxiliary lock of 110' x 600'. The main lock is located riverward of the auxiliary lock. Filling and emptying systems are designed to fill and empty the locks in about eight minutes for each of these operations. Filling and emptying systems are designed to fill and empty the locks in about eight minutes for each of these operations. The main lock is filled or emptied through longitudinal culverts in both walls; the auxiliary locks' culverts are in the land wall only. Flow is then distributed in both locks using ports along the monoliths. Emergency gates are located immediately upstream of the upstream miter gates. These gates are vertical lift gates. An esplanade is along the landward lock. Other primary components of the locks are the miter gates, culvert valves, electrical system, mechanical system, miter gate sills, lock wall monoliths, lock chamber monoliths, and miter gate monoliths.

Figure ED 4-26. Aerial View of the Robert C. Byrd Locks and Dam

The dam is non-navigable, high lift, gated dam, top length 1,132'. It consists of 8 roller gates with each gate having a clear span of 125' 6" between piers and a damming height of 29' 6"' above the sills.

Normal upper pool is elevation 538.0 mean sea level and the normal upper pool surface area is 12,600 acres. Normal lower pool is elevation 515.0 mean sea level. The lift at normal pool levels is 23'.

4.12.3 Assessment of Concerns and Needs – Robert C. Byrd

There has not been any major deterioration or any significant deficiencies noted during recent inspections. The auxiliary chamber emergency gate failed in January 1994. One of the cables on the hoist equipment failed resulting in the gate becoming wedged in a partially raised position. The lower miter gates then had to be closed through the help of two 5600 horsepower tow boats supplied by the American Electric Power Company. After the lower miter gates were closed, the emergency gate was then lowered and the failed lifting cables were repaired. No other major issues noted.

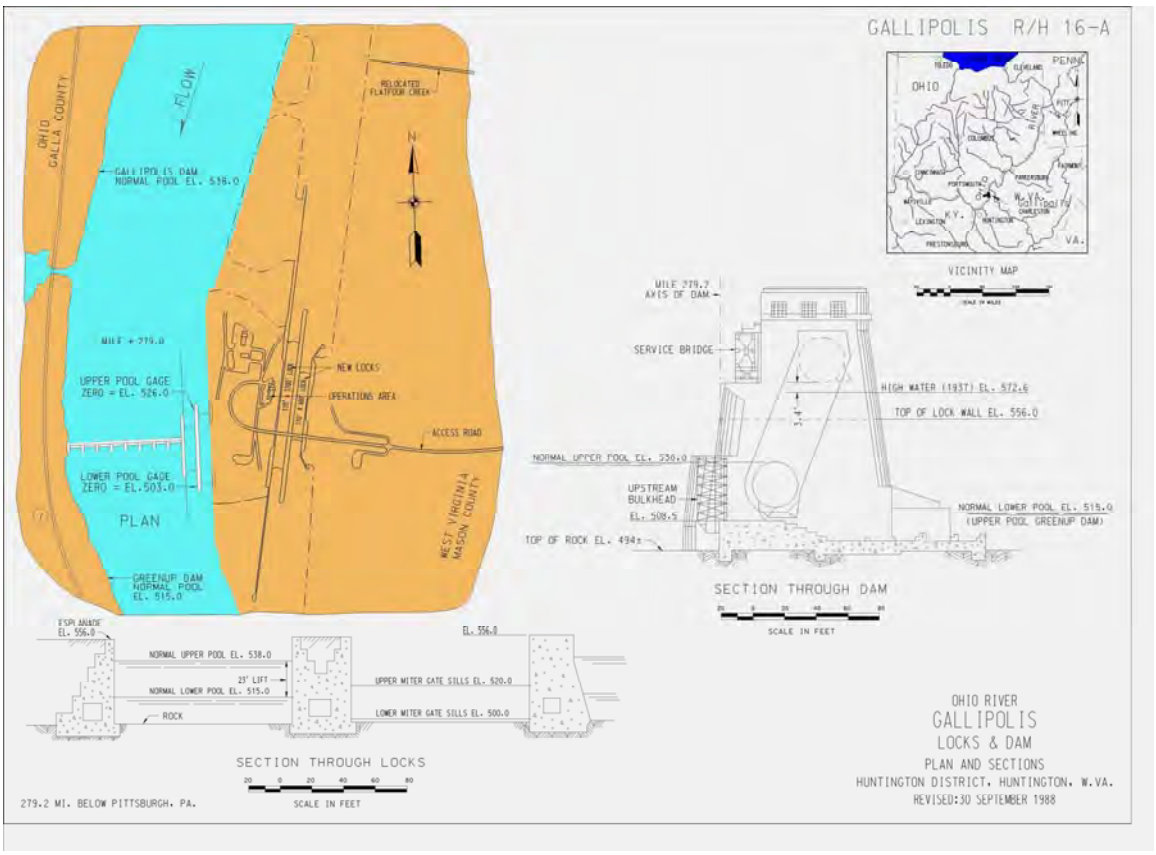


Figure ED 4-27. Plan View and Vicinity Map of the Robert C. Byrd L&D Project

4.13 GREENUP LOCKS AND DAM

4.13.1 Project Information - Greenup

Greenup Locks and Dam (L&D) was authorized by the Secretary of the Army under the authority of the River and Harbor Act approved 3 March 1909, as a replacement for Locks and Dams Nos. 27, 28, 29, and 30 on the Ohio River and Locks and Dam No. 1 on the Big Sandy River. Construction of the locks was initiated in October 1955 and they were placed in operation 27 November 1959. Construction of the dam was started in June 1958 and the pool was raised to full height 4 June 1962. It is under the jurisdiction of the Huntington District.

Greenup L&D is located 341.0 river miles downstream of Pittsburgh, Pennsylvania. It is also 5.0 miles downstream of Greenup, Kentucky. The navigation locks are located on the West bank, or the Kentucky side. The pool extends from the dam upstream for a distance of 61.8 miles to Robert C. Byrd Dam located at river mile 279.2. A profile of the navigational pools of the Ohio River is presented in Figure ED 4-1 to provide orientation with other Ohio River navigation pools relative to the Greenup project.

4.13.2 Project Layout - Greenup

The Greenup project features two parallel lock chambers with a non-navigable, high-lift, gated dam. The dam includes a 245' fixed weir with a 223' open crest. In addition to the fixed weir adjacent to the dam, Greenup has a hydroelectric plant operated by the City of Vanceburg, Kentucky. A recent aerial photograph is shown in Figure ED 4-28 and a site plan/vicinity map is shown in Figure ED 4-29 to give the reader a better feel of the project's characteristics.

Figure ED 4-28. Aerial View of the Greenup Locks and Dam

Two adjacent parallel locks are located on the Kentucky bank, the main lock chamber has clear dimensions of 110' x 1,200' and the auxiliary lock of 110' x 600'. The main lock is located riverward of the auxiliary lock. Filling and emptying systems are designed to fill and empty the locks in about eight minutes for each of these operations. The main lock is filled or emptied through a system of gated culverts located in the lock walls. These culverts are connected to sets of transverse laterals across the floor of the lock chambers. Emergency closure of the locks is accomplished by two sets of vertical lift gates upstream of the upper miter gates. An esplanade is along the landward lock. Other primary components of the locks are the miter gates, culvert valves, electrical system, mechanical system, miter gate sills, lock wall monoliths, lock chamber monoliths, and miter gate monoliths.

The dam is non-navigable, high lift, gated dam, top length 1,287' including a 245' fixed weir with a 223' open crest. It consists of 9 tainter gates with each gate having a clear span of 100' between piers, a damming height of 35' above the sills, and a clearance above the maximum high water level of approximately 5' when fully raised. There are two types of gates within the dam, submergible and non-submergible ogee sill units.

Normal upper pool is elevation 515.0 mean sea level and the normal upper pool surface area is 11,200 acres. Normal lower pool is elevation 485.0 mean sea level. The lift at normal pool levels is 30'.

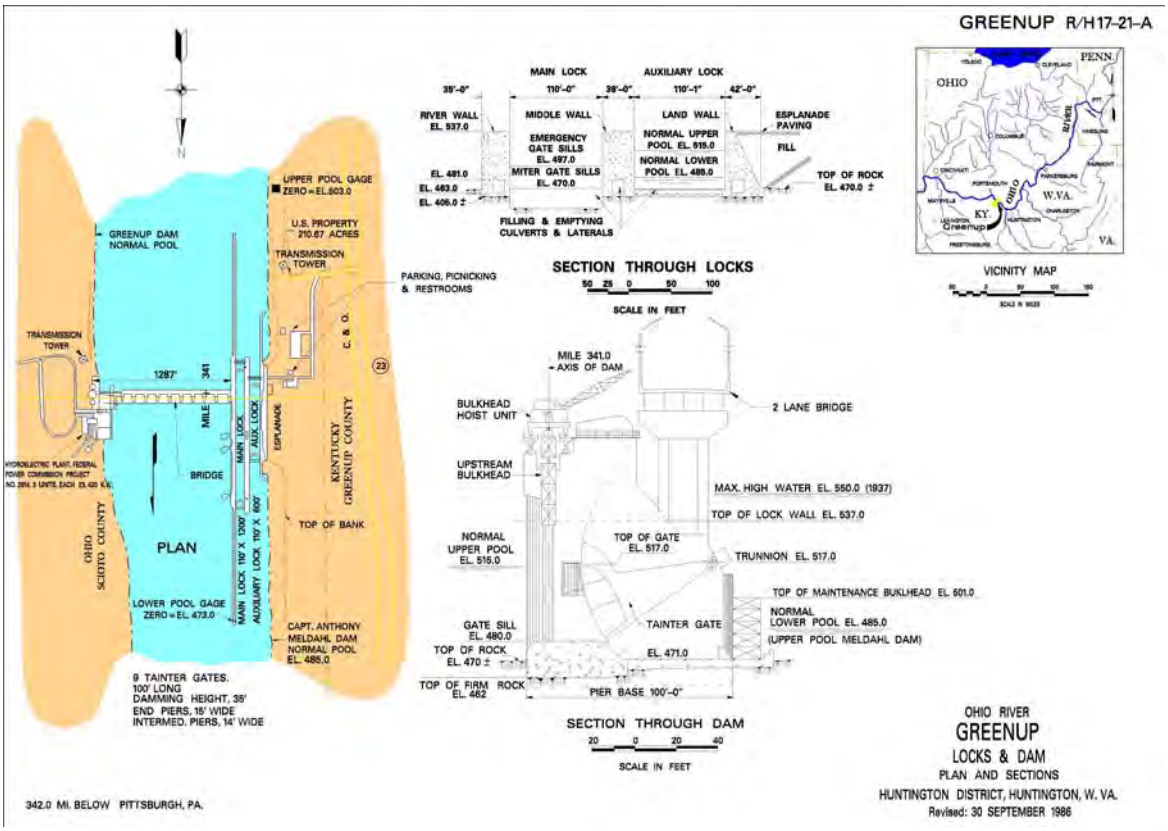


Figure ED 4-29. Plan View and Vicinity Map of the Greenup L&D Project

4.13.3 Assessment of Concerns and Needs - Greenup

There are a couple of major concerns associated with the Greenup Project. First, inadequate auxiliary lock chamber capacity is an issue that is being addressed through the Greenup Lock Extension Project, which was authorized as part of WRDA 2000. When completed, this project will have twin 1200-ft lock chambers which essentially eliminates the concerns regarding insufficient auxiliary chamber capacity. This is of primary importance when the existing main chamber is closed for maintenance, emergency, or other requirements. The Greenup Lock Extension Project was authorized as part of an interim report on the ORMSS and also included a capacity improvement project at J.T. Myers Locks and Dam in the Louisville District. Refer to the J.T. Myers section of this engineering appendix for more detail associated with that project. The capacity improvements at Greenup included extending the existing auxiliary chamber by a nominal 600 feet, providing a new supplemental filling and emptying system for the extended lock chamber, extensions to the existing approach walls, approach mooring cells for improved transit, and new gates/operating machinery for the extended auxiliary lock chamber. The Greenup Lock Extension Project is currently in design. The "on-line"

date for both Greenup and J.T. Myers capacity improvements was assumed to be 2010 at the time of the authorization.

Another major concern specific to Greenup is the condition of the miter gates in the existing main chamber. During 2003, an extended maintenance closure was required to make emergency repairs to the heavily cracked miter gates. While the repairs were extensive, they are essentially temporary since these gates have reached the end of the service life. As a part of the overall Greenup Lock Extension Project, a major rehabilitation of the existing main chamber is included to replace damaged components, most notably the miter gates.

4.14 MELDAHL LOCKS AND DAM

4.14.1 Project Information - Meldahl

Meldahl Locks and Dam (L&D) was authorized by the Secretary of the Army under the authority of the River and Harbor Act approved 3 March 1909, as a replacement for Ohio River Locks and Dams Nos. 31, 32, 33, and 34. Construction of the locks was initiated in March 1959 and they were placed in operation in November 1962. Construction of the dam was started in April 1961 and the pool was raised to full height 31 March 1965. It is under the jurisdiction of the Huntington District.

Meldahl L&D is located 436.2 river miles downstream of Pittsburgh, Pennsylvania. It is also 1.7 miles downstream of Chilo, Ohio. The navigation locks are located on the North bank, or the Ohio side. The pool extends from the dam upstream for a distance of 95.2 miles to the Greenup Dam, located at river mile 341.0. A profile of the navigational pools of the Ohio River is presented in Figure ED 4-1 to provide orientation with other Ohio River navigation pools relative to the Meldahl project.

4.14.2 Project Layout - Meldahl

The Meldahl project features two parallel lock chambers with a non-navigable, high-lift, gated dam. The dam includes a 372’ fixed weir with a 310’ open crest. A recent aerial photograph is shown in Figure ED 4-30 and a site plan/vicinity map is shown in Figure ED 4-31 to give the reader a better feel of the project’s characteristics.

Two adjacent parallel locks are located on the Ohio bank, the main lock chamber has clear dimensions of 110’ x 1,200’ and the auxiliary lock of 110’ x 600’. The main lock is located riverward of the auxiliary lock. Filling and emptying systems are designed to fill and empty the locks in about eight minutes for each of these operations. The lock chambers are filled and emptied through a system of gated culverts in the interior of the lock walls. These culverts are connected to sets of transverse laterals, with openings on the floor of the lock chambers between the lock walls. Emergency closure of the locks is accomplished by sets of vertical lift gates upstream of the upper miter gates. The downstream leaf of each emergency gate can be raised in flowing water. An esplanade is along the landward lock. Other primary components of the locks are the miter gates, culvert valves, electrical system, mechanical system, miter gate sills, lock wall monoliths, lock chamber monoliths, and miter gate monoliths.

Figure ED 4-30. Aerial View of the Meldahl Locks and Dam

The dam is non-navigable, high lift, gated dam, top length 1,756' including a 372' fixed weir with a 310' open crest. It consists of 12 tainter gates with each gate having a clear span of 100' between piers, a damming height of 35' above the sills, and a clearance above the maximum high water level of approximately 5' when fully raised. There are two types of gates at the dam, submergible and non-submergible ogee sill units.

Normal upper pool is elevation 485.0 mean sea level and the normal upper pool surface area is 21,700 acres. Normal lower pool is elevation 455.0 mean sea level. The lift at normal pool levels is 30'.

4.14.3 Assessment of Concerns and Needs - Meldahl

Significant deterioration was noted during an inspection of the auxiliary lock chamber in 2002. The most extensive deterioration was noted on the lower girders of the downstream miter gate (G-10 and G-11) and included corrosion that had reduced members from an original thickness of 7/16" down to a thickness range of 0" (complete voids in girder web material) to 1/8" in several locations (see Figure ED 4-32). The cause of the accelerated deterioration in these locations was corrosion from excessive debris build-up inside the girder webs (see Figure ED 4-33). The Huntington District Maintenance Repair Fleet conducted emergency repairs to prevent further deterioration and catastrophic failure of the miter gate. These emergency repairs are only a temporary fix for the problem. There are no spare miter gates for this project and design and fabrication of new gates could take up to 18-24 months.

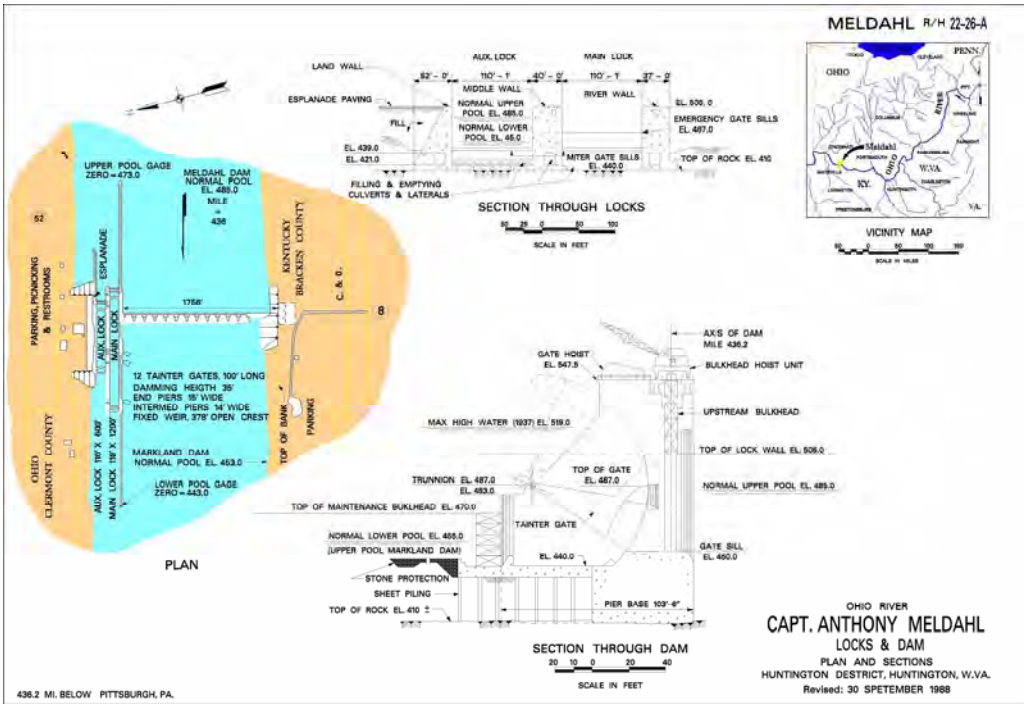


Figure ED 4-31. Plan View and Vicinity Map of the Meldahl L&D Project

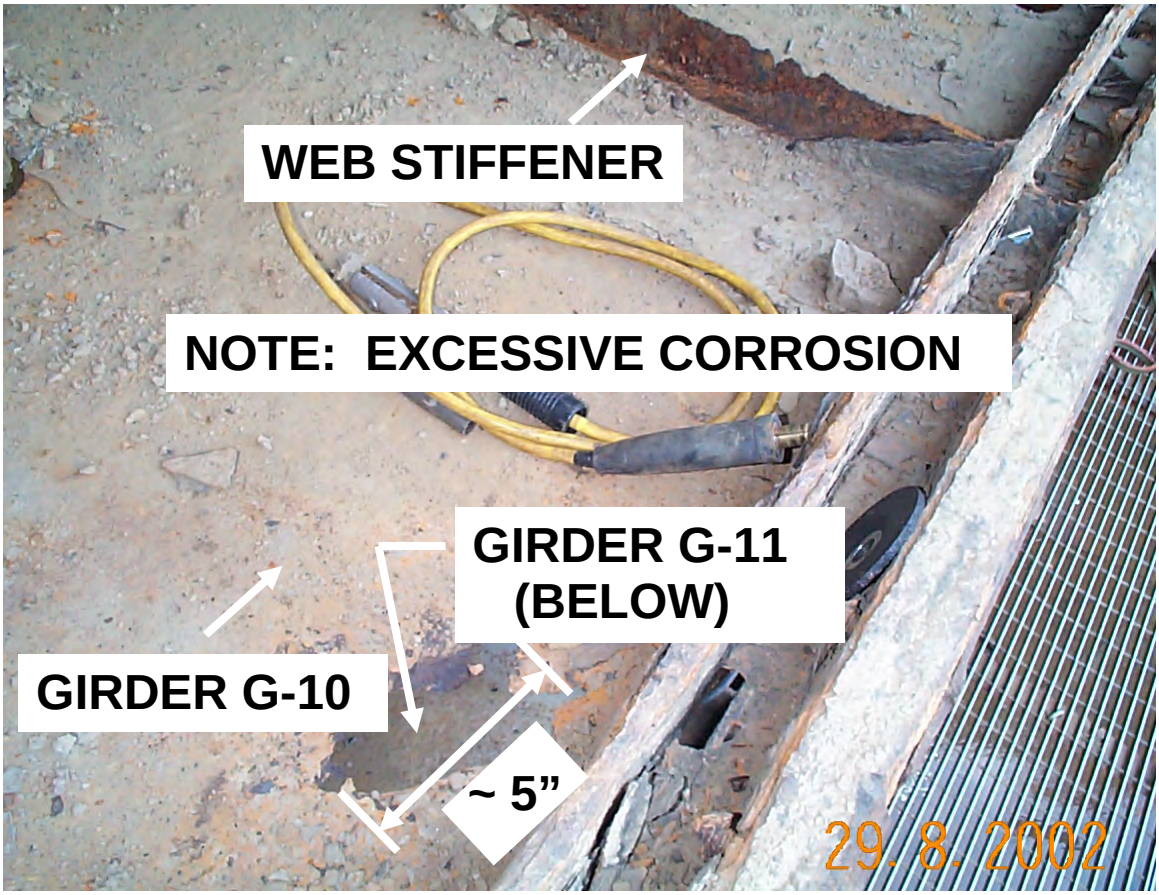


Figure ED 4-32. Corrosion Damage of the Downstream Aux. Miter Gate

This accelerated corrosion due to debris build-up is also a significant possibility on other Ohio River locks and dams that may not be identified during Periodic Inspections. During the initial inspection conducted at Meldahl after dewatering the auxiliary chamber in August 2003, no significant deterioration of any of the miter gates was noted. This inspection was conducted prior to the gates being thoroughly cleaned and then sand-blasted in apparent trouble locations. Following the thorough cleaning, the corrosion noted above was discovered. This would indicate that unless thorough cleaning is done prior to inspections on other projects, this same corrosion may go unidentified. Additionally, added Operations and Maintenance resources would enhance preventive maintenance by conducting a thorough cleaning annually thus possibly reducing corrosion.

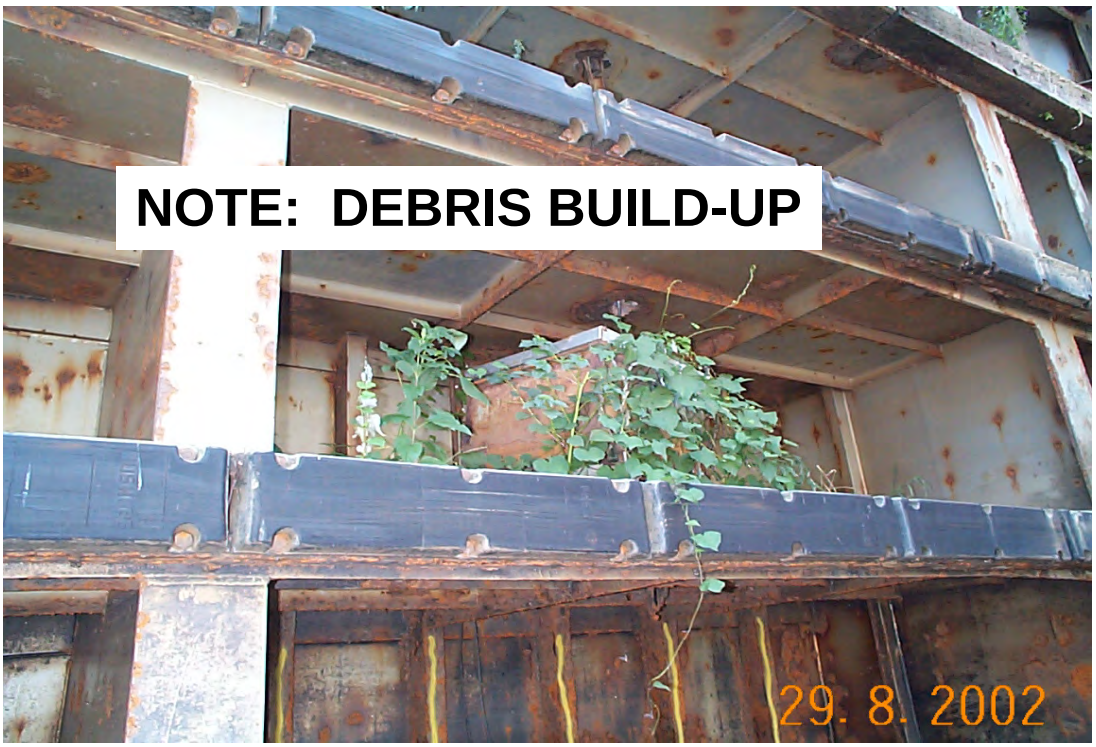


Figure ED 4-33. Excess Debris on Downstream Auxiliary Miter Gate

4.15 MARKLAND LOCKS AND DAM

4.15.1 General Background Information - Markland

Markland Locks and Dam (L&D) was authorized by the Secretary of the Army on 11 March 1953 under the authority of Section 6 of the River and Harbor Act approved 3 March 1909, as replacement for Ohio River Locks and Dams No. 35, 36, 37, 38 and 39. Construction of the locks was completed in 1956 with lockage beginning in 1958 during construction of the dam. Construction of the dam was completed in 1964. It is under the jurisdiction of the Louisville District. Markland L&D is located 531.5 river miles downstream of Pittsburgh, Pennsylvania, which is also 26.5 miles upstream of Madison, Indiana and 3.5 miles downstream of Warsaw, Kentucky. The navigation locks are located on the left bank, or the Kentucky side, of the river. The pool extends from the dam upstream for a distance of 95.3 miles to the Captain Anthony Meldahl L&D, river mile 436.0. The port of Cincinnati lies within Markland's pool, which extends short distances on three navigable tributaries – the Great Miami, Little Miami and Licking Rivers and borders portions of Kentucky, Indiana and Ohio. A profile of the navigational pools of the Ohio River is presented in Figure 4-1 to provide orientation with other Ohio River navigation Pools relative to the Markland project. Markland is a post-World War II lock which replaced the low-lift Ohio River Locks and Dams No. 35,36,37,38 and 39.

4.15.2 Project Layout - Markland

The Markland project features two lock chambers with a non-navigable, gated dam. Instead of the typical fixed weir adjacent to the dam, Markland has a small hydroelectric plant operated by an independent entity. A recent aerial photograph is shown in Figure ED 4-34 and a site plan/vicinity map is shown in Figure ED 4-35. A basic description of each main feature is provided below.

Two adjacent parallel locks are located on the Kentucky bank, the main lock chamber has clear dimensions of 110' x 1,200' and the auxiliary lock 110' x 600'. The main lock is located riverward of the auxiliary lock. Filling and emptying systems are designed to fill and empty the locks in about eight minutes for each of these operations. The main lock is filled or emptied through longitudinal culverts in both walls; the auxiliary lock's culverts are in the land wall only. A lateral system in the lock chambers extends from the culverts across the lock floors to distribute flows and reduce turbulence. Emergency gates are located immediately upstream of the upper miter gates of each chamber. These are double-leafed submergible gates that are electrically operated. An esplanade is along the landward lock. Other primary components of the locks are the miter gates, culvert valves, electrical system, mechanical system, miter gate sill, lock wall monolith, lock chamber monolith, and miter gate monolith.

Figure ED 4-34. Aerial Photograph of Markland Locks and Dam

The dam is non-navigable gated-crest structure, 1,395 feet long. It consists of a low concrete weir with 12 tainter gates supported by concrete piers. Each gate is 100' long and 42' high, with an operating radius of 64'. In 1977, the five submergible gates were converted to non-submergible, making all 12 gates non-submergible. Normal upper

pool is elevation 455.0 mean sea level. Normal lower pool is elevation 420.0 mean sea level. Thus, the lift is 35 feet at normal pool levels.

A bridge crossing the Ohio River, utilizing the Markland Dam as its foundation, was completed in August 1978. The bridge connects Indiana State Highway 156 in Switzerland County, Indiana and U.S. Highway 42 in Gallatin County, Kentucky. The nearest other bridges which cross the Ohio River are the I-275 and U.S. 421 bridges, about 40 river miles upstream and about 26 river miles downstream, respectively.

The Public Service Company of Indiana, under license granted by the Federal Power Commission, completed construction of a "run-of-river" hydroelectric power plant at Markland L&D. Capacity of the plant is 81,000 kilovolt-amperes (kva)

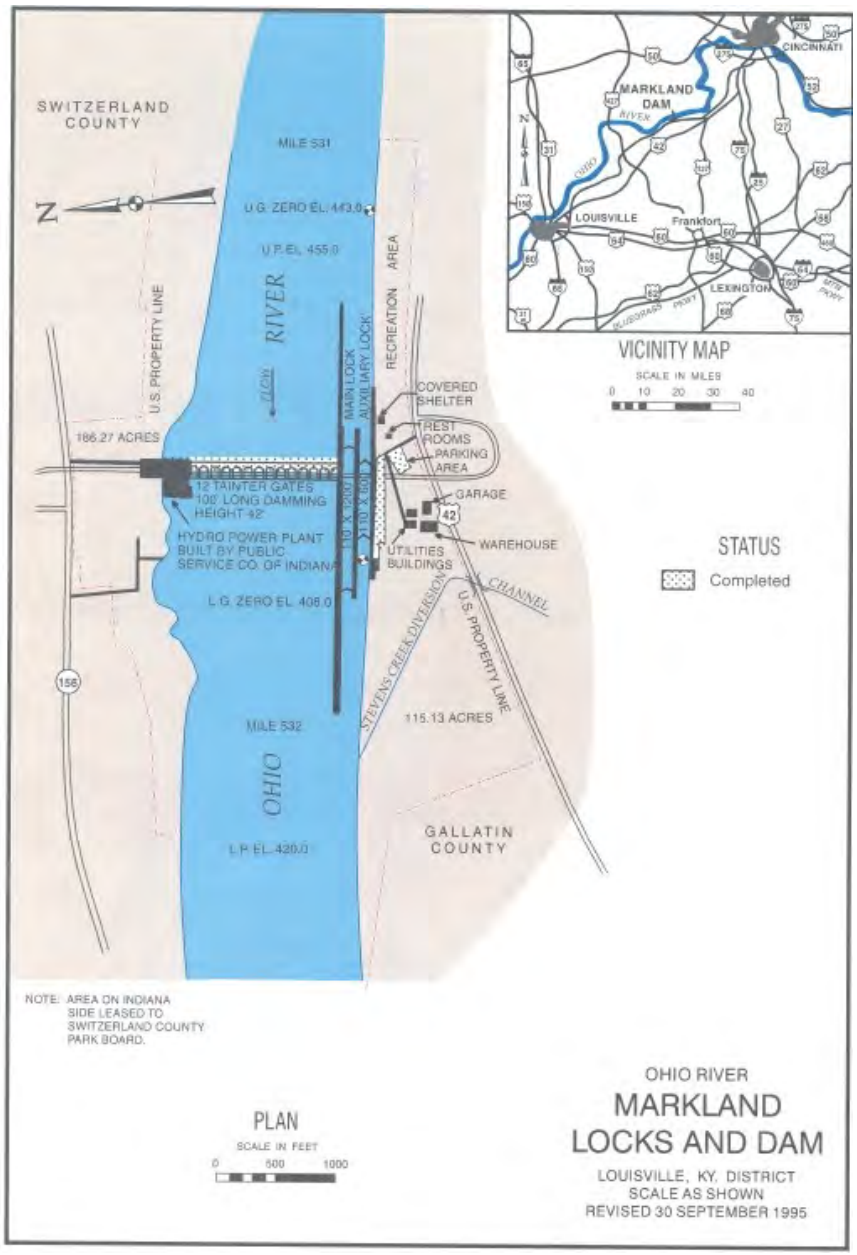


Figure ED 4-35. Project Layout of Markland Locks and Dam

4.15.3 Assessment of Concerns and Needs - Markland

Current traffic levels are near the capacity of the auxiliary chamber, which caused major delays to occur when the main chamber is closed. Unlike locks on other rivers, Ohio River locks operate throughout the entire year. The amount of traffic, and the level of service Markland L&D is called upon to provide to the towing industry, is evenly distributed throughout the year.

The major problem at Markland is the potential loss of service of the main lock due to the deteriorated condition of the existing miter gates and reverse tainter culvert valves and the subsequent impact to Ohio River Navigation. Emergency repairs to cracking and buckling of the main lock miter gates have been made several times since major fatigue damage was found during a routing 1994 maintenance dewatering. However, emergency repairs of the miter gates are only a temporary fix for the problem. Inspections following these prove that propagation of the fatigue cracking of the gates continues an increasing rate. This is also anticipated to occur on the welded reverse tainter culvert valves in the near future due to similar original construction technique and a high number of fatigue cycles. Typically, the main chambers of Louisville District locks on the Ohio River are dewatered every 5 years as part of on-going maintenance. However, the main chamber at Markland is now dewatered *every year* due to the deteriorated condition of the miter gates.

As a result of the deteriorated condition of the miter gates and limited funding through O/M sources, a Major Rehabilitation Evaluation of the Markland Project was undertaken in the late 1990's as a potential means to acquire new miter gates and culvert valves. The recommended plan resulting from this evaluation includes replacement of the main lock miter gates and culvert valves at the earliest possible time. This evaluation analyzed the existing and expected future reliability of the main auxiliary lock mite gates and several other essential lock components. The first cost of the recommended plan is $17.6 million, in Fiscal Year 2000 price levels. Annual costs of the recommended plan are almost $1.7 million and annual benefits are $4.3 million, giving a benefit-to-cost ratio of 2.6 and net benefits of $2.6 million. The Major Rehabilitation Report was approved at HQUSACE level in summer of 2000. However budget constraints have kept the Louisville District from receiving the necessary funds to replace the miter gates and culvert valves. Due to the inability to secure funds through Congress, the Louisville District is seriously concerned about the potential for a catastrophic failure of the miter gates and thus, has gone to dewatering the Markland main chamber every year until the miter gates and culvert valves can be replaced. This inability to secure funds is costing both USACE and the navigation industry millions of dollars due to the low reliability of these structures.

4.16 McALPINE LOCKS AND DAM

4.16.1 General Background Information - McAlpine

The McAlpine Locks and Dam project is located on the Ohio River at Mile 604.5 below Pittsburgh, Pennsylvania, at Louisville, Kentucky. The navigation locks are located on the left bank or Kentucky side of the river at Mile 606.8 and the upper pool

extends approximately 75 miles to the Markland Locks and Dam. The Secretary of the Army approved the project on November 8, 1955, under authority of Section 6 of the Rivers and Harbors Act approved March 3, 1909. It is under the jurisdiction of the Louisville. Refer to Figure ED 4-1 to see where the McAlpine project is located relative to other Ohio River navigation projects.

The Falls of the Ohio at Louisville consists of a rock reef, which extends across the river and forms rapids about 3 miles long. Prior to canalization, the Ohio River dropped 26 feet through the falls and navigation was impossible except at high water stages. The first navigation improvement was a 1.9 mile long canal and a three-flight lock built by a private stock company, which opened on 22 December 1830. By 1854, the United States had acquired practically all stock in the company and from 1868 to 1872, carried out a project of widening the 64-foot canal and replacing the 50-foot wide lock with a lager two-flight lock. In June 1874, the Corps of Engineers assumed supervision of navigation in the canal and in 1909, a movable weir dam was built to provide a minimum channel depth of 9 feet form Louisville to Madison, Indiana. Further improvements were made from 1911 to 1930 with the existing 110' x 600' lock completed ion 1921. The old two-flight lock was replaced in 1930 by a single lift 56' x 360' lock. Between 1925 and 1927, a movable weir dam with a navigable pass was built in conjunction with a hydroelectric power project of the Louisville Gas and Electric Company. This dam provided a 9-foot minimum channel depth from Louisville to Markland, Kentucky. Construction of the existing 110' x 1,200' main lock and the widening of the canal from 200' to 500' were completed in 1961. A major portion of the dam, the non-navigable fixed weir, and gate-controlled structures were constructed from 1961 to 1964. Reconstruction of the 600- foot intermediate lock and the 360-foot auxiliary lock was accomplished from 1963 to 1965.

The McAlpine replacement project was authorized by the water resources development act of 1990 to replace the dilapidated 360' and 600' lock chambers with a new 1200' lock chamber. Construction of the temporary cofferdam and demolition of the existing smaller lock chambers (360' and 600') began in the year 2000. Prior to these construction activities, the 600' chamber was only used as an emergency backup to the existing main chamber due to its poor condition. Figure ED 4-36 depicts the project at the start of the cofferdam construction process. Figure ED 4-37 shows an artists rendering of the completed project that is currently scheduled for completion in 2007.

4.16.2 Project Layout - McAlpine

The project is a high lift, gate controlled structure with and upper and lower gated site separated by a 1-1/2 mile long upstream-downstream concrete fixed weir along the upper edge of the former "Falls of the Ohio;" three adjacent parallel navigational locks located at the lower end of the Louisville and Portland Canal; a hydroelectric power plant located between the right downstream end of Shippingport Island and the lower gated structure and Shippingport Island itself. A site plan/vicinity map is shown in Figure ED 4-38 and a basic description of each main feature is provided below.

The dam consists of two non-navigational gated-crest type structures separated by a concrete fixed weir extending longitudinally with the river for about 1-1/2 miles. The lower gated section and powerhouse are separated from the locks by high ground (Shippingport Island), which forms a surge basin for the lock approach canal. The lower

Figure ED 4-36. Aerial Photograph of McAlpine Locks Prior to Replacement Project

gated section is separated form the powerhouse by a 70-foot section of concrete fixed weir and consists of four 100 feet long by 22 feet high tainter gates supported by concrete piers. These gates were originally of the submergible type but have been changed to the non-submergible type by converting the sills to ogee sections. The total length of the lower gated site is about 450 feet. The powerhouse is owned and operated by the Louisville Gas and Electric Company. The concrete fixed weir section between the lower and upper-gated structures is about 6,630 feet in length. It consists of fixed weir and pier sections, with the crest rising from elevation 422 at the lower end to elevation 423 at the cross-river leg or upper end. The upper-gated section consists of five non-submergible tainter gates 110 feet long by 22 feet high supported by concrete piers. The total length of the upper-gated site is about 560 feet. The concrete fixed weir section to the right of the upper-gated structure extends some 980 feet to the right-bank or Indiana side of the river. Each gated section with its tainter gates is of sufficient height to permit the raising of each gate 5 feet above maximum high water. These sections also have gate sills, a

crane bridge, and individual hoisting equipment for each gate. A set of three upstream bulkhead sections, sufficient for closing off one gate bay, is provided for each gated section.

Figure ED 4-37. Artist's Rendering of Completed McAlpine Lock Replacement

The lock chambers, and existing 110' x 1,200' chamber and new 110' x 1,200' chamber under construction, are located along the Kentucky shore on the left side of the river. The new 110' x 1,200' lock chamber is replacing an inoperable 56' x 360' and deteriorated 110' x 600' lock chamber. After completion, the project will have twin 110' x 1,200' locks with a large esplanade between the lock chambers, as shown in Figure ED 4-5. A set of hydraulically operated steel miter gates is provided for each lock. The filling and emptying system of the main lock fills or empties the lock in about 8 minutes. The existing main lock emergency gate is located immediately upstream form the upper miter gates and consists of a double-leaf vertical submergible gate, electrically operated. Provisions are also provided for maintenance bulkheads immediately downstream of each set of miter gates. Eight aluminum truss maintenance bulkheads are available throughout

the Louisville District. By use of these bulkheads, each of the culvert valves, miter gates, and the entire lock chamber are designed for dewatering to facilitate maintenance.

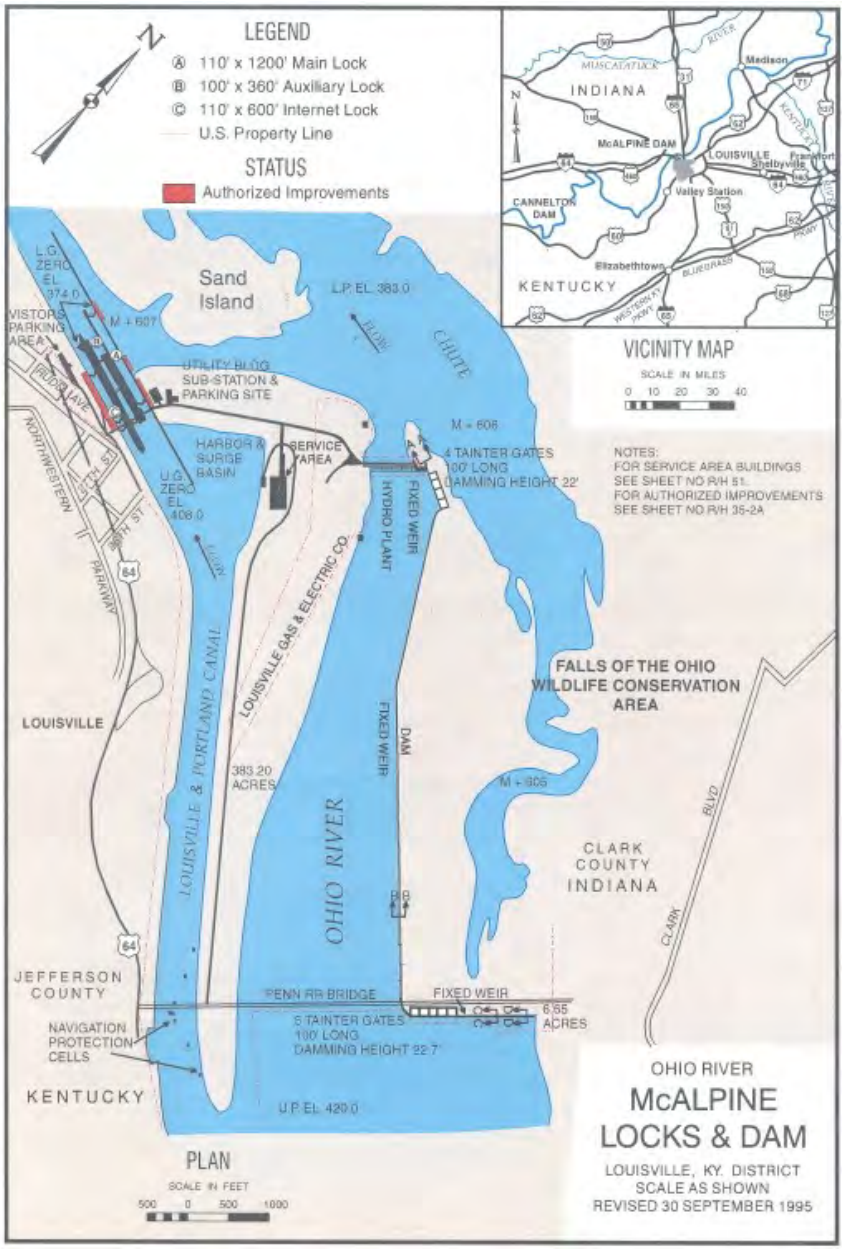


Figure ED 4-38. McAlpine Project Layout (Prior to Lock Replacement)

The Louisville and Portland Canal has a length of 2-1/7 miles including the locks and lower entrance. The width of the canal is 500 feet to the head of the locks where it widens to approximately 700 feet to include the harbor, etc. The minimum depth of the canal is 15 feet at normal pool. At the entrance to the canal are navigation protection cells upstream and downstream of the Pennsylvania Railroad Bridge with a horizontal clearance of 241.5 feet under the bridge.

Normal upper pool is at elevation 420.5 mean sea level. Normal lower pool (Cannelton Pool) is elevation 383.0 mean sea level. The lift is 37 feet at normal pool levels, which is the highest of all projects on the Ohio River.

The hydroelectric plant, owned and operated by the Louisville Gas and Electric Company, is located near the downstream end of the existing dam. The dam, together with the natural fall of some 26 feet in the riverbed at the falls, provides a maximum operating head of about 37 feet. At present, eight 13,500 horsepower units are installed with a total rated capacity of 80,320 kilowatts.

4.16.3 Assessment of Concerns And Needs - McAlpine

The McAlpine replacement project, when completed in 2007, takes care of the most critical needs of the overall project. As a part of the McAlpine replacement project a new set of miter gates, termed stand-by-gates, have been included in the event the deteriorated existing 1,200-ft chamber miter gates fail during construction of the new lock chamber, which would cause a total river shutdown. The stand-by miter gates will replace the existing 1,200' miter gates after the new chamber is operation if they are not needed during current construction. Beyond the lock replacement and replacement of the existing 1,200' chamber miter gates, the only foreseeable need will be to maintain the operating components of both 1,200' chambers. This may require individual component replacements for full-scale rehabilitation, particularly the existing 1,200' chamber that is already over 40 years old and has seen a high number of operating cycles.

4.17 CANNELTON LOCKS AND DAM

4.17.1 General Background Information - Cannelton

The Cannelton Locks and Dam project is located on the Ohio River at Mile 720.7 below Pittsburgh, Pennsylvania, 3 miles upstream from Cannelton, Indiana. The upper pool maintained above the dam extends upstream for a distance of 114 miles to the McAlpine Locks and Dam at mile 607 and for a short distance up Salt River. The navigation locks are located on the right descending bank or Indiana side of the river. It is under the jurisdiction of the Louisville District.

The project was approved as replacement of existing Locks and Dam 43, 44, and 45 on January 27, 1960, by the Secretary of Army under authority of Section 6 of the Rivers and Harbors Act approved March 3, 1909, as amended. Construction of the Cannelton Locks was started in July 1963; they were placed in operation December 1966 and completed April 1967. Up bound traffic started passing thorough the locks on 10 December 1966, while locking in both direction started in June 1970. Construction of the Cannelton Dam was started in August 1965 and was completed in 1974. As work progressed on the dam, the old outmoded upstream Locks and Dam Nos. 43, 44 and 45 were demolished and the pool progressively rose until maximum pool stage was reached. The Overlook property, consisting of 128 acres, was initially built during construction of the project. The property was excessed in 1995 to the US Fish and Wildlife to use as a wildlife habitat.

4.17.2 Project Layout - Cannelton

The project is a high lift dam with two adjacent parallel. A recent aerial photograph is shown in Figure ED 4-39 with the main lock chamber dewatered for maintenance. A site plan/vicinity map for Cannelton is shown in Figure ED 4-40. A basic description of each main project feature is provided below.

Figure ED 4-39. Aerial Photograph of Cannelton Locks and Dam

The dam consists of a non-navigable gated-crest type structure 1,395 feet long, a fixed weir section 213 feet long, and a concrete-capped sheet pile cutoff wall and dike 482 feet long terminating in natural ground on the left bank or Kentucky side of the river. There are 12 non-submergible tainter gates 100 feet long by 42 feet high supported by concrete piers. The fixed weir section is composed of concrete-capped sheet pile cells. The concrete-capped sheet pile cutoff wall extends from the end of the weir section further into the bank. The gated section of the dam is topped with a prestressed concrete service bridge and includes a crane for lifting the upstream emergency bulkheads. The two adjacent parallel lock chambers are located along the Indiana shore, the main lock chamber having clear dimensions of 110’ x 1,200’ and the auxiliary lock 110’ x 600’, with a 25-foot lift within the locks at normal pool. Two sets of hydraulically operated steel miter gates are provided for each lock. Emergency gates are located immediately upstream of the upper miter gates and are double-leaf vertical submergible electrically operated gates. Provisions for maintenance bulkheads are also provided immediately downstream of each set of miter gates. Sixteen aluminum truss maintenance bulkheads

are available throughout the Louisville District. By the use of bulkheads, each of the culvert valves, the miter gates and the entire lock chambers are designed for dewatering to facilitate maintenance. Normal upper pool is at elevation 383.0. Normal lower pool (Newburgh Pool) is elevation 358. Thus, the lift is 25 feet at normal pool levels.

4.17.3 Assessment of Concerns and Needs - Cannelton

There are several concerns and needs associated with the Cannelton project. The auxiliary chamber capacity relative to current and projected traffic levels, coupled with reduced reliability in future years, is one of the primary concerns associated with the Cannelton project. The economic issues relative to this situation is described in brief in Section 4.2 of this Engineering Appendix. The structural features of the projects are approaching 40 years of age. In addition, this project has historically been one of the higher use projects on the Ohio River due to its location on the lower river. Therefore, the long-term performance of major components such as miter gates, culvert valves, and operating machinery are of significant concern, particularly on the main chamber where historical and future projected cycles are considerable higher than the smaller, auxiliary lock chamber. In addition, many of the electrical and mechanical components are of the age that replacement components are no longer available due to improved technology. Therefore, when select mechanical and electrical components fail, sometimes the only option is completely replace the system since repair components are no longer manufactured. Full-scale probabilistic reliability modeling was carried out for the major project components on the Cannelton project for project operations through the end of the study period, assumed to be 2060 for engineering reliability modeling. During the study period, long-term reliability concerns for the miter gates, operating machinery, hydraulic system, and electrical systems will need to be addressed through individual component replacement and/or full-scale major rehabilitation for the overall project. For more detail concerning the engineering reliability analysis and subsequent economic analysis, please refer to the engineering reliability sections of the Engineering Appendix and Economics Appendix.

It should be noted that the culvert valves at Cannelton warrant special concern since one of the main chamber culvert valves failed in 1999 due to fatigue/corrosion of the welded connection at the vertical rib/horizontal girder interface. Emergency repairs were made to the valve, but the damaged valve needs to be replaced. The other valves are also the same design and warrant immediate attention. For a more detailed analysis of the culvert valve analysis, refer to the reliability section of this appendix.

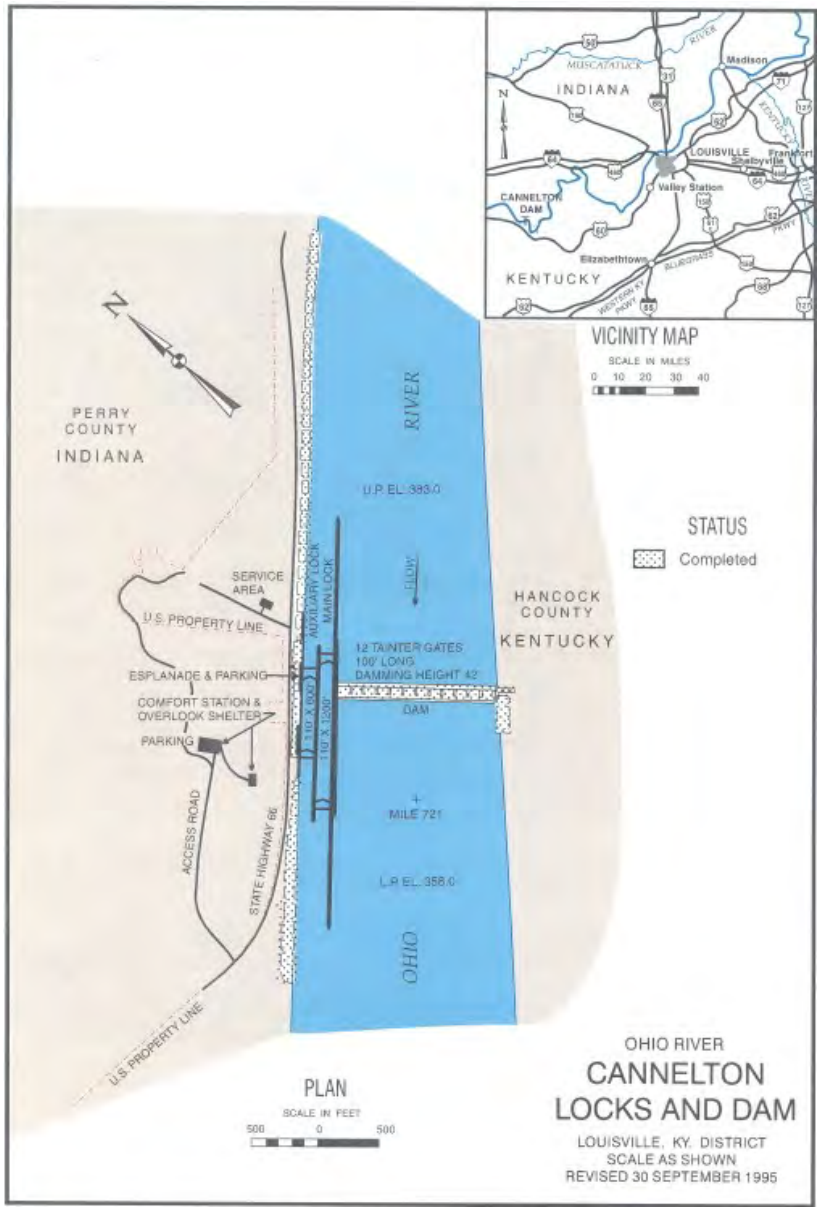


Figure ED 4-40. Cannelton Locks and Dam Project Layout

There is another major concern associated with the Cannelton project. It is the stability of the dam under seismic loading. The Cannelton project is situated in southwest Indiana, which is influenced by both the Wabash fault zone, as well as the New Madrid fault zone. During a recent investigation of the stability of the Cannelton dam on another project evaluating a potential dam retrofit for hydropower, it was determined that select dam sections at Cannelton do not meet current day deep-seated sliding stability criteria under seismic loadings. Therefore, the Louisville District is planning on initiating a Dam Safety Assurance Report to retrofit the dam with rock anchors at Cannelton to meet current day stability criteria. This was not investigated as part of the ORMSS because the engineering team did not look at extreme loading events

such as earthquakes and floods as per HQUSACE guidance. However, it is important to note from an overall project perspective that this issue is being addressed at Cannelton.

4.18 NEWBURGH LOCKS AND DAM

4.18.1 General Background Information - Newburgh

The Newburgh Locks and Dam are located on the Ohio River near Newburgh, Indiana, at mile 776.1 below Pittsburgh, Pennsylvania. It is about 16 miles upstream from Evansville, Indiana. The navigation locks are located on the right descending bank or Indiana side of the river. The upper pool maintained above the dam extends upstream for a distance of 55.4 miles to the Cannelton Locks and Dam at mile 720.7. Newburgh Locks and Dam was authorized as a replacement for existing Locks and Dams 46 and 47 on April 24, 1962, by Secretary of the Army under authority of Section 6 of the Rivers and Harbors Act approved March 3, 1909. Construction or the Newburgh Locks began in June 1966 and were placed in operation in December 1969. Dam construction began in June 1970 and the pool was raised to final level with the dam completion in 1975. The most significant change was an addition of a centralized control station on top of the lock operations building in 1980. Lock operators do a major portion of the lock and dam operations from the central control station. The lock operators can view eleven miles of river from the top of the building. The Newburgh project is essentially a replica of the John T. Myers project, which is the next lock project downstream, with site-specific changes for dam configuration.

4.18.2 Project Layout - Newburgh

The project is a high lift dam with two adjacent parallel locks, which is similar to the majority of other Ohio River navigation projects. A recent aerial photograph is shown in Figure ED 4-41 and a site plan/vicinity map is shown in Figure ED 4-42.

The dam consists of a non-navigable, gated-crest type structure 1,152.5 feet long and a fixed-weir navigable section 236 feet long terminating within natural ground on the left bank, or Kentucky side of the river. There are nine tainter gates 110 feet wide by 32 feet in height supported by concrete piers. The fixed-weir section is composed of a 13-foot high concrete crest structure over concrete-capped sheet pile cells. A concrete-capped sheet pile cutoff wall extends from the end of the weir section further into the bank. The gated section of the dam, including the upstream section of the locks, is topped with a prestressed concrete service bridge and includes a crane for positioning the upstream emergency bulkheads.

Figure ED 4-41. Aerial Photograph of Newburgh Locks and Dam

The two adjacent parallel lock chambers are located along the Indiana shore. The main lock chamber has clear dimensions of 110 feet by 1,200 feet and the auxiliary lock has clear dimensions of 110 feet by 600 feet. Normal upper pool is at elevation 358.0. Normal lower pool (John T. Myers Pool) is elevation 342.0. Thus, the lift is 16 feet at normal pool levels, which makes it the smallest lift of the Louisville District locks on the Ohio River. Two sets of hydraulically operated steel miter gates are provided for each lock. Each lock has provisions immediately upstream of the upper miter gates for the placement of open truss emergency bulkheads. Provisions for maintenance bulkheads are also provided immediately downstream of each set of miter gates. Aluminum truss maintenance bulkheads are available for dewatering and can be used at Newburgh. By use of bulkheads, each of the culvert valves, miter gates and the entire lock chamber are designed for dewatering to facilitate maintenance. When the lock is closed due to high water, navigation may pass by the structure over the fixed weir between the gated section and the left bank, although this is a rare occurrence.

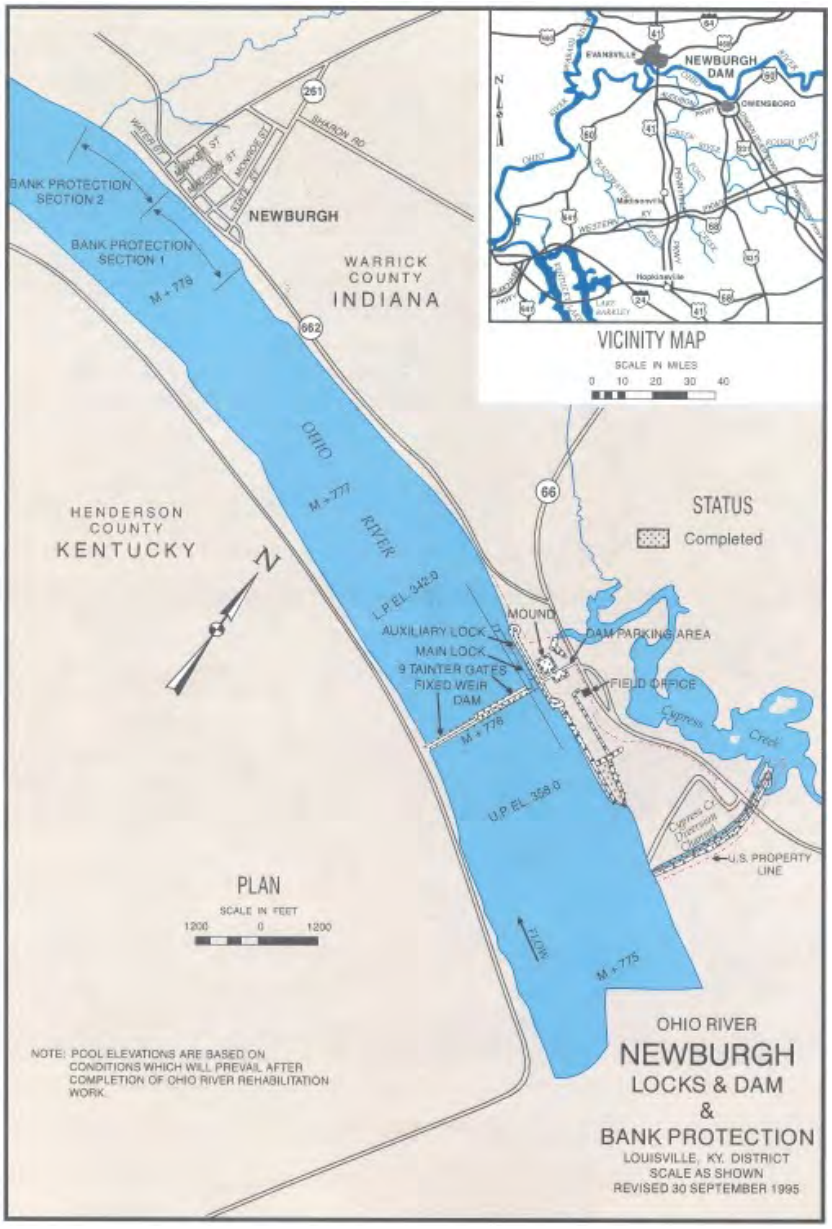


Figure ED 4-42. Project Layout for Newburgh Locks and Dam

4.18.3 Assessment of Concerns and Needs - Newburgh

The major concern associated with the Newburgh project is similar to many of the other Ohio River projects, decreasing reliability of major features coupled with reduced auxiliary lock chamber capacity (as described in Section 4.2 of this appendix). The major navigation components associated with project are approaching 40 years of service with a high historic level of traffic. The main chamber availability is even more of a concern at Newburgh because it represents one of the highest traffic level projects on the Ohio River where the auxiliary lock chamber is not authorized for a 600-ft extension (since the John T. Myers and Greenup auxiliary lock chambers were authorized for extensions as part of the Water Resources Development Act of 2000). Reduced reliability of the main lock

chamber operating components during the study period was determined through the analytical engineering reliability modeling. Refer to that portion of this appendix for a detailed description of the engineering reliability analysis at Newburgh. The economic effects of reduced future reliability is detailed in the Economics Appendix. This is the major contributor when assessing the need for other improvements at Newburgh, such as auxiliary lock extensions similar to those authorized at John T. Myers and Greenup Locks and Dams.

4.19 JOHN T. MYERS LOCKS AND DAM

4.19.1 General Background Information - John T. Myers

John T. Myers Locks and Dam (J.T. Myers), formerly Uniontown Locks and Dam, was renamed on October 12, 1996, by direction of Public Law 104-303. The project is located on the Ohio River about 3½ miles downstream from Uniontown, Kentucky, at mile 845.9 below Pittsburgh, Pennsylvania. The navigation locks are located on the right bank or Indiana side of the river. The upper pool maintained above the dam extends upstream for a distance of 69.9 miles to the Newburgh Locks and Dam at Mile 776.1. The project was authorized as replacement for existing Locks and Dam 48 and 49 on September 17,1958, by Secretary of the Army under authority of Section 6 of the Rivers and Harbors Act approved March 3, 1909, as amended. Construction of Uniontown Locks started in June 1965 and were completed and placed in operation in December 1969. Dam construction started in May 1970, pool raised to final level in January 1975, and completed in 1977. It is essentially a replica of the Newburgh Locks and Dam, the adjacent project upstream of John T. Myers, with modifications to the dam as necessary with respect to fixed weir configuration and dam gate layout.

4.19.2 Project Layout - J.T. Myers

The project is a high lift dam with two adjacent parallel locks. A recent aerial photograph is shown in Figure ED 4-43 and a site plan/vicinity map is shown in Figure ED 4-44. Note the location of Wabash Island downstream of the project, as well as the mouth of the Wabash River just downstream of the project. Both of these have a significant impact on navigation conditions around this project.

The dam consists of a non-navigable gated-crest type structure 1,277.4 feet long, a fixed weir section 2,239 feet long, and a concrete-capped sheet pile cutoff wall and dike 300 feet long terminating in natural ground on the left bank or Kentucky side of the river. There are 10 non-submergible tainter gates 110 feet by 32 feet high supported by concrete piers. The fixed weir section is composed of an 11-foot high concrete crest structure over concrete filled sheet pile cells. A concrete-capped sheet pile cutoff wall extends from the end of the weir section further into the bank. The gated section of the dam, including the upstream section of the locks, is topped with a prestressed concrete/service bridge and includes a crane for lifting the upstream emergency bulkheads.

Figure ED 4-43. Aerial Photograph of J.T. Myers Locks and Dam

The two adjacent parallel lock chambers are located along the Indiana shore, the main lock chamber having clear dimensions of 110 x 1,200 feet and the auxiliary lock 110 x 600 feet. The lock chambers have an 18-foot lift at normal pool with normal upper pool at elevation 342.0 and normal lower pool (Smithland pool) at elevation 324.0. Two sets of hydraulically operated steel miter gates are provided for each lock. Each lock has provisions immediately upstream of the upper miter gates for the placement of open truss emergency bulkheads. Provisions for maintenance bulkheads are provided immediately downstream of each set of miter gates. Mobile maintenance bulkheads are available throughout the Louisville District for the 110-ft wide lock chambers. By the use of bulkheads, each of the culvert valves, the miter gates and the entire lock chamber are designed for dewatering to facilitate maintenance. When the lock is closed due to high water, navigation may pass by the structure over the fixed weir between the gated section and the left bank, although this is rarely done given the height of the lock walls.

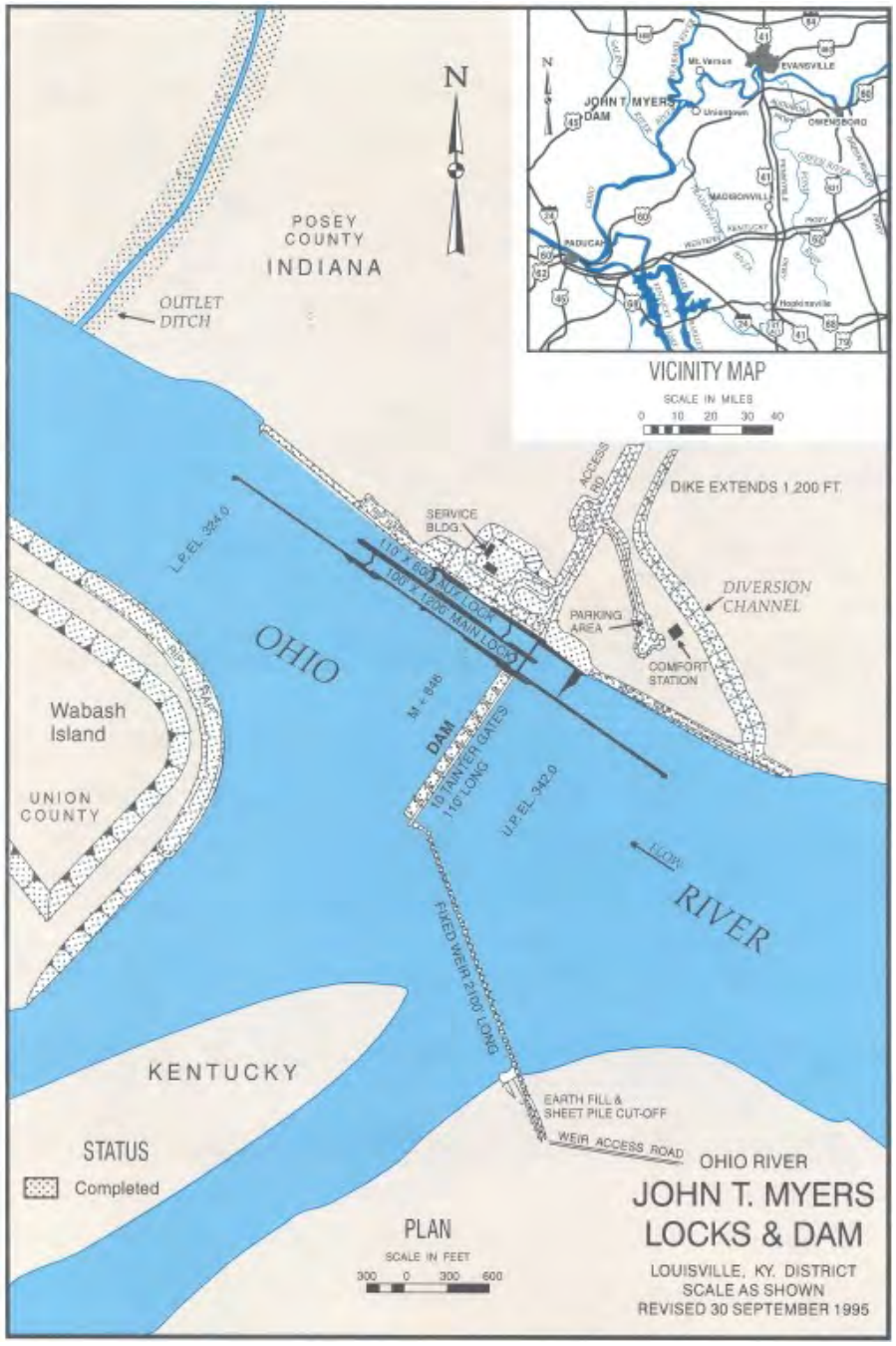


Figure ED 4-44. J.T. Myers Locks and Dam Project Layout

4.19.3 Assessment of Concerns and Needs - J.T. Myers

There are two major concerns regarding the J.T. Myers site. The first relates to the condition of the dam relative to the stilling basin and stability of the monoliths. An on-going major rehabilitation study of the J.T. Myers dam is scheduled for completion in late spring 2006. This report will detail the reliability issues associated with the dam. One problem is erosion of the stilling basin structure below the tainter gates. The

concrete section is being eroded out and currently can not be repaired because it is below the dewatering slots for the dam. The secondary issue is the stability of the monoliths for both seismic load cases, as well as meeting criteria for other load cases. Recommended repair options included procuring a specialized dewatering bulkhead to make repairs to the stilling basin floor and anchoring the monoliths. These are detailed in the J.T. Myers Dam Major Rehab Report.

The other major concern at J.T> Myers is associated with inadequate auxiliary lock chamber capacity and is being addressed with the J.T. Myers Locks Improvements Project, which was authorized as part of WRDA 2000. When completed, this project will have twin 1200-ft lock chambers which essentially eliminates the concerns regarding insufficient auxiliary chamber capacity. The project was authorized as part of an interim report on the ORMSS and also included a capacity improvement project at Greenup Locks and Dam in the Huntington District. Refer to the Greenup section of this engineering appendix for more detail associated with that project. Both the J.T. Myers Locks Improvements Project and the Greenup Lock Extension Project are currently in design. Anticipated "on-line" dates for these projects are currently estimated to be around 2010 pending appropriate funding levels for design and construction activities.

4.19.4 Overview of J.T. Myers Locks Improvements Project

There are several features associated with the J.T. Myers Locks Improvements Project. The primary feature is an extension of the auxiliary lock chamber from 600-ft to a nominal 1200-ft length. This will eliminate the need for "double-cutting" of tows during closures of the existing main chamber. Other major improvements include a supplemental filling and emptying (F/E) system to provide water flow into and out of the extended end of the lock chamber, new downstream miter gates, new filling and emptying culvert valves for the supplemental F/E system, as well as floating approach wall extensions for the upper end of the project. In addition, new lower land and middle approach walls are also provided for the authorized project to improve navigation approach conditions on the lower end of the newly extended lock chamber. Finally, aquatic mitigation features, as well as supporting construction facilities (resident engineer's office, bank line modifications, etc.) to support the project are also included. Many of the project features (land wall extension, approach walls, etc…) utilize innovative construction techniques such as float-in and lift-in construction in order to minimize on-site interference with navigation traffic, as well as reduce costs and time when compared to traditional methods. The authorized cost of the John T. Myers Locks Improvements Project was approximately $182 million in year 2000 dollars. Refer to Figure ED 4-45 for a plan view showing the major project improvements for the authorized project at J.T. Myers.

Currently, there are several potential cost saving features being evaluated as part of on-going design with the J.T. Myers Locks Improvement Project. These were done as part of an overall evaluation that investigated how to reduce construction costs for lock extension projects since there are other projects that could potentially benefit from extensions of the shorter auxiliary lock chambers. Physical hydraulic modeling at ERDC-WES was undertaken to determine more cost effective way to provide supplemental filling and emptying to the lower end of the extended lock chamber. A 1:25 scale F/E model was built replicating the J.T. Myers project. Several potential

alternatives were evaluated for the supplemental F/E system, but the one that provided the best combination of cost savings and performance was a through-the-sill filling system coupled with most of the existing emptying features of the authorized project. A basic description of the planned changes include providing twin supplemental culverts that go through the upper sill and rest on the lock floor before transitioning into the new lower land wall. Reverse tainter filling and emptying valves are provided in the new lower land wall. A downstream lateral diffuser system is also provided to better distribute water flow in the lower end. Finally, a landside outlet diffuser empties the lower half of the extended lock chamber landward of the new lower land approach wall.

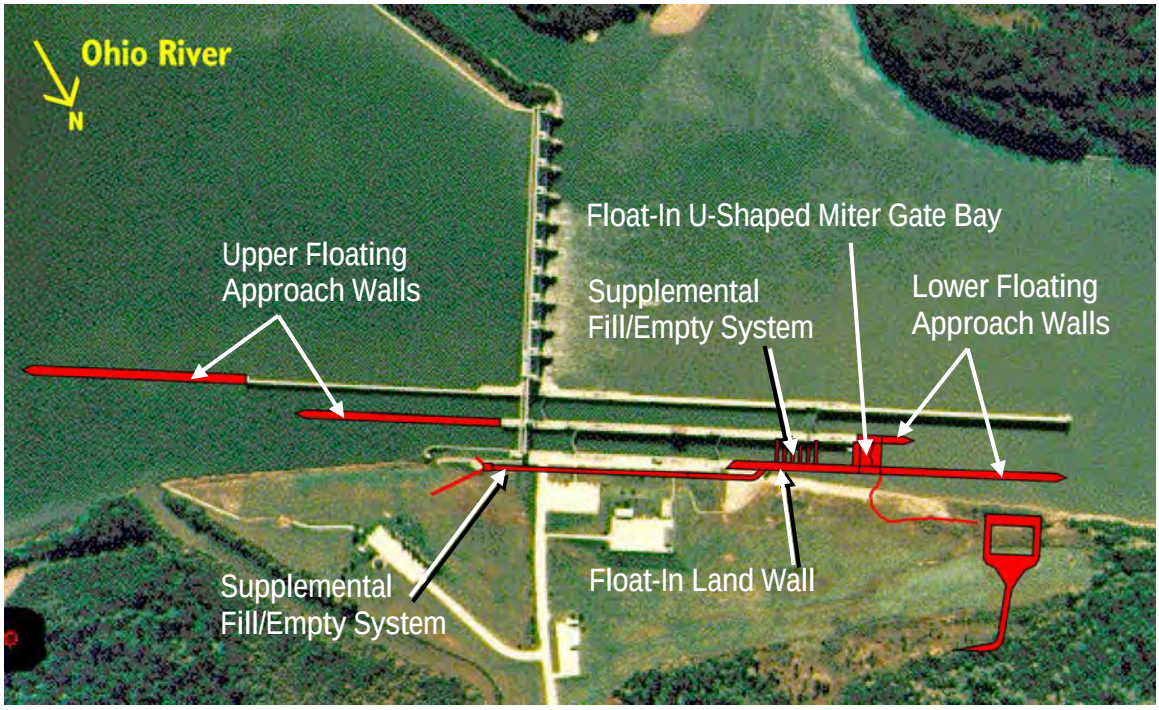


Figure ED 4-45. Authorized John T. Myers Locks Improvements Project Features

The diffuser system, land wall culvert, and downstream lateral system were part of the authorized lock extension plan at J.T. Myers. The big difference between the two F/E systems is the elimination of the long wrap around culvert tucked behind the existing land wall as shown in Figure ED 4-47. The adequate clearance at J.T. Myers affords the opportunity to eliminate this costly excavation and dewatering along with the features required to put that system in place. A plan view of the alternative supplemental F/E system envisioned at J.T. Myers is shown in Figure ED 4-46. This plan is still undergoing refinement, but the basic premise should remain as the preferred option at J.T. Myers due to its cost savings, currently estimated to be approximately $15 million, compared to the wrap around system.

Additionally, a 1:100 scale navigation model is being tested at ERDC-WES looking at potential changes required for access and approach wall configurations at J.T. Myers as a result of the planned project changes. This portion of the authorized project also has a significant potential for savings since most project team members believed that

conservative approach wall extension lengths were provided as part of the authorized project. Initial indications from the 1:100 model results are that the authorized approach wall lengths are indeed longer than required for navigation conditions at J.T. Myers. The authorized project approach extension lengths were as follows: 960 feet on the upper river wall, 900 feet on the upper middle wall, 100 feet on the lower middle wall, and 700 feet on the lower land wall. After coordinating 1:100 model tests with the navigation industry, it appears as if only 500 feet is need on the upper river wall, 800 feet on the upper middle wall, and 400 feet on the lower land wall. The lower middle wall should remain at 100 feet. This is a savings of 860 linear feet of approach wall length that is currently estimated to save approximately $7 million when compared to the authorized project. Testing of the 1:100 navigation and 1:25 F/E models is continuing. Most of these tests are refinements to the basic plans described above.

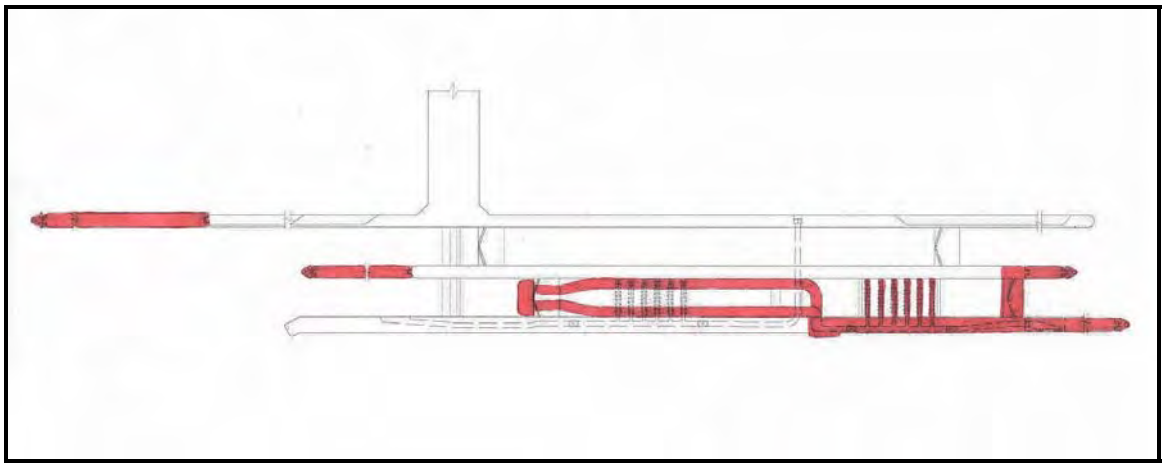


Figure ED 4-46. Alternative F/E System Features at J.T. Myers (Shown in Red)

4.20 SMITHLAND LOCKS AND DAM

4.20.1 General Background Information - Smithland

The Smithland Locks and Dam project is located on the Ohio River, at Mile 918.5, below Pittsburgh, Pennsylvania, 2 miles upstream from Smithland, Kentucky, where the Cumberland River joins the Ohio River and 16 miles upstream from Paducah, Kentucky where the Tennessee River joins the Ohio River. The upper pool extends upstream 72.5 miles to the J.T. Myers Locks and Dam project. The navigation locks are located on the right bank or Illinois side of the Ohio River. The project is a high lift dam with twin navigational locks.

The Smithland Locks and Dam was authorized on December 8, 1965, as a replacement for existing Locks and Dam 50 and 51, under authority of Section 6 of the Rivers and Harbors Act of March 3, 1909. Construction was started beginning with the locks in 1971, and dam structures in 1974. The locks were placed in operation in 1979 with the dam essentially completed in November 1980.

4.20.2 Project Layout - Smithland

The two Smithland Locks are each 110 feet wide and 1,200 feet long making it the only twin 1200-ft lock chamber project on the Ohio River, although this will change soon with construction at Olmsted and McAlpine and authorized lock extensions at J.T. Myers and Greenup. The overall length of the river lock wall, including the guard walls, is approximately three-quarters of a mile. Each miter gate leaf weighs approximately 250 tons. The miter gates and valve machinery are hydraulically operated. Each lock chamber requires eight minutes for filling and nine minutes for emptying for maximum pool differentials. A recent aerial photograph is shown in Figure ED 4-47 and a site plan/vicinity map is shown in Figure ED 4-48. A basic description of each main feature is provided below.

Figure ED 4-47. Aerial Photograph of Smithland Locks and Dam

The dam consists of a non-navigable gated-crest type structure, a fixed weir section, and a concrete-capped sheet cutoff wall and dike. The gated structure is 1,390 feet long with 11 nonsubmergible tainter gates. Each gate is 110 feet long by 36 feet high. Pier 1 ties into the river wall of the lock chamber and pier 12 ties into the fixed weir. The fixed weir section is approximately 1,740 feet long with 22 circular sheet pile cells and connecting arcs. Cell W1 ties to the gated structure. The fixed weir has a uniform crest elevation of 326.0. A prestressed concrete service bridge traverses the gated dam structure and the approaches to the locks. The bridge provides access to and

rails for the bulkhead hoist-crane. This crane is used for the handling and placement of the emergency bulkheads in either lock approaches or the gate bays. In 1995 construction of the prototype wicket test facility was added to test the design of hydraulically operated wicket gates for the proposed Olmsted Locks and Dam project. Five, 9'-7" wide by 25'-6" long wickets are installed at the facility. A 1,200-foot approach channel was dug connecting the upper pool to the facility and an 800-foot retreat channel connected the lower pool. Completion of the test facility was in August 1995. The site was abandoned with all five wickets locked in the raised position with four-inch gaps between each wicket. The tops of the wickets are set at elevation 326.00. A pedestrian bridge crosses the channel allowing access to the Kentucky side of the river. The Olmsted Prototype facility is not shown in the aerial photograph or project layout figures since this post dates the times for both the aerial photograph and site layout map.

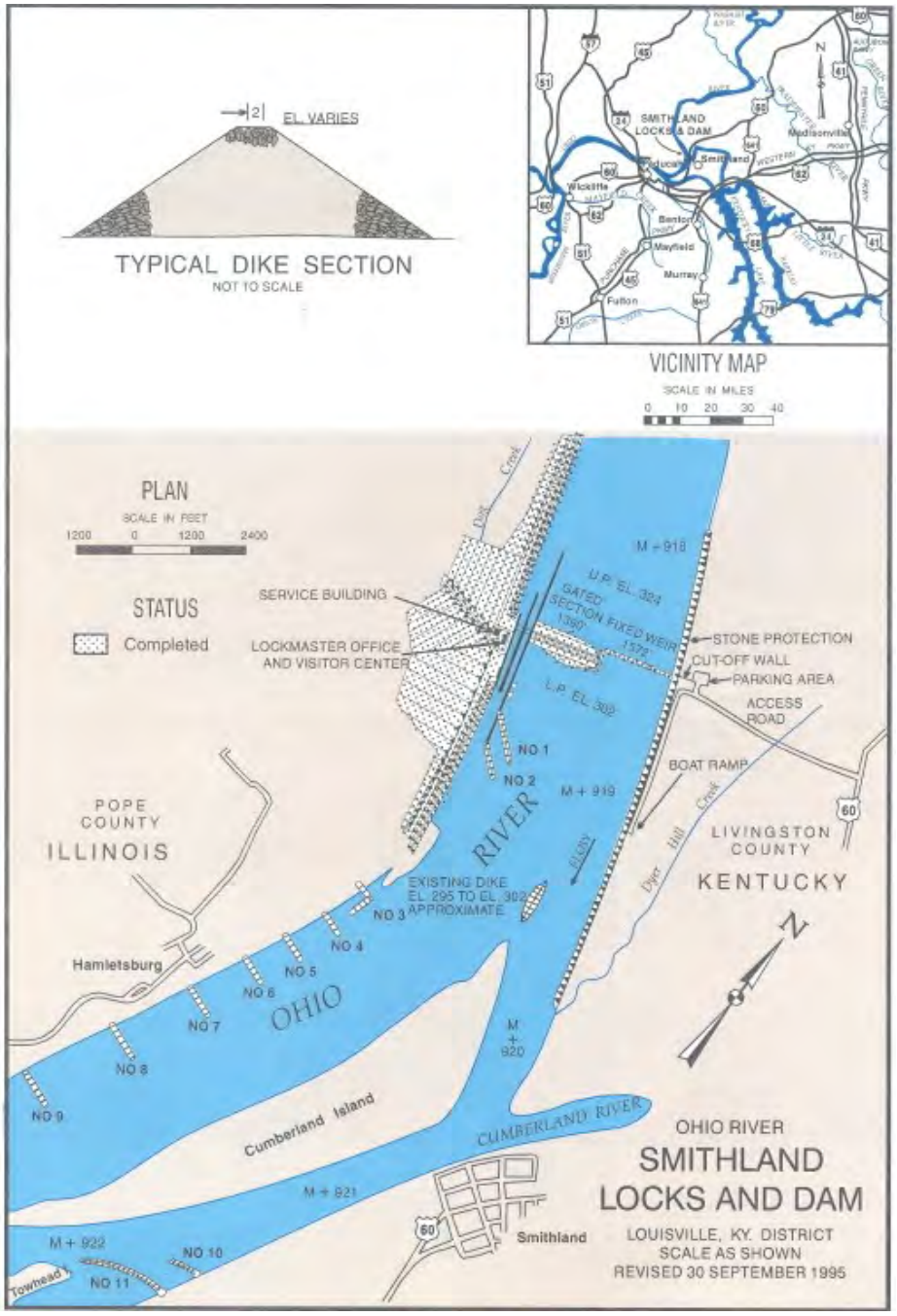


Figure ED 4-48. Project Layout for Smithland Locks and Dam

The locks are twin parallel chambers located along the Illinois bank. Each lock is 110 by 1,200 feet and has a 22-foot lift at normal pool. Two sets of hydraulically operated all-welded steel miter gates are provided for each lock. Each lock has provisions, immediately upstream and downstream of the miter gates, for the placement of the open truss, emergency bulkheads. The same bulkhead sections are used for the dam tainter gates. By the use of these bulkheads, and closure of the culvert valves, the entire lock chamber can be dewatered for inspection and maintenance. These locks are equipped with a fire protection system, which can spray water on the lock chamber of all

miter gates. Normal upper pool is at elevation 324.0. Normal lower pool (Olmsted Pool) is anticipated to be elevation 302.0, once Olmsted is complete. Thus, the lift is 22 feet at normal pool levels is expected.

4.20.3 Assessment of Concerns and Needs - Smithland

Smithland is a unique project from the standpoint that it has had twin 1200-ft lock chambers since it was constructed approximately 25 years ago. The project sees the most operational cycles when combining both lock chambers together, however, directional locking procedures keeps one chamber from receiving too many of the lock cycles. Currently, there is adequate capacity when one of the 1200-ft lock chambers is closed for maintenance. However, this could potentially change in the future depending upon traffic levels. It is in a key shipping location near the conjunction of the Ohio, Mississippi, and Tennessee Rivers. It is crucial that this overall project stays reliable given current and future project traffic.

The major structural concern at Smithland now is the condition of the culvert valves. The valves are original, but one of the valves failed in 1997. A detailed explanation of the valve failure is described in the reliability section of this appendix, but it was essentially a fatigue/corrosion failure of the welded connection at the vertical rib and horizontal girder interface. The valve suffered major damage, but was salvaged and emergency repairs were made. Fortunately, this only caused a short shutdown of the lock chamber as there are two filling and emptying valves each for both 1200-ft lock chambers at Smithland. After a short shutdown period, the valve was repaired on-site by operating the chamber at ½ filling and emptying speed until the repairs to the damaged valve could be completed. The remaining valves at Smithland showed signs of pending damage as well, but temporary repairs were made to improve their reliability for the short-term. Full-scale reliability modeling was carried out on the major components (miter gates, culvert valves, operating machinery, etc.) and there are anticipated reliability problems besides the culvert valves during the study period. These are specifically addressed in the reliability section of this appendix.

4.21 OLMSTED LOCKS AND DAM

4.21.1 General Background Information - Olmsted

Olmsted Locks and Dam is located approximately 1.8 miles below existing Locks and Dam 53 at Ohio River mile 964.4. It is located just upstream of the Ohio Rivers confluence with the Mississippi River near Cairo, Illinois. The Olmsted project was authorized by the October 17, 1988 WDRA, PL 100-676. It will replace low-lift Locks and Dams 52 and 53, providing a navigation pool to the next project upstream, Smithland Locks and Dam.

4.21.2 Project Layout - Olmsted

The project consists of twin 110-ft wide by 1200-ft long lock chambers located on the Illinois side of the Ohio River. The dam will consist of tainter gates and a boat-

operated wicket navigable pass that can be raised or lowered for navigation purposes. Tows will bypass the locks and go over the top of the dam during high water, approximately 60 percent of the year. An additional 425 feet of fixed weir ties the dam to the Kentucky shore. An artist's rendering of the completed project is shown in Figure ED 4-49. There have been some minor modifications to the rendering, however, the basic layout remains unchanged.

4.21.3 Current Status of Project

There are four major construction contracts for the Olmsted project. The first was the cellular cofferdam. The cellular cofferdam and base lock foundation preparation was completed between 1993 and 1995. The second major construction contract completed was for building the twin lock chambers. The locks were constructed between 1996 and 2001. The third major construction contract was for the floating approach walls and nose piers. The approach wall pontoons were constructed off-site and floated into place. The nose piers for the floating pontoons and lower land guide wall were completed on-site. This approach wall contract was recently completed. Construction on the approach walls was started in 1999. The final contract will be for the construction of the dam. The final major contract for Olmsted is the construction of the dam. This contract was recently awarded and construction has started on this last segment of the project. Due to funding constraints and other issues, it is anticipated that the project will be completed sometime between 2012 and 2015.

Figure ED 4-49. Rendering of Completed Olmsted Locks and Dam Project

Section 5

LOCK AND DAM RISK AND RELIABILITY MODELING

This section describes the effort involving the engineering and economic modeling of major lock and dam components for ORMSS. The purpose of engineering reliability modeling is to determine the long-term performance of major lock and dam components. Additionally, the analysis predicts the consequences of unsatisfactory performance from both a navigation delay standpoint as well as repair cost standpoint as structures age and see increased operating cycles. The engineering reliability and economic risk assessment of these components play an important role in the development of net benefits for the various alternatives being considered.

5.1 COMPONENTS REQUIRING RELIABILITY ANALYSIS

The initial effort of the overall reliability assessment of the lock and dam was to determine which components should have reliability analysis conducted on them. Since there are several components that can cause disruption of navigation service and/or be very costly to replace, a process of eliminating "minor" components had to be developed. Therefore, the team developed a two-phase screening process that eliminated several minor components from consideration for reliability analyses. This screening process also made the overall effort manageable in terms of available funding and time constraints.

5.1.1 Selection of Components

The initial effort on the ORMSS was for a team of engineers, one from each of the three districts with navigation locks on the main stem of the Ohio River, to go out and inspect every lock and dam on the Ohio River to determine their condition relative to one another. Included in this effort was interviewing personnel at the project site in order to get as much information as possible. This group was kept as consistent as possible in order to have a fair rating of the locks relative to one another. The second step was for the same group of engineers to review the plans and Periodic Inspection Reports for each of the sites. From this effort, an initial master list of 150 components was developed for screening. This list was developed to represent all the sites on the Ohio River. The list was screened in two stages. The first phase screening process was used to investigate the relative importance of a component in terms of the overall lock operation. The second phase screening investigated the overall importance of the component from both a site specific and an overall Ohio River systems standpoint.

First Phase Screening

A sample of the original list of lock components, shown in Table ED 5-1, was screened based upon their relative importance to the overall operation of the lock. A multi-district, multi-discipline team of engineers screened the original list of components as part of the first phase. If a component was considered non-essential or is typically repaired as part of routine maintenance,

it was screened out during the first phase. If any of the following reasons were applicable, the component was screened out first phase:

Redundancy. The component's function could be accomplished by other means or there are numerous components that would have to perform unsatisfactorily at the same time to be considered a significant problem. An example would be that line hooks could be used instead of check posts if necessary.

Item #	Component	Component Use	Discipline	Screened Out	Reason for Screen Out
64	Chamber Monolith Stability	Lock	Struct/Geotech	No	
65	Miter Gate Monolith Stability	Lock	Struct/Geotech	No	
66	Concrete Horizontal Surfaces	Lock/Dam	Structural	No	
67	Guardwall/Guidewall Stability	Lock	Struct/Geotech	No	
68	Fixed Weir Stability	Dam	Struct/Geotech	No	
69	Sheet Pile Cellular Structures Stability	Lock	Struct/Geotech	No	
70	Pile Founded Structures Stability	Lock/Dam	Struct/Geotech	No	
71	Dam Pier Stability	Dam	Struct/Geotech	No	
72	Mass Concrete	Lock/Dam	Structural	No	
73	Overflow Spillway Stability	Dam	Struct/Geotech	No	
74	Miter Gate Sill Stability	Lock	Struct/Geotech	No	
75	Dam Gate Sill Stability	Dam	Struct/Geotech	No	
76	Retaining Wall Stability	Lock/Dam	Struct/Geotech	No	
77	Air Conditioning Units	Miscellaneous	Mech./Elec.	Yes	Not considered critical to operation of lock and dam.
78	Heating/Furnace Units	Miscellaneous	Mech./Elec.	Yes	Not considered critical to operation of lock and dam.
79	Raw Water Pump	Miscellaneous	Mech./Elec.	Yes	Handled through normal maintenance.
80	Strainer	Miscellaneous	Mech./Elec.	Yes	Handled through normal maintenance.
81	Bubbler System	Lock/Dam	Mech./Elec.	Yes	Redundant, other means available to serve purpose.
82	Fuel Oil Transfer Pump	Miscellaneous	Mech./Elec.	Yes	Handled through normal maintenance.
83	Water Heaters	Miscellaneous	Mech./Elec.	Yes	Not considered critical to operation of lock and dam.
84	Exhaust Fans	Miscellaneous	Mech./Elec.	Yes	Not considered critical to operation of lock and dam.
85	Service Building Crane	Maintenance	Mech./Elec.	Yes	Not considered critical to operation of lock and dam.
86	Piggy Back Crane	Maintenance	Mech./Elec.	Yes	Not considered critical to operation of lock and dam.
87	Dam Elevator Mechanical	Dam	Mech./Elec.	Yes	Redundant, other means available to serve purpose.
88	Closed Circuit TV System	Lock/Dam	Mech./Elec.	Yes	Redundant, other means available to serve purpose.
89	Batteries	Miscellaneous	Mech./Elec.	Yes	Not considered critical to operation of lock and dam.
90	Cathodic Protection	Lock	Mech./Elec.	Yes	Handled through normal maintenance.
91	Anodes	Lock/Dam	Mech./Elec.	Yes	Handled through normal maintenance.
92	Siren System/Air Whistle	Lock/Dam	Mech./Elec.	Yes	Not considered critical to operation of lock and dam.
93	Panel Heater	Miscellaneous	Mech./Elec.	Yes	Handled through normal maintenance.
94	Control Building Mechanical	Lock/Dam	Mech./Elec.	Yes	Handled through normal maintenance.
95	Control Building Electrical	Lock/Dam	Mech./Elec.	Yes	Handled through normal maintenance.
96	Service Building Misc. Mechanical	Maintenance	Mech./Elec.	Yes	Handled through normal maintenance.
97	Service Building Misc. Electrical	Maintenance	Mech./Elec.	Yes	Handled through normal maintenance.

Table ED 5-1. Sample of Master List of Components for Reliability Screening

Non-critical. The component was not considered critical to the overall operation of the lock. An example is wall armor along monolith vertical face.

Routine Maintenance. If the component were to perform unsatisfactorily in any manner, it would always be repaired as part of normal maintenance. An example would be handrails, grating, etc.

Reliable Component. The likelihood of unreliable performance was considered remote. An example is culvert bulkhead sill stability.

Any components that did not fall into one of these screening criteria were screened again during the second phase screening process. Out of 150 total initial components, a total for all Ohio River locks, 60 survived the first screening phase. Since there was not enough funding or time to warrant reliability models for 60 different components, the first phase survivors were re-screened during the second phase. This phase is described in the next section.

Second Phase Screening

Originally, all components that survived the first phase of screening were subjected to a second level screening. The second phase screening process was developed to incorporate the importance of a particular component not only on a site-specific basis, but also on a systems basis in relation to other lock and dams on the Ohio River. Sixty lock components survived the first phase screening process out of 150 initial components. These 60 survivors were next rated by the same multi-district/multi-discipline team of engineers on a scale of 1 to 3 based upon six categories: *System Number, Component Site Consequence, Component Site Cost, Component System Cost, System Consequence, and Likelihood of Problems*. Some of the categories based their results upon answering questions about the performance of the component. A description of each category is detailed below.

Ranking	Description
1.0	Low, No, Minor
2.0	Medium, Average
3.0	High, Yes, Major

System Number. Number of sites of locations where this component was present within the Ohio River Main Stem lock and dam system.

Component Site Consequence. From a site-specific standpoint, how would navigation traffic be directly and immediately affected by the unsatisfactory performance of the component. Is there a lack of redundancy for this component from a site-specific standpoint?

Component Site Cost. From a site-specific standpoint, does the total number of the components reflect a major rehab/replacement cost relative to the site?

Component System Cost. From an overall system standpoint, does the total number of this component reflect a significant rehabilitation/replacement cost on the entire system?

System Consequence. From an overall standpoint, if this component were to perform unsatisfactorily, would navigation be impacted significantly?

Likeliness of Problems. Is it likely that the component would need repairs based upon past performance or suspected degradation?

A special ranking system was developed to assist in ranking the system categories: *System Consequence, Component System Cost,* and *System Number.* The ranking system is shown in Figure ED 5-1 on the following sheet. The values that were computed from that sheet were input into the overall ranking sheet for the three categories for the Phase 2 rating, as shown in Table ED 5-2.

The results for each of the six categories were added together to determine a final ranking. After reviewing the overall rankings, it was determined that there was a general break in the rankings for components around the 12-13 range. Therefore, the engineering team decided that components which had a phase 2 overall ranking of 13 or above (out of a maximum of 18), would have reliability analyses completed for them, assuming budget and schedule allowed as the study progressed. The results of the Phase 2 screening are depicted in Table ED 5-2.

There were a total of 20 components that survived both the first and second phase screenings. This represents the original list that was intended for reliability modeling during the early phases of the ORMSS when budgets, scheduling, and overall direction were still being developed for all parts of the study. The original list of components to be analyzed through probabilistic means is shown on the following page.

Original List of Components for Reliability Model Development

1. Horizontally-framed Miter Gates
2. Vertically-framed Miter Gates
3. Miter Gate Anchorage
4. Reverse Tainter Gate Culvert Valves
5. Butterfly Valves
6. Reverse Tainter Culvert Valve Anchorage
7. Chamber Monolith Stability
    a. Unanchored Lock Wall Monoliths
    b. Anchored Lock Wall Monoliths
8. Miter Gate Monolith Stability
9. Guard/Guide Wall Stability
    a. Gravity Structures
    b. Pile-Founded
10. Miter Gate Sill Stability
    a. Unanchored Sills
    b. Anchored Sills
11. Hydraulic Power System (Mechanical)
12. Power and Control Equipment (Electrical)
13. Dam Tainter Gates
14. Dam Tainter Gate Anchorage
15. Dam Roller Gates
16. Dam Vertical Lift Gates
17. Dam Pier Stability
18. Fixed Weir Stability
19. Dam Gate Sill Stability
20. Sheet Pile Cellular Structure Stability

Further Screening and Prioritization of Model Development

It was intended that reliability models would be developed for all 20 survivors of the screening process as listed in Table ED 5-2 for the ORMSS. As model development progressed, a few changes to the original list of 20 survivors were made based upon judgment, study schedule, and available funds. For example, the reverse tainter gate culvert valve anchorage model was lumped into the overall reverse tainter valve model. Therefore, a single model covered both. Additionally, the butterfly valves were incorporated as part of the mechanical model for the lock since there was available data for the performance of butterfly valves relative to reliability analysis. Also, it was determined that a separate miter gate anchorage model was not necessary since previous analyses indicated the critical element to be the I-bars. Since the I-bars are switched out and maintained as part of normal maintenance, the component was eliminated from consideration. Also, there were two types of reverse tainter culvert valve models that had to be developed, one for horizontally-framed valves and the other for vertically-framed valves.

	Individual Lock and Dam Component Data							1994 Traffic Information		
	Miter Gates		Culvert Valves		Dam Gates			Individual Site		
Project Site	**Hrz. Framed**	**Vert. Framed**	**Butterfly**	**R. Tainter**	**Roller**	**Tainter**	**Vertical Lift**	**'94 kilotons**	**% Total**	**Conseq. Rank**
Emsworth	2	2	44	-	-	-	13	24,272	2.24%	**1.0**
Dashields	2	2	6	-	-	-	-	25,602	2.36%	**1.0**
Montgomery Island	2	2	6	-	-	-	10	27,313	2.52%	**1.5**
New Cumberland	4	-	-	6	-	11	-	37,272	3.44%	**1.5**
Pike Island	4	-	-	6	-	9	-	43,643	4.03%	**2.0**
Hannibal	4	-	-	6	-	8	-	47,783	4.41%	**2.0**
Willow Island	4	-	-	6	-	8	-	45,802	4.23%	**2.0**
Belleville	4	-	-	6	-	8	-	48,641	4.49%	**2.0**
Racine	4	-	-	6	-	8	-	49,845	4.60%	**2.0**
Robert C. Byrd	4	-	-	6	8	-	-	56,079	5.18%	**2.0**
Greenup	4	-	-	6	-	9	-	68,695	6.34%	**2.5**
Meldahl	4	-	-	6	-	12	-	64,627	5.97%	**2.5**
Markland	4	-	-	6	-	12	-	60,011	5.54%	**2.5**
McAlpine	4	-	-	8	-	9	-	61,943	5.72%	**2.5**
Cannelton	4	-	-	6	-	12	-	64,257	5.93%	**2.5**
Newburgh	4	-	-	6	-	9	-	76,779	7.09%	**3.0**
Uniontown	4	-	-	6	-	10	-	85,718	7.92%	**3.0**
Smithland	4	-	-	8	-	11	-	93,337	8.62%	**3.0**
Olmsted	4	-	-	8	-	5	-	101,267	9.35%	**3.0**
Component Totals	**70**	**6**	**56**	**102**	**8**	**141**	**23**	**1,082,886**		
% of Total	**92%**	**8%**	**35%**	**65%**	**5%**	**82%**	**13%**			
System Cost Rank	**3.0**	**1.0**	**2.0**	**2.5**	**1.0**	**3.0**	**1.5**			
Sites w/ Compnt.	**100%**	**16%**	**16%**	**84%**	**5%**	**79%**	**11%**			
System # Rank	**3.0**	**1.5**	**1.5**	**3.0**	**1.0**	**3.0**	**1.0**			

System Cost Rank	
Overall %	Cost Rank
0 - 10%	1.0
11 - 25%	1.5
26 - 40%	2.0
41 - 65%	2.5
66 - 100%	3.0

System Number Rank	
Overall %	Number Rk.
0 - 15%	1.0
16 - 30%	1.5
31 - 45%	2.0
45 - 60%	2.5
61 - 100%	3.0

Consequence Ranking	
Site Overall %	Conseq. Rk.
0 - 2.5%	1.0
2.51 - 4.0%	1.5
4.01 - 5.5%	2.0
5.51 - 7.0%	2.5
Above 7.0%	3.0

Figure ED 5-1. Phase 2 Ranking Criteria

Type of Component	Engineering Discipline	System Number	Site Specific Consequence	Site Specific Cost	System Cost	System Consequence	Likelihood of Problems	Overall Ranking	Phase 2 Screening Results
Horiz. Framed Miter Gates	Structural	3.0	3.0	3.0	3.0	3.0	3.0	18.0	Reliability Analysis
Vert. Framed Miter Gates	Structural	1.5	3.0	3.0	1.0	1.5	3.0	13.0	Reliability Analysis
Lock Emergency Gates	Structural	2.0	2.0	3.0	1.0	1.0	2.0	11.0	Screened Out
Reverse Tainter Valves	Structural	3.0	3.0	2.0	2.5	3.0	3.0	16.5	Reliability Analysis
Butterfly Valves	Structural	1.5	2.0	3.0	2.0	1.5	3.0	13.0	Reliability Analysis
Dam Tainter Gates	Structural	3.0	3.0	3.0	3.0	3.0	3.0	18.0	Reliability Analysis
Vertical Lift Gates	Structural	1.0	3.0	3.0	1.5	1.5	3.0	13.0	Reliability Analysis
Roller Gates	Structural	1.0	3.0	3.0	1.0	2.0	3.0	13.0	Reliability Analysis
Boat-Operated Wicket Gates	Structural	1.0	1.0	1.0	1.0	3.0	1.0	8.0	Screened Out
Miter Gate Anchorage	Structural	3.0	3.0	2.0	1.0	3.0	2.0	14.0	Reliability Analysis
Tainter Gate Anchorage	Structural	3.0	2.0	2.0	1.0	3.0	2.0	13.0	Reliability Analysis
Vertical Lift Gate Anchorage	Structural	1.0	2.0	2.0	1.0	1.5	2.0	9.5	Screened Out
Roller Gate Anchorage	Structural	1.0	2.0	2.0	1.0	2.0	2.0	10.0	Screened Out
Reverse Tainter Anchorage	Structural	3.0	3.0	2.0	2.0	3.0	2.0	15.0	Reliability Analysis
Butterfly Valve Anchorage	Structural	1.5	2.0	2.0	1.0	1.5	2.0	10.0	Screened Out
Service Bridge Girders	Structural	3.0	2.0	2.0	2.0	1.0	1.0	11.0	Screened Out
Service Bridge Bearing Seats	Structural	3.0	1.0	1.0	1.0	1.0	2.0	9.0	Screened Out
Stilling Basins	Structural	3.0	2.0	2.0	1.0	1.0	2.0	11.0	Screened Out
Emergency Bulkheads	Structural	3.0	1.0	2.0	2.0	1.0	1.0	10.0	Screened Out
Culvert Bulkheads	Structural	3.0	1.0	2.0	1.0	1.0	1.0	9.0	Screened Out
Intake Screens	Structural	3.0	1.0	1.0	1.0	1.0	2.0	9.0	Screened Out
Miter/Quoin Blocks	Structural	3.0	1.0	1.0	1.0	1.0	2.0	9.0	Screened Out
Bulkhead Crane (Structural)	Structural	3.0	1.0	2.0	2.0	1.0	1.0	10.0	Screened Out
Maintenance Bulkheads	Structural	3.0	1.0	2.0	1.0	1.0	1.0	9.0	Screened Out
Tainter Gate Cable Anchorage	Structural	3.0	2.0	1.0	1.0	2.0	1.0	10.0	Screened Out
Service Bridge Bearing Memb.	Structural	3.0	1.0	1.0	1.0	1.0	1.0	8.0	Screened Out
Bulkhead Crane Lifting Beam	Structural	3.0	1.0	2.0	1.0	1.0	1.0	9.0	Screened Out
Poiree Dam	Structural	1.0	2.0	2.0	1.0	1.0	2.0	9.0	Screened Out
Floating Approach Walls	Structural	1.0	2.0	3.0	1.0	2.0	2.0	11.0	Screened Out
Chamber Monolith Stability	Structural	3.0	3.0	3.0	3.0	3.0	1.0	16.0	Reliability Analysis
Miter Gate Monolith Stability	Structural	3.0	3.0	3.0	3.0	3.0	1.0	16.0	Reliability Analysis
Concrete Horizontal Surfaces	Structural	3.0	1.0	3.0	2.0	1.0	2.0	12.0	Screened Out
Type of Component	**Engineering Discipline**	**System Number**	**Site Specific Consequence**	**Site Specific Cost**	**System Cost**	**System Consequence**	**Likelihood of Problems**	**Overall Ranking**	**Phase 2 Screening Results**
Guide/Guardwall Stability	Structural	3.0	2.0	3.0	3.0	2.0	2.0	15.0	Reliability Analysis
Fixed Weir Stability	Structural	2.0	3.0	3.0	2.0	3.0	2.0	15.0	Reliability Analysis
Sheet Pile Cellular Structures	Structural	3.0	2.0	3.0	3.0	2.0	2.0	15.0	Reliability Analysis
Pile Founded Structure Stability	Structural	2.0	1.0	3.0	2.0	1.0	1.0	10.0	Screened Out
Dam Pier Stability	Structural	3.0	3.0	3.0	3.0	3.0	1.0	16.0	Reliability Analysis
Mass Concrete	Structural	1.0	2.0	2.0	3.0	3.0	1.0	12.0	Screened Out
Overflow Spillway Stability	Structural	2.0	2.0	2.0	2.0	2.0	1.0	11.0	Screened Out
Miter Gate Sill Stability	Structural	3.0	3.0	2.0	2.0	3.0	1.0	14.0	Reliability Analysis
Dam Gate Sill Stability	Structural	3.0	3.0	2.0	2.0	3.0	1.0	14.0	Reliability Analysis
Retaining Wall Stability	Structural	1.0	1.0	2.0	1.0	1.0	1.0	7.0	Screened Out
Underseepage Control	Geotechnical	1.0	2.0	2.0	1.0	1.0	1.0	8.0	Screened Out
Erosion Control	Geotechnical	3.0	1.7	1.7	1.3	1.7	2.0	11.4	Screened Out
Slope Stability	Geotechnical	3.0	1.3	1.0	1.0	1.0	1.0	8.3	Screened Out
Riprap	Hydraulics	3.0	2.0	1.0	1.5	1.5	1.5	10.5	Screened Out
Navigation Channel Conditions	Hydraulics	3.0	2.0	1.3	2.0	2.3	2.0	12.6	Screened Out
Approach Conditions	Hydraulics	3.0	2.3	1.7	2.0	2.3	1.3	12.6	Screened Out
Dikes	Hydraulics	1.5	1.0	1.0	1.0	1.0	1.0	6.5	Screened Out
Tow Haulage Unit	Mech./Elec.	1.0	2.0	2.0	1.0	1.0	2.5	9.5	Screened Out
Bulkhead Crane Machinery	Mech./Elec.	2.7	1.3	2.3	2.0	1.0	2.3	11.6	Screened Out
Hydraulic Power System	Mech./Elec.	3.0	2.3	2.7	2.3	2.0	2.0	14.3	Reliability Analysis
Fire Protection Equipment	Mech./Elec.	1.3	1.0	1.3	1.0	1.0	1.3	6.9	Screened Out
Compressed Air System	Mech./Elec.	3.0	1.3	1.0	1.0	1.3	2.0	9.6	Screened Out
Lighting	Mech./Elec.	3.0	1.7	1.7	1.3	1.3	1.3	10.3	Screened Out
Emergency Generator	Mech./Elec.	3.0	2.3	1.3	1.0	1.7	2.3	11.6	Screened Out
Motor Control Center	Mech./Elec.	3.0	2.3	1.7	1.3	2.3	1.3	11.9	Screened Out
Power and Control Equipment	Mech./Elec.	3.0	2.3	1.7	1.7	2.3	2.0	13.0	Reliability Analysis
Dam Gages	Mech./Elec.	2.0	1.0	1.0	1.0	1.0	2.0	8.0	Screened Out
Intercom System	Mech./Elec.	3.0	1.0	1.0	1.0	1.0	1.0	8.0	Screened Out
Traffic Signal System/Lighting	Mech./Elec.	3.0	2.3	1.0	1.0	2.3	1.3	10.9	Screened Out

Total Number of Components Requiring Further Analysis --> 20

Table ED 5-2. Original Phase 2 Screening Results

In addition, the dam components were not modeled using reliability analysis as part of the ORMSS SIP. However, some sophisticated finite element analysis models of instrumented tainter gates on two Louisville District projects (J.T. Myers and Markland), which was partially funded by the ORMSS, indicated that these type of dam gates are both highly redundant and also operate primarily

under compressive stress loads. Therefore, significant reliability issues for the vast majority of dam gates on the Ohio River are not anticipated during the critical part of the study period, which is about the first 30 years or so. In addition, the dam roller gates at R.C. Byrd were recently replaced as part of major rehabilitation for that project. Some investment cost is included to upgrade the dam in the later portion of the study period, but it does not influence lock chamber performance and its cost will not be a significant part of the overall economic analysis because it will be late in the study period and the economic analysis puts future investments in present worth values. The only Ohio River project with anticipated needs to rehab of the dam gates early in the study period is at Emsworth Locks and Dam. As part of a separate major rehabilitation evaluation, a reliability analysis and subsequent economic analysis was done for the dam at Emsworth. This repair is currently under way and for the purposes of this study, it is assumed that the major rehabilitation of the Emsworth Dam will be completed within the next few years.

There are some anticipated investment needs during the study period associated with both the mechanical and electrical systems of the dams, but time and schedule did not allow reliability modeling for these components. These systems typically would not affect navigation performance anyways as part of any event tree consequences. Therefore, some future investments to upgrade mechanical and electrical systems are included in both the With Project and Without Project conditions based upon the age of the structure. These were timed by engineering judgment and placed in the cost schedules for each site.

Currently, there is no known stability issues associated with dam piers or fixed weirs for Ohio River dams. In support of this position, the lock wall monolith reliability models indicated no anticipated stability problems except for a few anchored monoliths at a couple of Upper Ohio projects. The reason there were no lock wall “failures” in the reliability analysis is because of the original safety factors included in the design of the structures. Since the overall condition of these type structures does not change significantly with time, these remain reliable throughout the study period. Due to the lock stability results and the fact there we no know dam pier/weir stability problems, the engineering team agreed that reliability models for dam stability were not warranted as part of the ORMSS.

There is one additional concern on going for several Ohio River dams and that relates to scouring of the stilling basin structure below the dewatering slots. This is a major issue at several Ohio River dams on the lower portion of the river (J.T. Myers, Newburgh, Cannelton, and Markland). A major rehab evaluation associated with the scouring of the stilling basin slabs at J.T. Myers is on-going and scheduled for submission to HQ in FY06. The preliminary results of that study indicate that roughly $30 million or so will be required to procure the necessary equipment and make necessary repairs. The optimal timing of this repair is to be determined as part of the major rehab study, but it is safe to assume it will be required before 2015. For the purposes of ORMSS, this cost will be embedded into both the With and Without Project for fixes to the dam. The same type of repair will be assumed at the other locations as noted with probable time frames for repair.

In the end, probabilistic models were developed for a total of 13 different components based upon the original rating system and the further screening as a result of budget and schedule effects. The components listed below represent the final list of major lock infrastructure modeled through probabilistic means to incorporate into the overall economic analysis. For reference below, EDM is representative of the three upper Ohio projects Emsworth, Dashields, and Montgomery.

Final List of Components for Reliability Models

1. Horizontally-Framed Miter Gates
2. Vertically-Framed Miter Gates
3. Horizontally-Framed Reverse Tainter Gate Culvert Valves

4. Vertically-Framed Reverse Tainter Gate Culvert Valves
5. Mass Concrete Degradation (EDM Only)
6. Lock Chamber Monolith Stability
    a. Unanchored Monoliths
    b. Anchored Monoliths (EDM Only)
7. Miter Gate Monolith Stability
    a. Unanchored Miter Gate Monoliths
    b. Anchored Miter Gate Monoliths (EDM Only)
8. Guard/Guide Approach Wall Stability
    a. Gravity Structures
    b. Pile-Founded Structures
9. Miter Gate Sill Stability
    a. Unanchored Miter Gate Sills
    b. Anchored Miter Gate Sills (EDM Only)
10. Hydraulic Power System (Mechanical)
11. Culvert Valve Machinery
12. Miter Gate Machinery
13. Power and Control Equipment (Electrical)

5.1.2 Types of Reliability Models

The reliability models developed for the final list of components can be separated into two general categories: non-time dependent and time dependent models. The non-time dependent models are assumed not to deteriorate significantly over time, whereas, the time dependent models degrade in reliability over time.

Time Dependent Reliability Models

Twelve of the final components were considered time dependent. These components degrade in reliability with time due to their cyclic use and associated age. The components considered time dependent are the miter gates (both horizontal and vertical), culvert valves (both horizontal and vertical), mass concrete degradation, anchored lock wall stability, anchored miter gate sill stability, anchored miter gate monolith stability, hydraulic power system, culvert valve machinery, miter gate machinery, and power and control equipment. With the miter gates and culvert valves, these structures are steel structures that are subject to fatigue and corrosion, thus, causing a decrease in reliability over time. The fatigue of the miter gate and culvert valves is a function of the number of historical load cycles that the structure has undergone over time, as well as those projected in the future. For the mechanical and electrical components, the time reliability models are a function of the number of operating cycles, along with the component's age. For the anchored walls and sills, these structures are time dependent because the anchors are subjected to fatigue and corrosion. The mass concrete degradation is an issue at EDM only. The reliability of the concrete at these projects is decreasing with time due to the several factors. This is better described in Section 5.2.8. Most importantly, hazard functions are developed for time dependent components. The hazard function is defined as the probability of unsatisfactory performance in a given year assuming it has survived up to that year, a truly time dependent analysis.

Non-Time Dependent Reliability Models

The non-time dependent components were all the unanchored gravity structures: chamber monolith stability, miter gate monolith stability, guide/guard wall stability, and miter gate sill stability. The reliability of the gravity structures at the Ohio River projects has not deteriorated over time to the point that the stability of the structure is in question. Also, since the team is only looking at normal operating loads (normal and maintenance load cases), there is not an issue of return periods or extreme loads for cases such as earthquakes or excessive barge impact forces. Therefore, the models are assumed to have the same reliability over time. This is consistent with guidance, as provided by HQUSACE for gravity structures. For these components, the probability of unsatisfactory performance is computed and assumed to be the same for every year in study period.

5.1.3 Integration of Engineering Reliability in Economic Modeling

The annual probabilities of unsatisfactory performance for each component are only one of the inputs that the engineering team must supply to the economists for their analysis. The engineering team is also required to provide the economists with an event tree for each component depicting several repair options given the limit state of the component.

For all of the components for which reliability analysis was completed, the engineering team supplied probabilities of unsatisfactory performance for non-time dependent components and hazard rates for time dependent components. These values are provided for every year between 2005 and 2070. As noted previously for non-time dependent components, the values are the same in each year. However, for time dependent components, each year could have a different value.

The engineering team also provides consequence event trees for each component to the economists. These event trees supply the economists with information regarding potential repair options if a component were to perform unsatisfactorily. Since the engineering team is only supplying probabilities associated with major types of unsatisfactory performance, the event tree reflects potential repairs for major events. Along with the repair scenarios, the engineering team also supplies the physical repair cost and required chamber closure time associated with each repair option, along with the effect the repair had on the component with regard to future reliability. Event trees vary for each individual component, however, the general format of each one is supplied in Figure ED 5-2. See the individual component sections for specific event trees.

The first branch of the event tree is the annual probability of unsatisfactory performance (PUP) for the component for any particular year between 2005 and 2070, the study period. The second branch is the level of repair associated with the annual PUP. In general, this branch will have a two or three legs whose total percentage must equal 100 percent. The percentages were selected by the team of engineers that developed the model, in consultation with Operations personnel experienced with the repair techniques for the particular component. The third branch is the cost to repair the component for each level or repair, along with the amount of time in days the chamber is closed to navigation. These costs and closures again were developed by the engineering team that developed the model, along with consultation with appropriate Operations personnel. The last branch is the upgrade to future reliability based upon the repair. This effect is based upon engineering judgment on the team that developed the model.

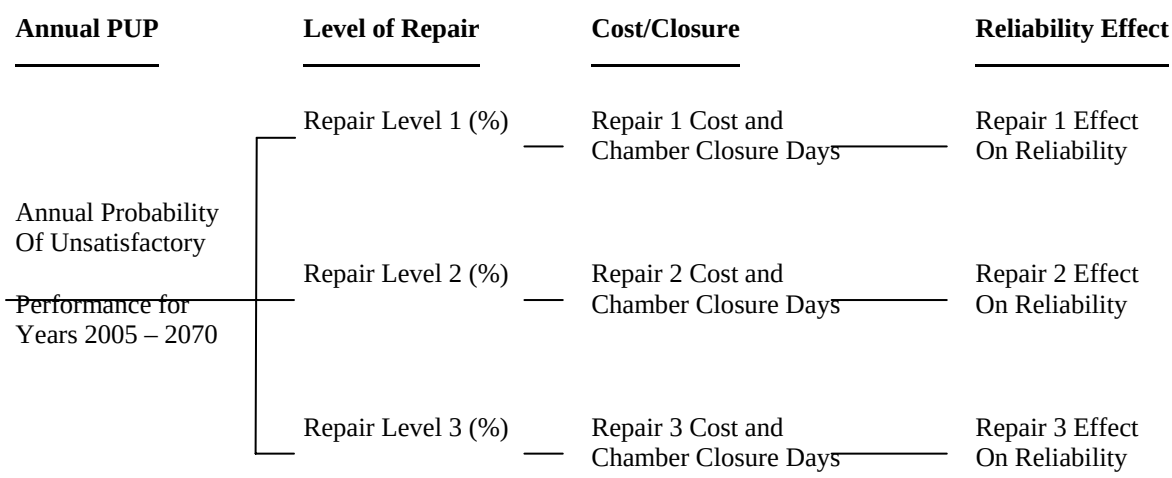


Figure ED 5-2. Typical Event Tree for Reliability Models

Engineering Reliability Analysis Sections

The overall amount of engineering data calculated and used for this report can be overwhelming for those not very familiar with process and details of the analysis. For just the engineering reliability analysis, time dependent hazard rates had to be computed for 35 lock chambers (Olmsted and the new lock chamber at McAlpine did not require reliability analyses) with roughly 6 components per lock, and 5 traffic forecasts for each component. This equates to over 1000 sets of time dependent hazard rates computed for this analysis. An additional hundreds of other calculations for non-time dependent components were also done. Trying to sort through this data in a clear and concise manner is not easy even for those doing the computations. Therefore, in order to clearly explain the modeling process for each individual component, it was thought that the best way to thoroughly explain the process was to go through each model at one of the Ohio River sites for a single traffic scenario. This would be done for each component modeled. Because different projects were used for calibration of different models, the narrative will detail components at different projects. This should give the reader a good overview of how each component reliability analysis was developed and followed through for the entire analysis.

5.2 HORIZONTALLY-FRAMED MITER GATE RELIABILITY

Each of the horizontally-framed miter gates on the Ohio River is of similar design and construction techniques. Each is designed for a 110-ft wide chamber and is constructed of built-up, welded members. The exception to this is the upper three auxiliary chamber miter gates for EDM. These chambers are 56-ft wide and the gates are made from rolled members. Because these auxiliary miter gates at the upper three sites are not used very often, are relatively new from recent major rehabilitations, and they are constructed of rolled sections, it was decided by the team that a reliability analysis for these gates was not warranted.

5.2.1 Background

The horizontally-framed gates on the Ohio River locks were separated into four distinct groups for their reliability analyses. The first group consisted of miter gates that had floating, welded pintle design with one set of diagonals per leaf. This group included the following sites: Willow Island, Belleville, Racine, Greenup, Meldahl, Markland, and McAlpine. The global finite element model for the first group was modeled after the Markland miter gates. The second group consisted of miter gates with fixed, bolted pintle design with two sets of diagonals per leaf. These sites included the miter gates at New Cumberland, Pike Island, and Hannibal. The second group global finite element model was based upon the downstream gates at New Cumberland. The third group consisted of miter gates with a fixed, bolted pintle design with one set of diagonals per leaf. These sites included Cannelton, Newburgh, J.T. Myers, Smithland, R.C. Byrd, and Olmsted. The basic, global finite element for group three was modeled based upon the Cannelton miter gates. The final group is the auxiliary chamber miter gates at Emsworth, Dashields, and Montgomery. As discussed previously, no reliability modeling was required for the group four miter gates. Refer to Figure ED 5-3 for the grouping of Ohio River horizontally-framed miter gates.

The basis for the analysis and reliability model for all horizontally-framed miter gates on the Ohio River was based upon the Markland miter gates. Markland represents the oldest project on the Ohio River that has not been rehabilitated. The gates are experiencing fatigue cracking and are nearing the end of their original design life (assumed to be 50 years). The team originally investigated traditional strength and fatigue analysis associated with the main load carrying members for bending. After initial results indicated no potential problems at Markland for the entire study period, it was decided to refocus the effort towards actual field experience at Markland. It is important to note that other miter gates on the Ohio River have experienced similar cracking patterns, but to a less extent than the current damage to Markland's gates. A brief history of the problems encountered with the Markland miter gates is described below followed by the development of the model and calibration.

5.2.2 Overview of the Miter Gate Model

Serious concern regarding the integrity of the miter gates at Markland arose during a scheduled maintenance dewatering in 1994. This dewatering was scheduled to do major maintenance for the main chamber, including jacking the miter gates and replacing the pintle, seals, etc. However, once the chamber was dewatered and the gates were inspected, severe cracking at several locations was noted. Many of the cracks were at welded connections of the main load carrying members. In particular, the heaviest cracking occurred near the pintle area on the lower girders. It was determined that the extensive cracking was fatigue-related. Since the gates had seen less than 40 years of operation at the time of the 1994 dewatering, the fatigue of the gates was considered to be an abnormal failure mode. In order to determine the cause for this type of extensive cracking, the Louisville District hired an engineering consultant specializing in nonlinear finite element modeling to help determine the cause for the early fatigue cracking. It was determined by the Louisville District and the consultant that the root cause of the early fatigue cracking was due to the original fabrication and erection when the flanges and webs were welded together and subsequent repair methods when welding was used to repair smaller cracks throughout the history of operation. Because of the large number of structural members joined together in the pintle area, the entire region is highly constrained from movements due to temperature fluctuations. When welding occurs, large stresses are developed in the members near the weld joints. As the weld joint cools, large tensile stresses (termed residual stresses) are "locked" in place because the restraints of the gate in the pintle area. The large tensile stresses then are subjected to normal operating loads due to pool fluctuations as a chamber goes between upper and lower pool. When the gate is holding back pool, compressive stresses are applied to these areas where the tensile, residual stresses are locked in, thus, causing a stress reversal during each operation. This large stress reversal,

Ohio River Main Stem Systems Study

Horizontally-Framed Miter Gate Information Sheet

									Gate Properties at Pintle Area							
	Site	Service Year	Lift (ft)	Pintle Design Base	Pintle Design Connection	Diagonals per Leaf	Number of Girders	Bottom Girder Depth	Web Thickness	Downstream Flange	Thrust Plate Thickness	x-dist. from quoin	Girder Depth at x-dist.	Flange Crack Length	Critical Crack Length	Upstream Flange
Group 1	Willow Island	1972	20	floating	welded	one	11	70"	5/8"	16 x 1	0.75" avg.	44"	38"	3.75"	23.31"	16 x 1
	Belleville	1965	22	floating	welded	one	12	70"	5/8"	16 x 1	0.75" avg.	44"	38"	3.75"	23.31"	14 x 1
	Racine	1967	22	floating	welded	one	13	70"	5/8"	18 x 1	0.875" avg.	44"	38"	4.25"	23.31"	20 x 7/8
	Greenup	1959	30	floating	welded	one	15	70"	5/8"	18 x 1	0.75" avg.	44"	38"	4.25"	23.31"	20 x 7/8
	Meldahl	1962	30	floating	welded	one	15	70"	5/8"	18 x 1	0.75" avg.	44"	38"	4.25"	23.31"	20 x 7/8
	Markland	1959	35	floating	welded	one	14	70"	5/8"	18 x 1	0.75" avg.	44"	40"	4.25"	23.31"	20 x 7/8
	McAlpine	1962	37	floating	welded	one	16	70"	5/8"	18 x 1	0.75" avg.	44"	40"	4.25"	23.31"	20 x 7/8
									Gate Properties at End of Quoin Diagonal Plate							
Group 2	N. Cumberland (u)	1959	20.5	fixed	bolted	double	8	61-3/8"	7/16"	15"x 5/8"	0"	100"	61-3/8"	7.28"	0"	15 x 1
	N. Cumberland (d)	1959	20.5	fixed	bolted	double	11	61-3/8"	3/8"	15"x 5/8"	0"	100"	61-3/8"	7.31"	0"	15 x 1
	Pike Island (u/s)	1963	21	fixed	bolted	double	9	61-3/8"	3/8"	15"x 3/4"	0"	100"	61-3/8"	7.31"	0"	15 x 1
	Pike Island (d/s)	1963	21	fixed	bolted	double	11	61-3/8"	7/16"	15"x 3/4"	0"	100"	61-3/8"	7.28"	0"	15 x 1
	Hannibal	1972	21	fixed	bolted	double	11	61-3/8"	3/8"	15"x 5/8"	0"	100"	61-3/8"	7.31"	0"	15 x 1
									Gate Properties at End of Quoin Diagonal Plate							
Group 3	Cannelton	1973	25	fixed	bolted	one	14	54"	1"	9 x 1	0"	89"	54"	19.3"	0"	18 x 2
	Newburgh	1974	16	fixed	bolted	one	12	54"	3/4"	9 x 1	0"	89"	54"	19.65"	0"	14 x1.25
	JT Myers	1972	18	fixed	bolted	one	13	54"	1"	9 x 1	0"	89"	54"	19.5"	0"	16 x 1.375
	Smithland	1979	22	fixed	bolted	one	13	54"	3/4"	9 x 1	0"	89"	54"	19.73"	0"	12 x 1
	RC Byrd	1993	23	fixed	bolted	one	12	70"	3/4"	12 x 1/2	0"	89"	70"	26.25"	0"	8 x 3/4
	Olmsted	2006	15	fixed	bolted	one	11	54"								
Grp 4	Emsworth Aux.	1982	18	fixed	bolted	one	15	24"	1/2"	7"x 7/8"						
	Dashields Aux.	1984	10	fixed	bolted	one	16	24"	1/2"	7"x 7/8"						
	Montgomery Aux.	1984	18	fixed	bolted	one	14	24"	1/2"	12-3/4"x 3/4"						

Figure ED 5-3. Ohio River Horizontally-Framed Miter Gate Data Sheet.

coupled with the historical number of load cycles, has caused the fatigue-related cracking on these of gates. Figures ED 5-4 through ED 5-8 shows several photos from the 1994 dewatering.

Figure ED 5-4 depicts the widespread cracking present in the main chamber miter gates. The white arrows in the photo show areas where large cracks were found and in need of immediate repair. Note most of the cracking on this leaf is occurred where the vertical stiffeners were welded to the horizontal girders. Cracks initiated at that connection and grew through the girder flange.

Figure ED 5-5 shows repair technique on one of the miter gate leafs. Repair consisted of gouging out the entire length of the weld and re-welding material back together. Note cracking on this leaf initiates at corners of small diagonal plates and girder/stiffener flanges and then proceeds through flange. Additionally, note extensive length of cracks.

Figure ED 5-6 depicts cracking also prevalent near pintle region where diagonal plate is welded to the gate. White arrows show positions of extensive cracking. Note new flange for lower girder for this leaf. This was added due to damage to lower girder flange on this girder.

Figure ED 5-7 shows main chamber miter gate damage to the lower girder downstream flange. Note damage to lower girder flange plate due to buckling of the web. The buckling of the web helped cause the connection between the web and flange plate to separate as shown in Figure ED 5-8.

Figure ED 5-8 is a photograph that shows a close-up of the damage to the flange plate looking from "inside" the girder towards the downstream flange plate. Note the separation of the flange plate from the web of the girder. coupled with the historical number of load cycles, has caused the fatigue-related cracking on these of gates. Figures ED 5-4 through ED 5-8 shows several photos from the 1994 dewatering.

Figure ED 5-4. Main Chamber Miter Gate Cracking Above Pintle

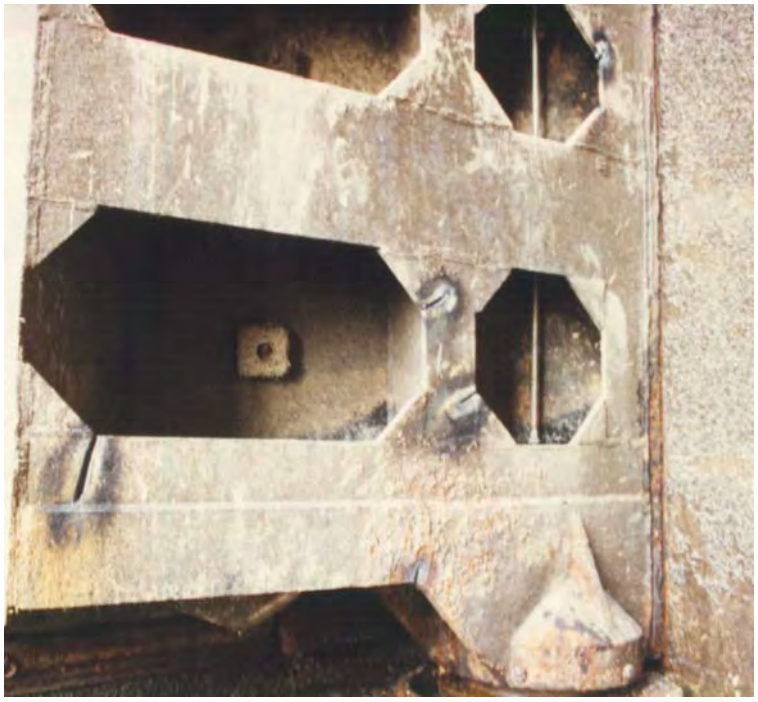


Figure ED 5-5. Main Chamber Miter Gate Crack Repair in Pintle Region

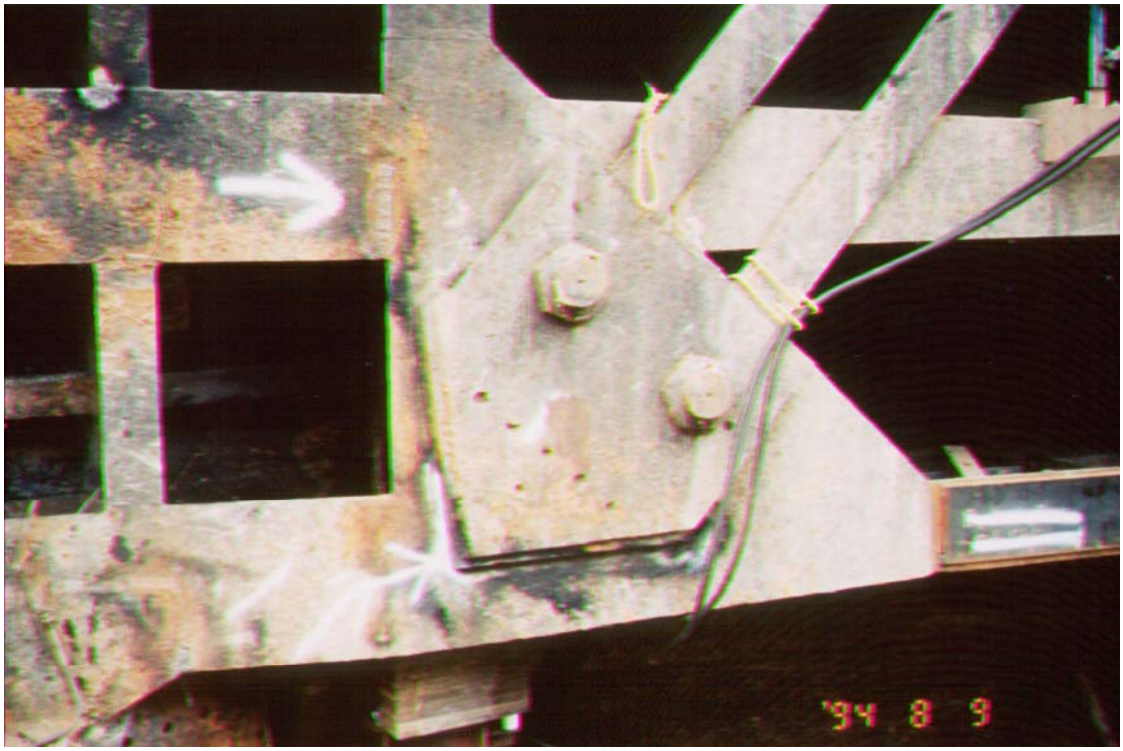


Figure ED 5-6. Main Chamber Miter Gate Cracking Near Diagonal Plate

Figure ED 5-7. Miter Gate Damage to Lower Girder Downstream Flange

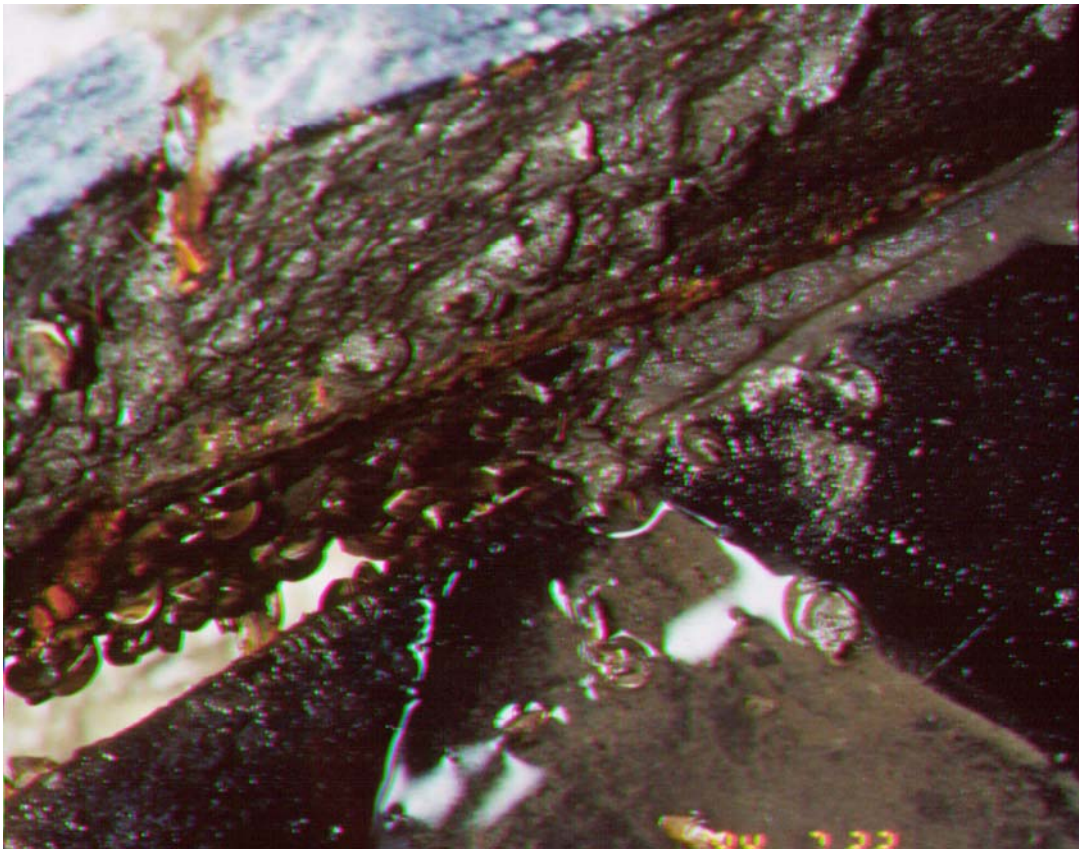


Figure ED 5-8. Miter Gate Damage to Lower Girder Downstream Flange

5.2.3 Finite Element Modeling of Miter Gates and Calibration

The fatigue cracking problem at welded flange connections on the Markland miter gates was summarized in previous sections. To evaluate the fatigue cracking problem from a reliability standpoint, the initiation and growth of the fatigue cracks must be characterized in terms of the variability of the parameters that control the fatigue cracking. The development of such a reliability model has three major components; 1) to determine the characteristics and variability of the initiation of fatigue cracks, 2) to establish the rate of crack growth and its variability, and 3) determine the limit state of the gate, which is defined as the extent of fatigue crack growth that will compromise the integrity of the gate.

The fatigue crack initiation and growth is primarily influenced by the residual stresses that develop during the welding of the girder flange and vertical stiffener flange. Large tensile residual stresses can develop in the flanges around the welded area due to constraints against thermal expansion (and contraction) during the welding process. The arch action of the gate under hydrostatic operating loads develops compressive stress in the flanges in the pintle region. These compressive operating loads, which are exasperated by the geometric re-entrant corner at the welded flange connection and the usually rough surface at the weld bead coupled with residual stress field, produce large stress cycles that initiate fatigue cracks.

A numerical study using finite element modeling was conducted to evaluate the cracking at welded flange connections.[1] As depicted in Figure ED 5-9, this study used global modeling of the gate leaf to define the range of compressive loads that develop in the girder flanges near the welded connections. Normal operating conditions as well as pintle wear and gate misalignment were considered. Detailed local models of the flange connection were used to establish the residual stress distributions by numerically simulating the weld process. This methodology was benchmarked against test data from the literature where stress magnitudes and distributions were measured around a weld on A36 steel as illustrated in Figure ED 5-10. Once the residual stress field was established in the local model, the flange loads were applied consistent with the global operational loads. The stress range for a cycle of operation was determined from a gate open condition, which includes gravity load, diagonal prestress, and residual stresses, to a gate closed condition that adds the operational loads. This stress range is then used to evaluate the number of cycles for crack initiation based on the American Society of Mechanical Engineers' design fatigue curve for carbon steel.[2] This calculation for fatigue crack initiation correlated very well with the observed cracking in the Markland miter gates during the 1994 and 1996 dewatering inspections.

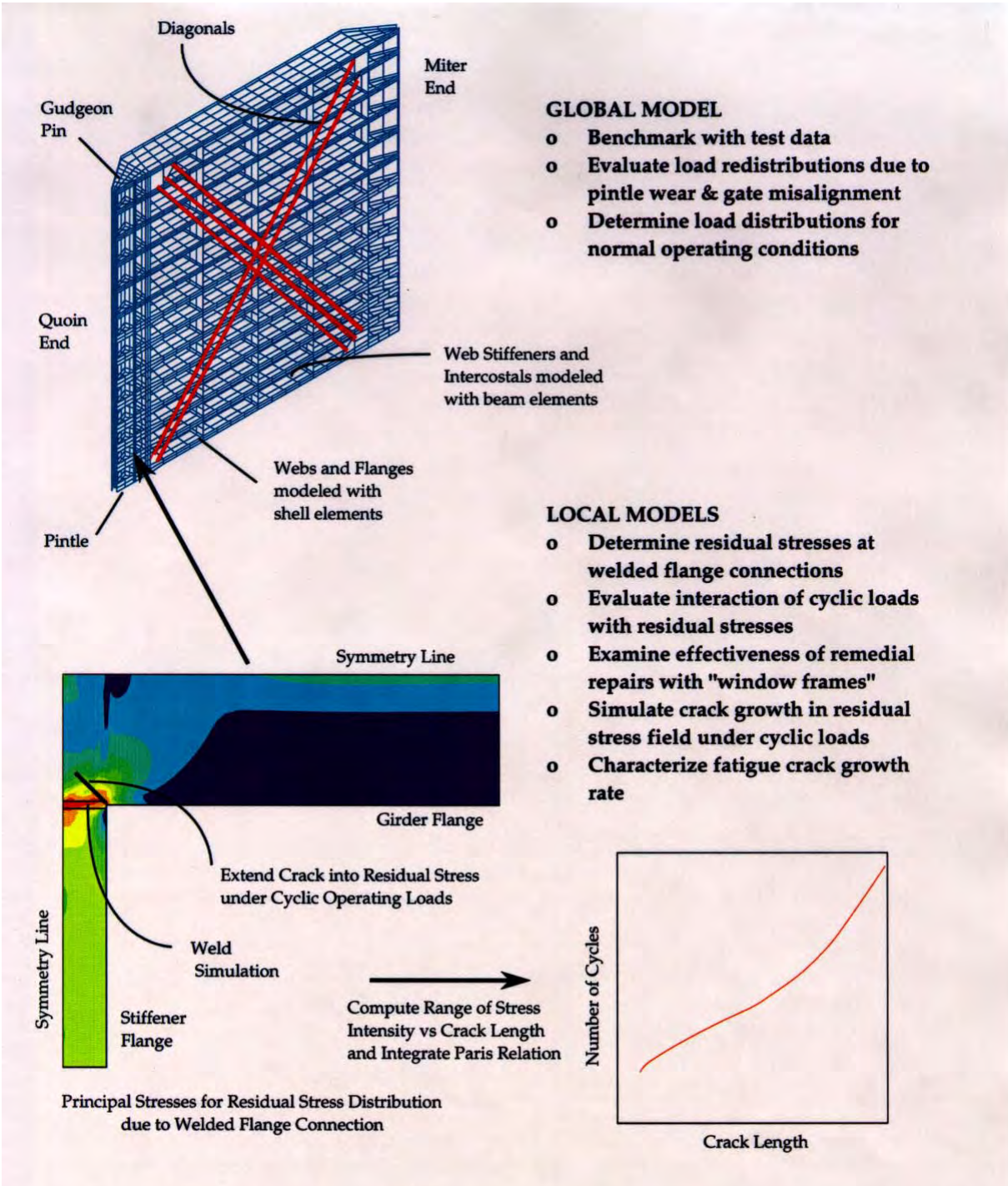


Figure ED 5-9. Global Finite Element Model of Markland Miter Gates

The next step was to develop a method for evaluating the rate of fatigue crack growth. Typically, the linear elastic fracture mechanics (LEFM) based formulas for stress intensity as a function of stress level and crack length of the form,

$$K = Q\sigma\sqrt{\Pi a}$$

are used to develop a relationship for the change in stress intensity versus crack length. This stress intensity relationship is then used with the Paris relation,

$$da/dN = C(\Delta K)^n$$

Where C and n are material parameters (with variability) for integration to find the crack growth rate. This method is illustrated in the Corps of Engineers' procedure for structural inspection and evaluation of welded lock gates.[3] However, these LEFM formulas are developed based on uniform far field stresses and, most often, Mode I crack growth. In this case, the driving stress for crack growth is the tensile residual stress distribution at the crack rather than the remote compressive flange stress. Moreover, these residual stresses change as the crack extends. Thus, another method for determining the rate of crack growth was required. The method that was developed in the Markland study was to extend a crack within the residual stress field in the local finite element model and compute the resulting stress intensity value under gate open and closed conditions. This was accomplished using the J-integral method to calculate the energy release rate for an increment of crack extension. The stress intensity value is computed from the energy release rate using LEFM assumptions. This energy based method also accounts for contributions to crack growth from all modes of crack extension. The Mode II or shear contribution is considered significant in this situation. Thus, a relation for stress intensity versus crack length was constructed by numerically extending a crack from the corner of the welded flange connection in the local model for gate open and closed conditions. The range of stress intensity versus crack length was then used to integrate the Paris relation to determine the crack growth rate of the fatigue cracks. As illustrated in Figure ED 5-11, this calculated crack growth rate correlated very well with the observed crack lengths in the Markland gates during the 1994 and 1996 dewaterings.

The development of the reliability model for horizontally-framed miter gates is based upon the above methodology. The intent of the model is to characterize the variability of the fatigue crack initiation and growth. The engineering team evaluated the importance of the parameters that influence fatigue cracking to establish the variables for characterization. A matrix of calculations is then performed with variations of these variables to develop relationships on the fatigue crack initiation and growth. The residual stress at a welded connection is influenced by many parameters, such as type of weld, number of passes, yield strength, strain hardening characteristics of the base metal and weld metal, and the degree of was not necessary to develop a reasonable residual stress distribution around the welded areas that govern the extended growth of fatigue cracks. Based on this work, the engineering team identified the material yield stress and the degree of constraint as the important random variables for developing the residual stress distribution at a welded connection. The temperature dependence and strain hardening variations are tied to the variation in yield stress. The degree of constraint is incorporated in the evaluation by considering three different types of welded connections. Thus, local models are developed for 1) the stiffener flange to girder flange connection, 2) the pintle casting to lower girder connection, and 3) the diagonal anchor plate to girder flange connection. These connections represented areas of the miter gate where fatigue cracking has been observed and are considered likely to have serious reliability consequences for extended cracking. constraint during welding. The Markland miter gates demonstrated that modeling the weld process

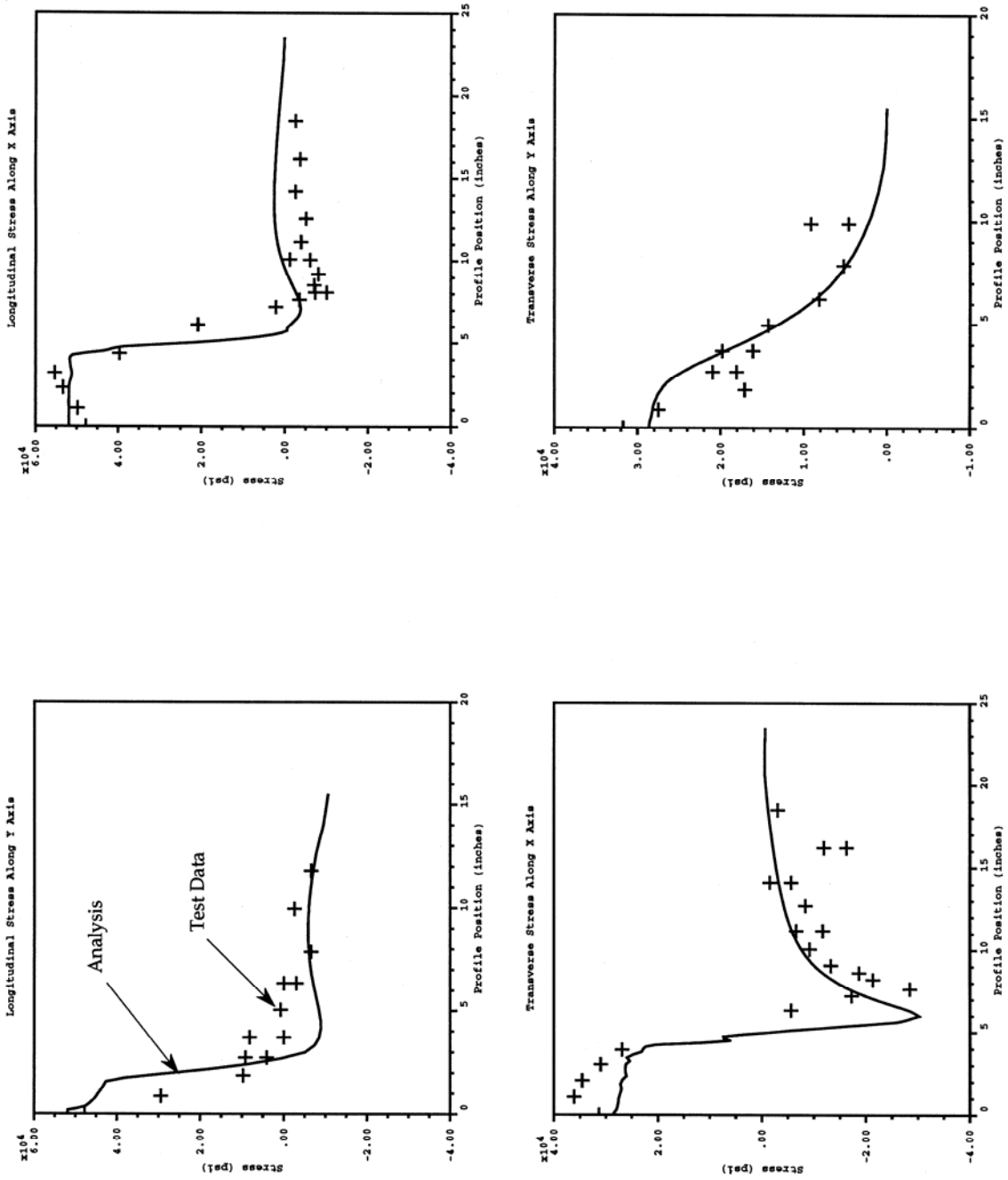


Figure ED 5-10. Stress Distribution Around Welds on A36 Steel.

The fatigue cracking is also governed by the compressive side of the stress cycle, so that the reliability model must be characterized in terms of operating stress on the connection, typically the girder flange stress, which can be related to the head variations. Finally, the crack growth is defined by the material constants in the Paris relation, and the material coefficient is also defined as a random variable. Thus, for each local connection model, analyses are conducted with material variation in yield stress to develop the resulting variations in residual stress distributions. Then variations of flange stress are applied to each variation of residual stress to develop combinations of stress ranges. That is, curves of peak tensile residual stress versus yield stress are constructed along with curves of peak

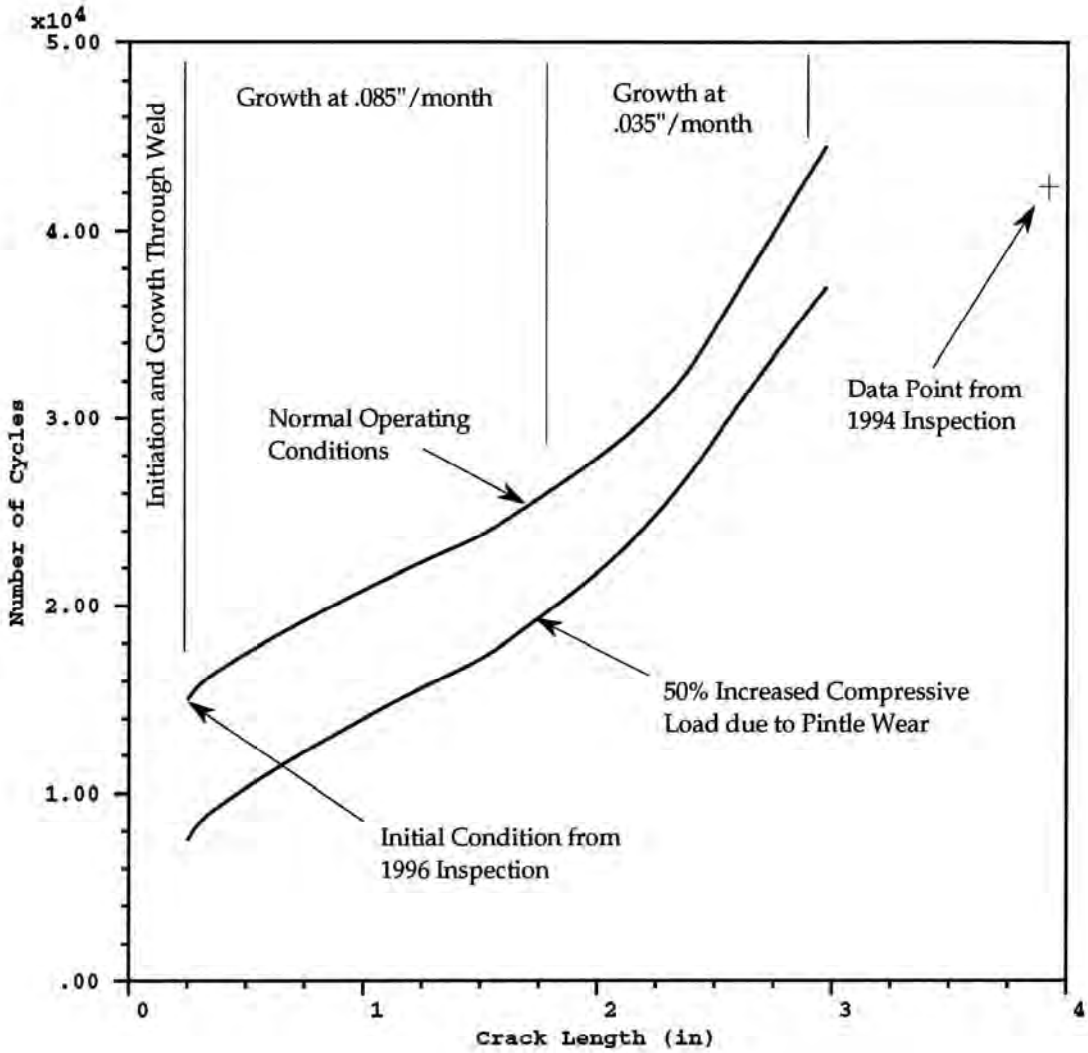


Figure ED 5-11. Graph Depicting Crack Growth Rate vs. Operating Cycles

compressive stress acting on the residual stress field vs. nominal flange stress. These relations are then fit with equations for defining the reliability model. The variation in crack initiation is characterized by evaluating the variation in cyclic stress range for given values of the random variables and using the ASME fatigue design curve to define the allowable number of cycles for crack initiation. A variation on the fatigue design curve was not considered necessary since this curve has been adjusted for material variation and because the results using the above method benchmarked very well with the observed crack initiation on the Markland gate.

The variability of the fatigue crack growth is developed in a similar manner. Cracks are extended in the variations of residual stress distributions for different variations of operating flange stresses to develop families of curves for stress intensity versus crack length. These variations are then used to integrate the Paris equation with variations in the material constant to develop families of curves for crack length vs. number of cycles for the variations in yield stress, flange stress, and fatigue rate coefficient. An equation is then fit to this data and the incremental form used to return an increment in crack extension for a given number of cycles and current values of the random variables.

5.2.4 Limit State of the Miter Gates

The methods and procedures used to characterize the initiation and growth of fatigue cracks at welded connections was described in the previous section. The next component in the reliability model is to define the limit state of the gate, which is the extent of fatigue cracking that will compromise the integrity of the gate. As the fatigue cracks grow into the flanges, the effective area for compression loads is reduced, and the effectiveness of the flange in preventing buckling of the webs is reduced. In the quoin region where compressive loads are high, buckling of the girder webs could lead to progressive failure of the gate. The limit state of the gate is thus defined by considering the degradation on the buckling characteristics for the growth of fatigue cracks. A baseline for the margin against buckling under normal operating loads is first established for the undamaged gate. Fatigue cracks are then extended in the global model by disconnecting elements in the mesh. Buckling calculations are conducted for increasing levels of damage until a criteria defining the limit state is reached.

For these redundant structures, local buckling can be tolerated without seriously compromising the gate integrity. Local buckling of girder webs in diaphragm bays is known to occur without serious consequences. In the buckling calculations, an eigenmode method is used to find a factor (eigenvalue) on the operating loads such that the associated buckling shape (eigenvector) has a zero stiffness. A sequence of buckling shapes and associated load factors is determined. A criteria must be established for the buckling characteristics that define a limit state for the gate. The criteria defined for this study is that any of the following conditions warrants a limit state that compromises the integrity of the gate;

(1) A buckling mode that extends over more than 1 girder (global buckling),
(2) A buckling mode that extends over more than ½ of a girder,
(3) Whenever the lowest buckling mode has a load factor less than 1.1.

Since the buckling characteristics are highly dependent on initial imperfections and the buckling calculations consider only nominal (perfect) geometries, the last criteria for a 10% safety factor is deemed appropriate. The buckling calculations also do not consider the progressive nature of buckling in that each calculated buckling mode is independent of the previous modes occurring with smaller load factors.

For each type of connection, the limit states are determined by progressively incorporating fatigue cracking damage into the global model and evaluating the buckling characteristics against the above criteria. Table ED 5-3 summarizes the levels of damage found to constitute limit states for the gate under fatigue cracking damage. The level of damage needed for failure due to cracking at the pintle casting connection and for the diagonal anchor plate to girder flange connection were found to be much greater than for the stiffener flange to girder flange connection in the pintle region. In addition, the crack initiation phase is typically longer and the growth rate slower due to lower compressive working stresses at these connections. The residual stresses are also lower because there is usually less constraint at these connections during the welding of the connection. Therefore, it was found and concluded by the engineering team that the stiffener flange to girder flange connection is the controlling case for reliability of the miter gates for Group 1. It was determined that the cracking at the girder flange to the diagonal anchor plate was the controlling case for the Group 3 miter gates, which includes J.T. Myers. Figure ED 5-12 illustrates the buckling mode for the undamaged Markland gate.

Figure ED 5-13 illustrates the level of damage needed to compromise the integrity of the gate due to buckling of the girder webs in quoin region. This level of damage basically needs to be such that the horizontal flanges are rendered completely ineffective in supporting the webs on the bottom two girders.

The first scenario investigated was that the cracks initiating in the girder flange at the corner of the connection would grow through the flange width to reach the web. Cracking would need to initiate and proceed from both the top and bottom of the flange and at the connections on both ends of the span along the web between stiffeners. However, as this type cracking develops, the global model showed that the resulting load redistribution in the gate would inhibit the continued crack growth at two of the opposite corners of the flange connections. The detailed local models also indicated that while the crack starts along a 45° angle from the corner of the connection, the residual stress field would cause the crack to turn horizontal toward the stiffener web. This leads to the conclusion that the fatigue crack would turn and grow into the secondary residual stress field of the welded connection joining the stiffener web on the underside of the girder flange. Because of the continuous tensile residual stress along the flange to girder connection, the fatigue crack is likely to have a fairly constant growth rate during this mode for very long crack lengths. As the cracking extends toward the girder web along the stiffener to girder flange connection, the large compressive loads in the girder will then cause the cracking to continue along the girder web to girder flange connection. This type of cracking at the girder web to girder flange connection has been observed in the Markland gate in the diaphragm bay next to the quoin region. This cracking will completely separate the flange from the web leading to buckling of the web in the highly compressive load region. Because the local models of the welded flange connection only considered the growth of the fatigue crack in the girder flange, an additional local model was developed to define the growth rate of the crack along the flange to web connection. This model required three-dimensional finite element modeling because of the geometry involved.

Type of Connection	Damage Required for Gate Instability
Girder Flange to Stiffener Flange in Quoin Region	Separation of Girder Flange on Bottom 2 girders
Girder Flange to Diagonal Anchor Plates at Quoin Region	Cracking through Flanges and into girder web for 1/8 of web depth on bottom 2 girders
Welded Pintle to Bottom Girder	Extensive Cracking Required. Will not Govern Fatigue Life

Table ED 5-3. Levels of Damage for Limit State of Markland Miter Gate

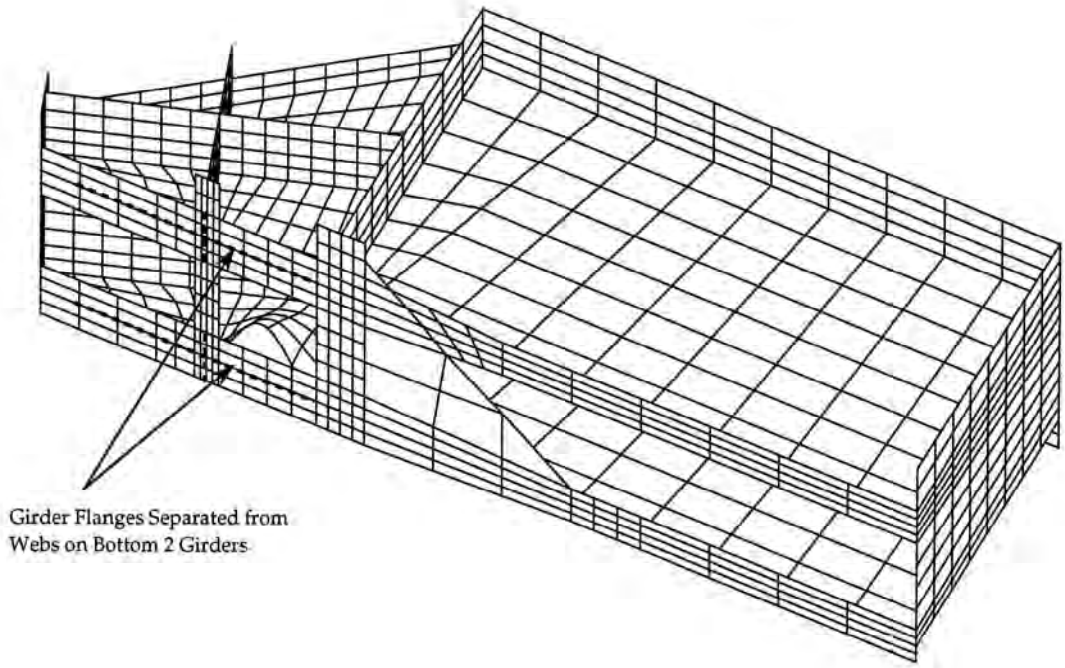


Figure ED 5-12. Buckling Damage of Markland Gate from Finite Element Model

5.2.5 Baseline Condition for Horizontally-Framed Miter Gates

The baseline condition represents the current Louisville District Operations personnel's method of operation concerning Ohio River lock maintenance. In general, the main chambers are dewatered at 5-year intervals for inspection and routine maintenance on the entire chamber. These dewaterings are usually 10 to 15 days in duration and repair work consists of inspection of the miter gate, along with minor repairs. Additionally, an overall inspection of the chamber is completed including machinery and valves. However, every 15 years (or the third dewatering of the 5-year cycle) is for significantly more maintenance to the chamber. At this dewatering, the miter gates are jacked in place and pintles, seals, and quoin/miter blocks are re-worked or replaced. Other chamber work also takes place during this dewatering such as culvert valve repair, gate and valve machinery work, along with clearing the culvert of debris build-up. These larger dewaterings usually take anywhere from 30 to 45 days. Intermittent dewaterings 15 to 30 days in duration are also required for non-miter gate work to properly maintain the lock chamber. For a more detailed description of maintenance scenarios and their effect on lock chamber closures on a district/lock project basis, please refer to Section 6 of this appendix.

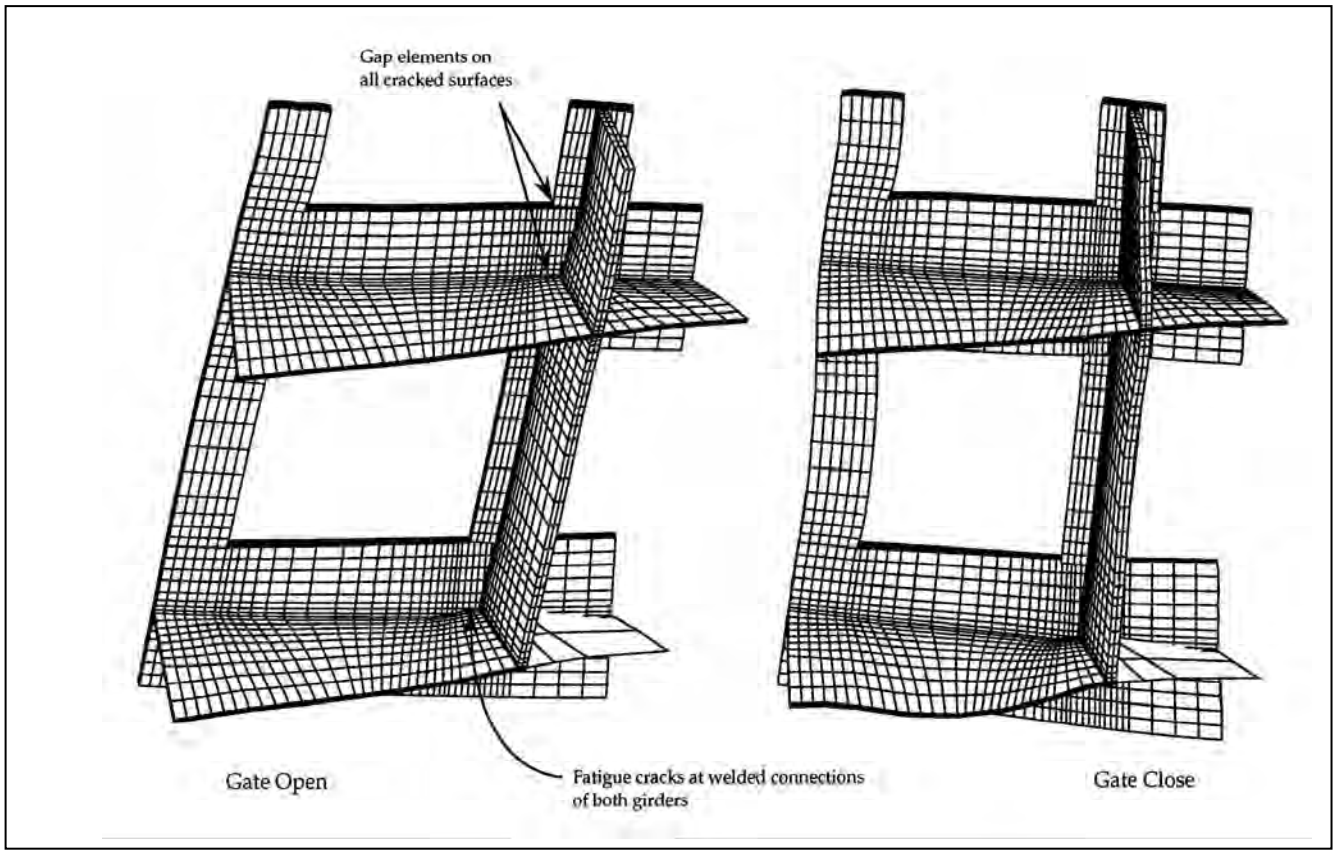


Figure ED 5-13. Buckling Damage Required for Major Failure of Miter Gates

Because the work involved with the normal maintenance schedule is generally for repair/replacement of maintenance items (seals, pintles, etc.), it is assumed that normal maintenance does not upgrade the overall reliability of the gate from a fatigue and corrosion standpoint. Therefore, for the reliability assessment, the baseline condition is considered a "fix-as-fails" approach.

5.2.6 Reliability Model Parameters

The reliability analysis for the horizontally-framed miter gates was developed to focus specifically on the type of cracking and problems that were occurring in the field. In order to accomplish this effort, the team focused its effort toward developing a model based upon the finite element analysis of the Markland miter gates. It was learned from developing the vertically-framed miter gate model for ORMSS that using the spread sheet on time dependent models was time consuming and often difficult to track changes and output. After initially developing a basic model with the spreadsheet, the engineering team decided to develop a Visual Basic coded model specifically for the ORMSS horizontally-framed miter gates and use Markland as the basis for the analysis. Therefore, the team coded their own model focusing on the cracking of the miter gates near the pintle and used @Risk^{TM} libraries for the Monte Carlo simulation within the reliability model. Immediately, it was determined that the coded model served the team's needs better for this component as it was easier to track changes and make calibration runs. The model was named HWELD since it was based upon the premise of crack initiation at welded connections.

5.2.7 HWELD Reliability Model Input

The following sections detail the input menus for HWELD for running a reliability analysis for a set of ORMSS horizontally-framed miter gates. A few of the sections have figures supplied with them for the Markland input values to give the reviewer a feel for inputting data into the program.

A) Lock Information. The first portion of input file is the project location, chamber, and girder that is bei~~ng analyzed. Fo~~r most ORMSS sites, the miter gates for both the main and auxiliary chamber gates are the same in terms of design and construction technique. However, operating cycles and age are different for the chambers and thus, each must be analyzed separately. The input menu from HWELD for the Markland miter gates is shown in Figure ED 5-14 as an example.

B) Cross-Section Properties of Miter Gate. The properties of the miter gate girder are required in order~~ to compute the operating stresses in the~~ area where the gate is susceptible to cracking. The required input for cross-section properties of the miter gate in HWELD is for the web/flanges, thrust plate, and overall gate geometry. The values are treated initially as constants but decrease over time in thickness dependent upon the paint life and corrosion rate. A series of input menus guide the user through the necessary property inputs for the girder properties, thrust plate properties, and finally, the overall gate geometry.

Web/Flanges – The inputs required for the upstream (u/s) and the downstream (d/s) web/flanges in HWELD are the thickness and width of the flange and the thickness and depth for the web in the quoin area. The x-distance is defined as the "section cut" from the quoin contact block to the critical point of interest where cracking of the welded connection is being considered. Since cracking for the base case (Markland) miter gates is widespread in the pintle region, the average x-distance is used for the middle diaphragm location. As an example, the HWELD web/flange property input values for the web/flanges cross-section properties for Markland are shown in Figure ED 5-15.

Thrust Plate – The HWELD inputs for the thrust plate are the width, thickness, and the distance from the downstream (d/s) flange.

Geometry – The required inputs for the geometry of the horizontally-framed miter gate are the gate height, spacing of girders, skin plate thickness, and working length. Other data is input into HWELD and is not directly used in the reliability calculations. This data is used only for information and includes items such as the gate height, length of girders, and tangent of angle that the girders are oriented.

C) Crack Parameters. The crack parameters required for the HWELD program are the initital crack l~~ength, the flange crac~~k length, and the critical crack length. The initial crack length is set to a default value of 0.25 inches. This value is based on the results from the finite element analysis discussed in the previous section. The flange crack length is the distance from the initial crack through the flange to the web. The critical crack length is defined as the critical distance along the web and flange welds to which the limit state buckling of the thrust plate occurs.

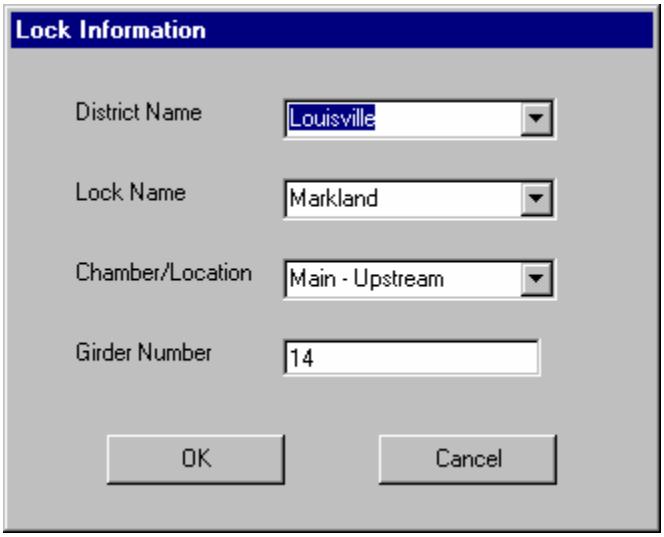


Figure ED 5-14. Lock Information Input Menu for HWELD Reliability Model

D) Head Histogram. The head histogram reflects the actual past distribution of head differential f~~or operating cycl~~es for the each set of miter gates. This distribution is based on true daily lockage cycles available from the Lock Performance Monitoring System (LPMS) combined with the true head differential for each day. This distribution is valuable in determining the fraction of annual cycles versus the expected head differential that is used for fatigue analysis. The head histograms developed by WES are based on data collected and analyzed for approximately 12 years (1984–1995, inclusive) of lock operation. The HWELD program allows the input of up to 20 different blocks for head (at specified midpoints for ranges) and fraction of cycles from the histograms. This histogram is used in HWELD to parse the input annual cycles into the defined stress range blocks and number cycles for fatigue analysis. The example head histogram input for Markland is shown in Figure ED 5-16.

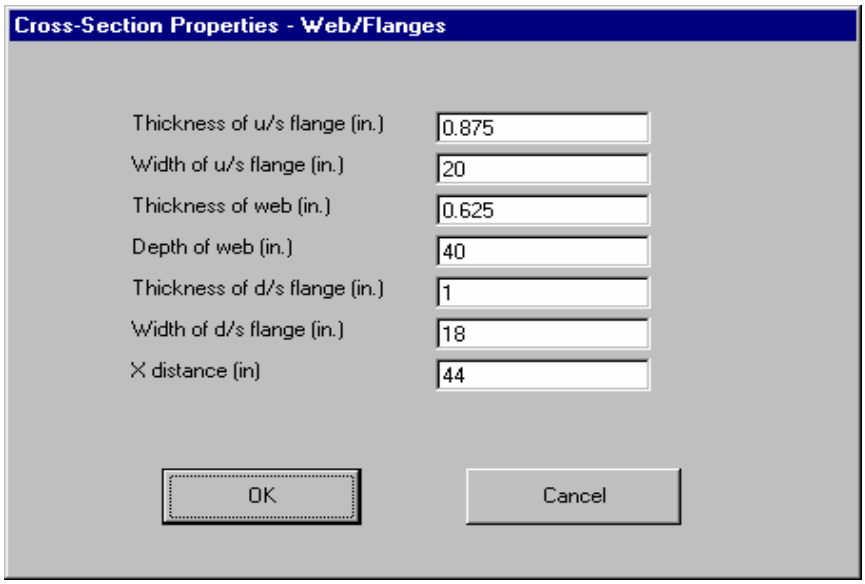


Figure ED 5-15. HWELD Web/Flange Properties Input Menu

E) Traffic Cycles. The number of operating cycles for the gates are determined for each lock based on actual and predicted future cycles for the study period. The cycle information is used in fatigue analysis incorporated into the HWELD program. The cycles are input from the start of operation to the end of the study period. Operating cycles from the origination of the each project through 1983 were determined by going through the log books to determine the number of lockages in each chamber. A ratio of lockages to operating cycles was determined and assumed to be the same in the past as well as for future projected cycles. Traffic cycles for 1984 through 2004 were determined on historical traffic using LPMS data. Future traffic projections for each of the five scenarios (Clear Skies, Modified Clear Skies, NAAQS, Utility Based, and Utility High) were provided by the ORMSS Economics Team.

F) Paint History. The painting of the miter gates can be incorporated in the reliability analysis. This directly effects the corrosion of the gate members based on the defined paint life. The input required is the specified paint life and the year in which the gates were painted. These paintings are assumed to be for the entire gate and not just spot painting of gate. If a gate is painted after the initial paint life is exceeded then corrosion is not invoked until the end of the paint life. Paint histories can be entered for up to three different years.

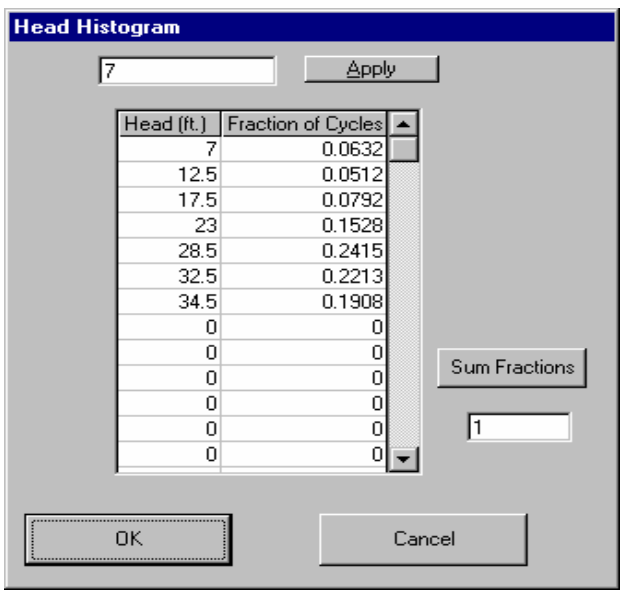


Figure ED 5-16. HWELD Head Histogram Input Menu

5.2.8 Random Variables

The random variables incorporated into the reliability analysis of the miter gates are the yield strength of the steel, corrosion rate, stress concentration factors, and misalignment/pintle wear factors. These random variables are simulated using either direct Monte Carlo simulation or a modified simulation method called Latin Hypercube. The Latin Hypercube method utilizes stratified sampling of the input distributions for quicker convergence and both methods are incorporated into the HWELD program. Pool level differential between the upper and lower pools (commonly referred to the head) is essentially a random variable because the actual histogram allows for heads in eight different ranges but the values are not chosen separately for each iteration, therefore, it represents a more accurate

measure of the pool level distribution at each project. The input distributions and statistical moments for the random variables are defined in the sections below.

A) Yield Strength. The distribution for yield strength is based on data from the published literature and previous Corps of Engineers reliability studies. The distribution is based on a truncated lognormal with a nominal yield stress of 38.88 ksi (i.e., mean yield strength times the strength ratio) and a standard deviation of 5.44. The lower limit for truncation is based on one standard deviation below the nominal (33.88 ksi) and the upper limit is based on approximately two standard deviations above the nominal (51 ksi).

B) Corrosion Rate. The distribution for corrosion rate is based on the data from the published literature and previous Corps of Engineers reliability studies. Corrosion is based on a power law that has been fit to actual field data in various corrosive environments. The equation used for the corrosion is $C(t) = A*t^B$, where A is a random variable based on field measurements, B is generally a constant based on different corrosive environments and C(t) is the corrosion in micromils/yr.[4] For this report, the mean value of A was selected based on submerged corrosion since the portion of the gate that was being investigated is always below lower pool. This distribution used for A was a truncated lognormal with a mean value of 77.33 and standard deviation of 24. The upper limit of the distribution was taken at 128 and the lower limit at 32. The value for B was a constant of 0.593. These limits and constants are based on actual field measurement of submerged hydraulic steel structures.

C) Stress Concentration and Pintle Misalignment/Wear Factors. Two types of factors are utilized in the reliability model to account for differences in stress values between traditional hand calculations and finite element analysis. One adjustment is the stress concentration factor due to the intensification of the stress in the flanges near the pintle area. Separate local finite element models specific to each miter gate group were run to determine group-specific stress concentration factors, thus, not all sites used the same values for input. Additionally, a gate misalignment and pintle wear factor that accounts for an increase in stress in the girder flange during operation is provided in the analysis. The adjustment values for both the stress concentration and misalignment/pintle wear factors were based upon finite element modeling results and calibration with field test data at Markland. The distribution for the stress concentration factors was considered uniform, meaning that any number within the specified range has equal chance of being selected in an iteration, since only the upper and lower limits can be well defined as well as the equal for the probabilities. For Group 1 (Greenup, Markland, etc.), the minimum stress concentration factor value was determined to be 1.1 and the maximum value to be 1.4. For Group 2 (Cannelton, etc.), the minimum value was determined to be 1.2 with a maximum of 1.8. For Group 3 (J.T. Myers, etc.), the minimum stress concentration factor value was determined to be 1.4 and the maximum value to be 2. The misalignment and pintle wear factors were determined on a percentage increase in the flange stress. A truncated lognormal distribution was selected with a mean of 20% with a standard deviation of 30%. The lower limit was 10% and the upper limit taken as 50%. Again, these values were calibrated with the field measurements relating to cracking at Markland and were assumed to be the same for all groups.

5.2.9 HWELD Reliability Model for Horizontally-Framed Miter Gates

A) Reliability Model Purpose. The computer program HWELD has been developed to complete a reliability analysis of the horizontally-framed miter gates for Ohio River lock projects. The model is used to determine if it is a better decision to replace the gates at some scheduled date as opposed to fixing them after they perform unsatisfactorily.

B) Reliability Analysis. The basis of the model is that it is a time dependent reliability model for a structure subject to fatigue and corrosion. Therefore, input items such as paint history, corrosion rates, and other variables are used in conjunction with the operating cycles to determine the time dependent reliability of the structure. Using the analysis and limit state information from the finite element modeling, HWELD computes the time dependent reliability of the miter gates given the input values. For each iteration, the model determines the year in which a fatigue-related crack initiates and marks that year. Once the crack reaches the first length, the crack is allowed to grow relative to the operating cycles within the histogram for each year after the time which it initiates. The crack then grows until it reaches the critical lengths input in the menu. Once the crack grows to the flange length, the growth rate is reset for the second growth rate associated with it growing along the web/flange connection. Once the crack reaches the limit state crack length, the year is tracked, recorded and marked as the year of unsatisfactory performance. This is done for each iteration with the results tabulated in a separate output file.

C) Baseline Condition. The baseline condition is generally the way that maintenance is performed at each project today. This is typically inspection and repair during scheduled dewaterings with no overall improvement to the overall reliability of the gates. The baseline condition for the miter gates assumes that the structure does not receive any major rehabilitation, painting, or repairs from the start of operation to the end of study period, unless the miter gates have been painted prior to present day. The baseline condition also assumes a paint life of 20 years and that corrosion of the girder members occurs over the remaining study period, unless it has been totally sandblasted and painted.[5] The corrosion rate is always assumed to be for a submerged structure since that is the portion of gate being analyzed.

D) Calibration of HWELD Reliability Model**.** The calibration of the HWELD reliability models was made based on field data of crack lengths for Markland. These measurements and repairs were taken at two points in time (1994 and 1996) during lock dewaterings to fix and repair cracks in the welds in the pintle area. Since the HWELD program is based on the realistic flange stresses for the head values of the miter gates at Markland, the crack lengths and expected probability of failures determined from the model match well and support the field data.

5.2.10 HWELD Reliability Model Results and Event Trees

The Engineering Team is required to take the results from the reliability model, which are hazard functions for time dependent components, and supply them to the ORMSS Economics Team for their analysis and input into the Ohio River Navigation Investment Model (ORNIM). The hazard functions provided by HWELD represent the probability of unsatisfactory performance for a single gate leaf. Systems reliability applications must be used to incorporate the probability of unsatisfactory performance for all 4 miter gate leafs within a single lock chamber. For most projects, the upper and lower miter gates within the same lock chamber are of the same design and have seen most the same repairs and operational cycles. Therefore, the reliability of a single leaf essentially will be same for the other 3 gate leaves. All four leaves must be reliable for the chamber to be operational, thus, all 4 leaves are in series since the “failure” of any single leaf would shut the lock chamber down for some period of time. If significant repairs to improve the reliability of selected leafs have been completed, this improvement in reliability for that particular leaf was included in the analysis. Therefore, the calculation to determine reliability for the miter gates for an entire lock chamber, which is embedded in the economic analysis, is shown below.

$$\mathbf{R}_{\text{Miter Gates}} = \mathbf{R}_{\text{Leaf1}} * \mathbf{R}_{\text{Leaf2}} * \mathbf{R}_{\text{Leaf3}} * \mathbf{R}_{\text{Leaf4}}$$

$$\textbf{HAZARD RATE}_{\text{Miter Gates}} = \mathbf{1 - R}_{\text{Miter Gates}}$$

For those sites where upper and lower miter gates have different miter gate sill heights (upper and lower miter gates are not of the same design), there are separate hazard rates developed for the upper and lower miter gates. For these miter gates, only 2 leaves would be in series. This is only applicable for the New Cumberland and Pike Island sites. In addition to the time dependent hazard rates, the Engineering Team supplies a consequence event tree for each component that is used in conjunction with the reliability analysis for the economists to measure the economic impacts associated with each component. The event tree for the horizontally-framed miter gates is shown in Figure ED 5-17. The event tree is set up to investigate replacing both the upper and lower miter gates within a lock chambers since both sets of gates have the same level of reliability.

A) Baseline Condition for Miter Gates. The baseline condition represents a fix-as-fails plan with respect to the reliability analysis. It is assumed that any repairs that are done to the miter gate during normal scheduled dewaterings do not upgrade the reliability of the miter gate because these repairs typically only consist of replacing pintles, miter and quoin blocks, etc. These repairs do not significantly upgrade the structural reliability of the miter gate based upon the limit state set up in reliability model. Therefore, the reliability of the structure is allowed to degrade through time without repairs under the baseline condition.

For the purposes of this study, the hazard function is defined as the probability of unsatisfactory performance in a given year assuming it has survived up to that year. The formula for this is depicted below:

h(t) = number of failures in year t / number of remaining survivors up to year t

The computation of *h(t)* yields a yearly probability of unsatisfactory performance given that the miter gate has survived up to that particular year. The probability of unsatisfactory performance is tied to the limit state for the component (i.e. critical crack lengths reached on two lower girders for the horizontally-framed miter gates).

B) Baseline Condition Event Tree. The baseline condition is the scenario upon which all without project alternatives are compared against. The event tree for the miter gates was assumed to be the same for all projects with the same miter gates design on the upper and lower end of the lock chamber, which is the case for all projects except New Cumberland and Pike Island. Assuming the limit state for the miter gates as described previously and the need to investigate replacement for all four miter gates leaves within a chamber, the event tree shown in Figure ED 5-17 was developed for the horizontally-framed miter gates. Like all components, the repair branches of are developed by a consortium of engineering and operations personnel. The engineers and operations experts believed it was a more accurate reflection to increase the chance of more significant failure consequences with the age of the structure. Therefore, individual branch probabilities for components were linked to the age of the component. Regardless of the level of damage selected, the event tree represents a fix-after-failure situation because the miter gates already reached the critical limit state for which the hazard rate was developed. Thus, the repair is only initiated in the economic model once the gate “fails”. The

event tree for the miter gates at New Cumberland and Pike Island are structured in a similar manner, but formatted to replace a single set of miter gates (2 leaves). Because the gates for both the main and auxiliary chamber are the same design and construction technique, the same event tree is used for both the main and auxiliary chambers. However, economic results will differ for the auxiliary and main chambers as a function of navigation traffic and the hazard rates. The first branch of the event tree represents the annual hazard rate for the miter gates. The hazard rate changes depending upon the chamber which is being investigated. The second branch indicates various options associated with the level of repair for the miter gates. Since the limit state is based upon a major failure, minor repairs were neglected in the event tree. The group decided that minor repairs to the miter gates are taken care of during normal maintenance dewaterings and they do not affect the overall gate reliability. The percentages associated with each level of repair were determined from engineering judgment in consultation with Operations personnel. Associated with each of these repairs is a repair cost and chamber closure time. The loss of benefits associated with the chamber closure is modeled in the economic analysis by way of transportation delay curves. Finally, the last branch updates the reliability in the next year based upon the repair. A further breakdown of the event tree from the level of repair forward is provided below.

Catastrophic Failure, Install New Gates. This repair assumes the most catastrophic event, a total failure of one of the set of miter gates such that is not repairable to the point that the chamber can be made operational. Since the other gates would be of similar reliability, it is assumed these gates would also require replacement since they are in the same general condition. This repair assumes two new sets of miter gates are fabricated, delivered, and installed over a two-year period. There are no spare gates at any Ohio River projects, therefore, new designs and fabrications would be required to get the chamber operational again. Additionally, a repair cost of $33,100,000 is assumed for this repair. It is known that the Louisville Operations Repair Fleet costs on average about $100,000 per day including materials for emergency type of repair works. This cost was determined based upon recent emergency dewaterings at both the Markland and McAlpine lock chambers. The assumption is made that the repair fleet would need to be on-site approximately 90 days to conduct salvage operations for the failed miter gates in the first year. The first year would also be used to develop an emergency design and initiate fabrication of a pier at the site to assemble two new sets of miter gates delivered to the site in sections. Fabrication of the miter gates would be completed in the 2nd year and then the miter gates would be installed. Another additional 90 days is required in year 2 to install both sets of miter gates. Therefore, the repair costs for the new gate repair level and how they were determined is shown as follows:

Repair Fleet Pulls Damaged Gates Repairs (Year 1):	$9,000,000 ($100k/day for 90 days)
Construction of Miter Gate Assembly Pier (Year 1):	$1,500,000 (Markland Rehab)
Fabricate and Delivery of 4 Gate Leafs (Year 2):	$10,000,000 (McAlpine new gates)
Assembly of 4 Gate Leafs on Pier (Year 2):	$3,600,000 (McAlpine new gates)
Installation of 4 Gate Leafs in Chamber (Year 2):	$9,000,000 ($100k/day for 90 days)
~~**Total for All Items for Catastrophic Repair:**~~	~~**$33,100,000**~~

This repair scenario is deemed the least likely to occur for most years of the effective life of the miter gates. As discussed previously and shown in Figure ED-17, a sliding scale has been provided such that the chance of this type of failure/repair increases as the miter gates age. This level has a 5% chance of occurrence during the first 30 years the miter gates

HORIZONTALLY-FRAMED MITER GATE EVENT TREE (2 SETS OF GATES)

ALL MITER GATES ARE SAME SIZE, AGE, AND GENERAL CONDITION

ANNUAL HAZARD RATE	LEVEL OF FAILURE & SUBSEQUENT REPAIR		CLOSURE TIME	REPAIR COST	DESCRIPTION OF REPAIR SEQUENCE	EFFECT ON FUTURE COMPONENT RELIABILITY
Annual Reliability Value (1 - Annual Hazard Rate)						
	Catastrophic Failure Requiring New Gates	5% 0-30 years of service	365 days in year 1	Cost $10,500,000	Fleet on-site for 90 days for salvage operations, assembly pier construction	Assume R = 1.0 for All Future Years
		15% 31-50 years of service	180 days in year 2	Cost $22,600,000	Miter gates fabricated, delivered, assembled, and installed (90 days fleet time)	
		30% Over 50 years of service				
Annual Hazard Rate	Major Repair but Gates Still Useable for Future	35% 0-30 years of service	45 days in year 1	Cost $4,500,000	45 days to repair 1st set of damaged miter gates	Move Back 5 Years
		30% 31-50 years of service	45 days in year 2	Cost $4,500,000	45 days to repair 2nd set of damaged miter gates	
		20% Over 50 years of service				
	Temporary Repair and Construct Assembly Pier	60% 0-30 years of service	60 days in year 1	Cost $7,500,000	60 days to repair existing gates plus assembly pier construction	Assume R = 1.0 for All Future Years
	Assemble 1st Set of Gates on Pier and Switch Out	55% 31-50 years of service	45 days in year 2	Cost $11,300,000	1st set of gates delivered to site, assembled/painted on pier, 45 days to swith out	
	Assemble 2nd Set of Gates on Pier and Switch Out	50% Over 50 years of service	30 days in year 3	Cost $9,800,000	2nd set of gates delivered to site, assembled/painted on pier, 30 days to swith out	

Figure ED 5-17. Horizontally Framed Miter Gate Event Tree

event tree for the miter gates at New Cumberland and Pike Island are structured in a similar manner, but formatted to replace a single set of miter gates (2 leaves). Because the gates for both the main and auxiliary chamber are the same design and construction technique, the same event tree is used for both the main and auxiliary chambers. However, economic results will differ for the auxiliary and main chambers as a function of navigation traffic and the hazard rates. The first branch of the event tree represents the annual hazard rate for the miter gates. The hazard rate changes depending upon the chamber which is being investigated. The second branch indicates various options associated with the level of repair for the miter gates. Since the limit state is based upon a major failure, minor repairs were neglected in the event tree. The group decided that minor repairs to the miter gates are taken care of during normal maintenance dewaterings and they do not affect the overall gate reliability. The percentages associated with each level of repair were determined from engineering judgment in consultation with Operations personnel. Associated with each of these repairs is a repair cost and chamber closure time. The loss of benefits associated with the chamber closure is modeled in the economic analysis by way of transportation delay curves. Finally, the last branch updates the reliability in the next year based upon the repair. A further breakdown of the event tree from the level of repair forward is provided below.

Catastrophic Failure, Install New Gates. This repair assumes the most catastrophic event, a total failure of one of the set of miter gates such that is not repairable to the point that the chamber can be made operational. Since the other gates would be of similar reliability, it is assumed these gates would also require replacement since they are in the same general condition. This repair assumes two new sets of miter gates are fabricated, delivered, and installed over a two-year period. There are no spare gates at any Ohio River projects, therefore, new designs and fabrications would be required to get the chamber operational again. Additionally, a repair cost of $33,100,000 is assumed for this repair. It is known that the Louisville Operations Repair Fleet costs on average about $100,000 per day including materials for emergency type of repair works. This cost was determined based upon recent emergency dewaterings at both the Markland and McAlpine lock chambers. The assumption is made that the repair fleet would need to be on-site approximately 90 days to conduct salvage operations for the failed miter gates in the first year. The first year would also be used to develop an emergency design and initiate fabrication of a pier at the site to assemble two new sets of miter gates delivered to the site in sections. Fabrication of the miter gates would be completed in the 2nd year and then the miter gates would be installed. Another additional 90 days is required in year 2 to install both sets of miter gates. Therefore, the repair costs for the new gate repair level and how they were determined is shown as follows:

Repair Fleet Pulls Damaged Gates Repairs (Year 1):	$9,000,000 ($100k/day for 90 days)
Construction of Miter Gate Assembly Pier (Year 1):	$1,500,000 (Markland Rehab)
Fabricate and Delivery of 4 Gate Leafs (Year 2):	$10,000,000 (McAlpine new gates)
Assembly of 4 Gate Leafs on Pier (Year 2):	$3,600,000 (McAlpine new gates)
Installation of 4 Gate Leafs in Chamber (Year 2):	$9,000,000 ($100k/day for 90 days)
Total for All Items for Catastrophic Repair:	**$33,100,000**

This repair scenario is deemed the least likely to occur for most years of the effective life of the miter gates. As discussed previously and shown in Figure ED-17, a sliding scale has been provided such that the chance of this type of failure/repair increases as the miter gates age. This level has a 5% chance of occurrence during the first 30 years the miter gates

chamber, the chamber closure time and "repair" cost is reduced when compared to replacing the gates only after they fail. It is known from an extensive collection of historical data that the Louisville District fleet averages roughly $67,000 per day for maintenance dewaterings that are well-planned in advance. That would be this type of situation. The main features of this would be to construct an assembly pier on site and begin fabrication of the 1st set of gates in year 1. Year 2 would include assembling and installing the 1st set of miter gates and fabricate the 2nd set of miter gates. The 3rd and final year of repair ahead of failure would be to assemble the 2nd set of miter gates and install them in the chamber. Separate 30-day closures would be required in years 2 and 3 of this repair scenario. The total cost estimate for the replacement ahead of failure option is estimated to be $19,120,000. A breakdown of costs associated with this scenario is as follows:

Construction of Miter Gate Assembly Pier (Year 1):	$1,500,000 (Markland Rehab)
Fabricate, Deliver of 2 Gate Leafs (Year 1):	$5,000,000 (McAlpine new gates)
Assembly of 2 Gate Leafs on Pier (Year 2):	$1,800,000 (McAlpine new gates)
Installation of 2 Gate Leafs in Chamber (Year 2):	$2,010,000 ($67k/day for 30 days)
Fabricate, Deliver of 2 Gate Leafs (Year 2):	$5,000,000 (McAlpine new gates)
Assembly of 2 Gate Leafs on Pier (Year 3):	$1,800,000 (McAlpine new gates)
Installation of 2 Gate Leafs in Chamber (Year 3):	$2,010,000 ($67k/day for 30 days)
Total for All Items for This Repair Level:	**$19,120,000**

5.2.11 Miter Gate Reliability Results for Single Chamber (Newburgh Main)

Because there is an overwhelming amount of data associated with the engineering and economic analysis on ORMSS, it is believed that the best way to clearly illustrate the entire process being followed for an individual component is to step completely through the process for a single lock chamber. Previous portions of this document give a detailed description of how the hazard rates were computed for an individual lock chamber miter gate. For the purposes of this narrative, the Newburgh main chamber miter gates were selected as a prototypcial lock chamber to step through the process. The optimized replacement date for the miter gates of all other lock chambers for each traffic scenario are provided at the back of this narrative in the Economics Appendix. When reviewing this table keep in mind individual traffic levels peak for different projects for different scenarios. Thus, the one traffic forecast might have the highest traffic at one project and a different scenario might be highest at another project.

Referring back to Figure ED 5-3, the miter gates at Newburgh are represented within Group 3. These gates are similar to the Markland (Group 1) gates with the exception that the pintle castings are bolted to the miter gate and not welded. Additionally, relatively thicker plates were used in design compared to Group 1 miter gates, thus, reducing the operating stresses, and generally causing lower hazard rates over time compared to Group 1. The Newburgh miter gates followed the limit state criteria that involves fatigue-related cracking of the girders at the end of the quoin diagonal plate. This was determined from the finite element analysis of the typical Group 3 miter gates.

The Lock Risk Module within ORNIM requires three sets of hazard rates to be developed for each component. These are the hazard rates associated with the lowest, highest, and middle traffic scenarios. These vary by each site, but at Newburgh the lowest traffic scenario was the Clear Skies, the highest was the NAAQS scenario, and the middle traffic scenario was the Utility High forecast. ORNIM will take these hazard rates and then interpolate between them to determine an updated hazard rate for traffic levels that fall between these "limits" when traffic demand is put onto the system in the economic simulation analysis. A graphical representation of the main chamber miter gate hazard rates at Newburgh for each of these traffic scenarios is shown in Figure ED-18.

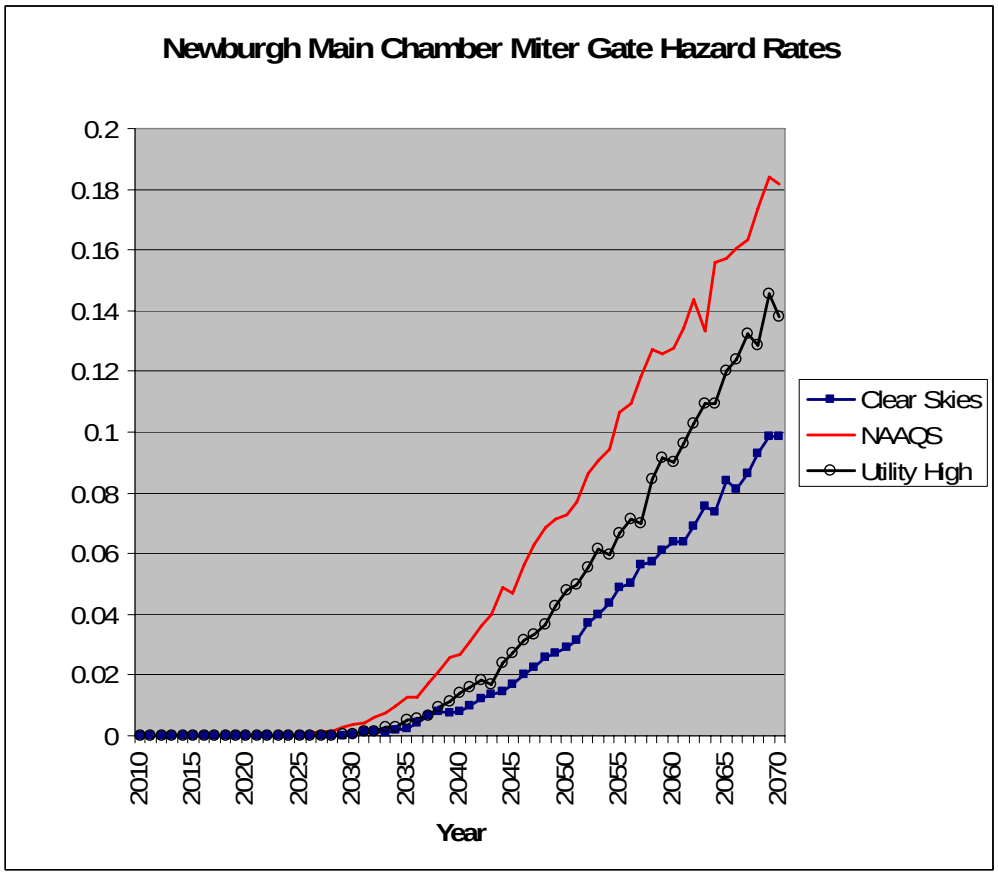


Figure ED 5-18. Newburgh Main Chamber Miter Gate Hazard Rates

As depicted in Figure ED 5-18, the highest traffic forecast (NAAQS) provides the highest hazard rate. The lowest traffic scenario at Newburgh (Clear Skies) is reflected in the reduced hazard rate through time. Forecast specific hazard rate computations from time of original service (1972) through the end of study (2070) were completed, but only the years which produced non-zero hazard rates are depicted in the figure for clarity sake. The first year of a non-zero hazard function was 2026 for the NAAQS scenario. Non-zero hazard functions for the other two scenarios first occurred in the year 2029 (Utility High) and 2030 (Clear Skies). The reason the hazard rates for the structural components take a "jagged" shape is due to the Monte Carlo simulation. In theory, the hazard rate would be smooth line increasing through time if an infinite number of iterations were run. A total of 50,000 iterations were run for each traffic scenario which is adequate for the purposes of this study.

5.2.12 Economic Analysis of Horizontally-Framed Miter Gates

The Engineering Team provides both the hazard rates, as shown in Figure ED 5-18, and the event tree shown in Figure ED 5-17 to the Economics Team for them to input into ORNIM. The other critical information for the main chamber miter gates provided to the Economics Team was the replace ahead of failure costs and closures as outlined in Section 5.2.10 of this appendix. ORNIM was then used to compute average annual costs for two repair options (fix-as-fails or replace ahead of failure) for the main chamber miter gates at Newburgh. The average annual costs include both navigation delay and physical repair costs. Improved reliability after the repair is also included in the analysis, as noted in the event tree for differing levels of repairs. The costs of each alternative, fix-as-fails versus selected replacement dates, are compared to determine the most economical option. The replacement

year with the lowest average annual cost sets the timed replacement of the miter gates with fix-as-fails costs added to the economic analysis up to the year of scheduled replacement. Refer to the Economics Appendix for a more detailed description of how the ORNIM optimizes individual component replacements. If the lowest average annual cost is associated with the baseline condition (fix-as-fails), then the replacement of the gates is not justified economically and the fix-as-fails costs are embedded into the overall economic analysis for every year of the study period. ORNIM produces a graphical output depicting the results and optimal timing of this process for each component and each traffic scenario. The ORNIM output for the Newburgh main chamber gates is shown for the Utility High traffic forecast in Figure ED-19.

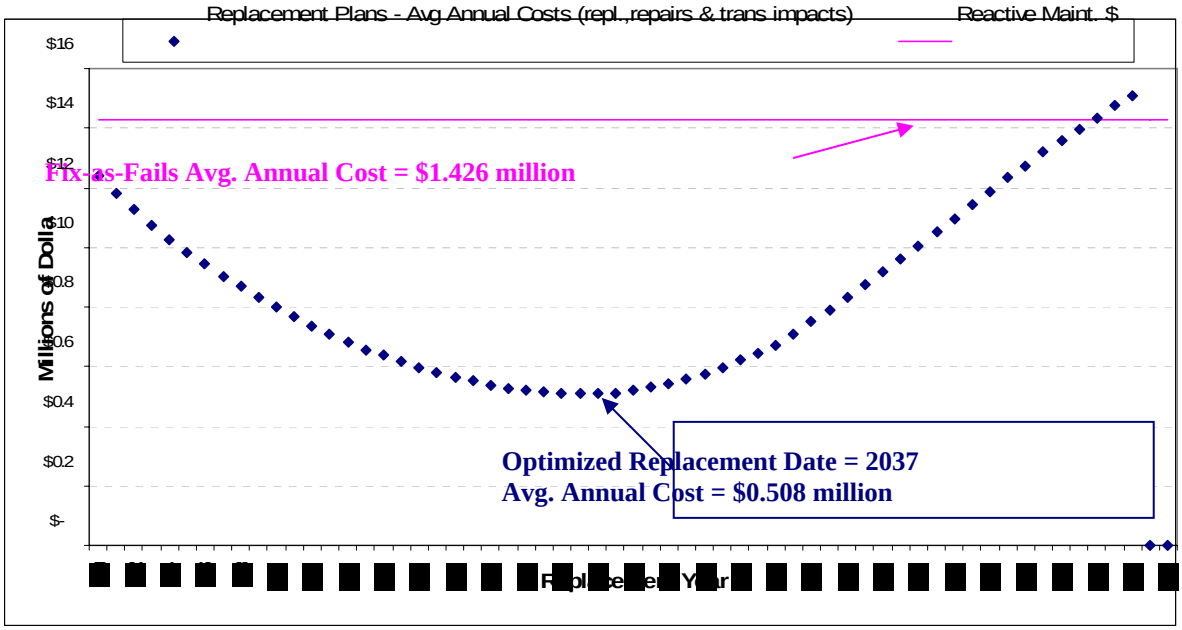


Figure ED 5-19. Newburgh Main Miter Gates Optimized Replacement Date (Utility High Traffic Scenario)

As noted earlier, the miter gates were evaluated for each traffic scenario. Using the same methodology, optimized replacement dates were determined for each traffic scenario. The projected replacement dates for each traffic scenario are provided in the Economics Appendix.

Please refer to the tables in the Economics Appendix for the optimized replacement date of all horizontally-framed culvert valves across the Ohio River projects. These are given for each lock chamber by traffic scenario.

5.2.13 References for Horizontally-Framed Miter Gate Reliability

1. "Fatigue Cracking Evaluation of the Markland Miter Gates," ANATECH Report ANA-96-0201 to Corps of Engineers, Louisville District, November 1996.
2. American Society of Mechanical Engineers Boiler and Pressure Vessel Code, 1989 Edition, American Society of Mechanical Engineers, July 1989.
3. "Structural Inspection and Evaluation of Existing Welded Lock Gates," U.S. Army Corps of Engineers, ETL-1110-2-346, Sept. 1993.

4. Ellingwood, Zheng, and Bhattacharya. "Reliability-based Condition Assessment of Steel Miter Gates," Final Report Submitted to Black & Veatch Engineers, March 1996.
5. "Reliability Analysis of Hydraulic Steel Structures with Fatigue and Corrosion Degradation," WES Report, March 1994.

5.3 VERTICALLY-FRAMED MITER GATE RELIABILITY

There are only three projects on the Ohio River that utilize vertically-framed miter gates. These are the upper three sites on the Ohio River: Emsworth, Dashields, and Montgomery (EDM) Locks and Dams. Additionally, only the main chamber at these sites have vertically-framed miter gates, the auxiliary chamber at each site has horizontally-framed miter gates. Therefore, out of 38 lock chambers on the Ohio River, only 3 use vertically-framed miter gates. However, since this is a major component that can potentially have major consequences, a reliability model was developed for vertically-framed miter gates.

5.3.1 Background of Upper Three Projects (EDM)

The upper three Ohio River projects, EDM, are the oldest operating locks and dams on the Ohio River. These projects were built in the early 1920's and 1930's. The oldest is Emsworth which was completed in the early 1920's. Because of overall deteriorating conditions at each of the three projects, the locks at each site were rehabilitated in the mid-to-late 1980's. All major components, with the exception of dam gates and concrete, were replaced as part of this rehabilitation. Included in the work was the replacement of the existing main chamber, vertically-framed miter gates with newer, stronger vertically-framed miter gates. The existing, original miter gates were constructed of riveted, plate girders. The new miter gates installed during the rehabilitation are made of rolled wide flanged girders. This makes a significant difference in the reliability of the miter gates. Additionally, the new miter gates were considerably stronger in terms of the section modulus when compared to the older gates. The new gates are stressed considerably lower in terms of bending and shear under normal operating loads. This is a controlling factor in the fatigue analysis.

5.3.2 Background of Vertically-Framed Miter Gate Reliability Model

The reliability model for the vertically-framed miter gates was the Corps of Engineers first attempt to develop time dependent hazard functions for lock structures for the purpose of subsequent economic analysis. Therefore, the engineering team was required to develop the proper methodology for developing hazard functions for lock and dam components. The vertically-framed miter gates were selected first because a preliminary reliability assessment of the original vertically-framed miter gates at Emsworth had already been investigated by Dr. Bruce Ellingwood of Johns Hopkins University for the Pittsburgh District. The model that Dr. Ellingwood developed was based upon the limit state of fatigue of the main load bearing beams.[1] The ORMSS engineering team's first goal was to attempt and develop a reliability model for the vertically-framed miter gates using Dr. Ellingwood's previous work as a basis. The insight and guidance provided by Dr. Ellingwood's model proved to be quite valuable in the initial modeling efforts. However, some changes were required to the model developed by Dr. Ellingwood in order to establish the necessary parameters that could be used for all three upper Ohio River sites. The engineering team developed its initial model using the parameters from the older, built-up girder miter gates that were in place from the early 1920's until the rehabilitation in 1984. Once the reliability results from the new model compared well with the newly adjusted results from

Dr. Ellingwood's model, the team believed it had a model that was accurate within the confines of the analysis itself. This model was then used for the analysis of the new vertically-framed miter gates at EDM to determine their time dependent reliability.

5.3.3 Vertically-Framed Miter Gate Reliability Model Development

The vertically-framed miter gate model is quite different from the horizontally-framed miter gates. Whereas an original, Ohio River specific Visual Basic coded model was developed for the horizontally-framed miter gate reliability model, the spread sheet Microsoft Excel™ was used in conjunction with the Monte Carlo simulation software, @Risk™ for the vertically-framed miter gate reliability model. Additionally, the limit states selected for the vertically-framed miter gate model were the strength and fatigue of main, load carrying beams and the top horizontal girder. The horizontally-framed miter gate limit state was selected based upon field experience of fatigue cracking at specific connections around the pintle region of the gate. There are a couple of reasons that the process selected for the vertically-framed miter gates was chosen. Foremost, the process and limit state for the vertically-framed miter gates was the same one as Dr. Ellingwood had used in his previous modeling efforts. Since he had credible results, the engineering team wanted to calibrate the new model versus his initial results since this was the first attempt to develop a truly time dependent model.

5.3.4 Vertically-Framed Miter Gate Reliability Model Details

Probabilistic evaluation of the structural components was performed with the aid of spreadsheet and a simulation program. Variables were treated as random where needed with appropriate values obtained from either the literature, past records or a combination of calibration and engineering judgment. The model consists of a workbook within a spread sheet. The overall spread sheet contains four separate sheets defined as *Inputs, Outputs, Horizontal Girder*, and *Vertical Beam*. The *Horizontal Girder* and *Vertical Beam* sheets are the where the computations for the reliability of the structure take place. The model tracks both the performance of the miter gate from a strength standpoint (load vs. capacity) and fatigue standpoint (when the number of *unfactored* allowable cycles is reached).

INPUTS SHEET

This sheet contains all the input parameters for the model. Fixed values such as top of miter gate and miter gate sill elevations were obtained from the as-built drawings. Examples of random variables used are the yield strength of steel, structural analysis factor, corrosion variables, fatigue strength and tail water elevation. During each iteration, a new set of random values is generated. Each iteration tracks the miter gate through the study period until either a limit state is reached or the end of the study period is reached without a failure. Once either of these occurs, a new iteration is begun with the selection of new random variables. A simulation is completed once all the pre-selected number of iterations is completed. The tail water elevation is generated once at the beginning of each iteration and is kept constant for the life span (study period) of the structure for that particular iteration. A brief description of the variables used is provided below.

<u>Pool Elevations.</u> Tail water elevation is taken as a random variable and the upper pool is kept constant. Daily pool records are readily available at all ORMSS sites from Lock Performance Monitoring System (LPMS) data from about 1982 to present. The differential head is used for checking the bending limit state for both the strength and fatigue modes. Since the hazard function is developed on an annual basis, the strength mode of the model required the maximum annual head differential since that occurred each year. This was the load that was computed for each year for the strength limit state.

For the fatigue limit state, a histogram of number of lockages versus differential head was built from LPMS data. This histograms yields actual number of operating cycles versus differential heads for various ranges.

Material Data. Statistics for yield strength were obtained from the literature and steel yield strength is generated once at the beginning of each iteration. Fatigue capacity (factor log c) was treated as a random variable and generated for each iteration. Another factor that was treated random is the corrosion rate, which depends on the material and the surroundings. Corrosion rate is different for atmospheric, splash and submerged regions. All random variables were selected once at the beginning of each iteration and kept constant throughout that particular iteration.

Corrosion. The cumulative number of years during which corrosion takes place is referred to as the variable t. Note that periodic painting affects the corrosion rate and must be taken into account in the

analysis. In the analysis, corrosion is treated as a random variable. Taking corrosion as:
where the penetration rate, C(t), with units of μm/year, is expressed as a function of time. The variable A, the rate parameter, is log-normally distributed with a mean, $\mu = 140$, and standard deviation, $\sigma = 42$, for the splash zone. The constant B, the time-order parameter, is an experimentally observed parameter and is treated as a deterministic value equal to 2/3.[1] Knowing the thickness at time t, the section modulus, S(t), with respect to time in terms of a variable flange and web thickness is computed.

Fatigue. Fatigue damage is based on the S-N curve and the data available in the literature, where S represents the stress and N represents the number of allowable cycles.

$N = C / (\text{stress range})^m$, where N = allowable cycle
C = variable depending on weld type
m = experimentally observed constant

Variable C is treated as random; statistics of C were taken from literature and is dependent upon the type of existing welded connection.

Hydraulic Cycles. Available records of lockages were used to obtain the hydraulic load cycles on the structure from installation through the present date. A load cycle is referred to as a complete filling and emptying of the chamber. For the future years, forecast by the economists must be provided to determine future reliability.

Analysis Factor. The moment demand is variable because of assumptions and inaccuracies in analytical procedures. This can be introduced by the factor B(I), which is log-normally distributed with mean, $\mu = 0.964$, and standard deviation, $\sigma = 0.12$. B(I) is an experimentally determined value for a vertical beam in a vertically framed miter gate. The value for B is different for the horizontal girder.[2]

COMPUTATION SHEETS

The computations are carried out in two sheets, *Horizontal Girder* for the top girder and

Vertical Beam for the vertical beams that transfer loads to the top horizontal girder. There are two failure modes (i.e., limit states) for both the vertical beam and horizontal girder, namely strength (in bending) and fatigue. Both modes consider the cumulative effect of corrosion and the paint history of the respective site. Calculations are performed in a similar manner for both components.

Random variables are first generated at the beginning of each iteration in the *Inputs Sheet*. For each iteration (i.e., life span of the structure), the properties are calculated considering the changes in dimensions due to corrosion and paint history.

The strength mode limit state was defined by mid-girder flexure for both the vertical beam and horizontal girder. For both the beam and the girder, the limit state is defined as "demand exceeds capacity." There are no safety factors or other criteria applied to either the demand or capacity side of the equation. The capacity is determined for each iteration by the random variable selected for the yield strength of the steel and the amount of corrosion on the structure. This is checked against the demand from the load and if the demand exceeds the capacity any time, the year it occurs is noted for each iteration. At the end of a simulation, annual unsatisfactory performance occurrences are tabulated for each year and hazard functions are computed with the help of a macro.

The hazard function, h(t), is the negative derivative of the natural log of L(t), or:

$$h_t = -d(\ln L_t) / dt.$$

h(t), therefore, is the negative slope of the curve defined by the function ln (L(t)). In the literature, h(t) is defined as the conditional failure rate in a given time period. That is, hazard rate is the probability of an unsatisfactory performance within time increment *t*, given the structure has performed satisfactorily from time zero up to time *t*. The hazard function is computed numerically using the output data from simulation

The fatigue mode limit state is also defined by demand versus capacity. Demand is the cumulative effect of fatigue damage at the mid-span for the beam connection type. Fatigue damage was defined as the ratio of actual number of load cycles to allowable number of load cycles for a constant amplitude loading. The stress that causes the fatigue is not constant for all load cycles. Thus, a head versus percentage of operating cycles histogram was built based on the LPMS data for each of the three project main chamber locks. The histogram partitions the total number of load cycles into appropriate stress categories. The standard Miner's Rule is used to sum the fatigue damage of variable amplitude loading and it is considered unsatisfactory when the cumulative damage exceeds unity. Similar to the strength case, macros in the spreadsheet are used to calculate the hazard function for the fatigue mode.

Outputs Sheet

The *Outputs* worksheet lists the time-dependent reliability and hazard rates for the two limit states considered for each of the component, fatigue and strength of both the vertical beam and horizontal girder. Graphs are also provided once the computation of the hazard function is completed in this worksheet. These results are sent to the economists when appropriate along with an event tree.

5.3.5 Model Results and Conclusions

The model was built for the purpose of determining time dependent reliability of vertically-framed miter gates. Once the model was completed, the first item to "test" was the performance of the

original Emsworth upper, main chamber miter gates. These gates were installed when the structure was built in the early 1920's. They were replaced during the rehabilitation of the Emsworth project in the early 1980's. It is known that the original miter gates were in very poor condition when they were replaced. Therefore, the actual reliability of the original miter gates was quite low when they were replaced. After making the appropriate adjustments during the construction of the model, the original miter gates at Emsworth were tested with the new ORMSS vertically-framed miter gate reliability model to determine their time dependent reliability. The results were excellent. Using the correct date for historical painting dates and operating cycles, a high hazard rate was computed for the miter gates by the early 1980's. These results compared well with the results that Dr. Ellingwood had for the initial modeling effort once the proper results were made to that model.

With confidence that the new model was yielding accurate results within the confines of the analysis itself, the team collected the necessary information to make the reliability runs for the main chamber miter gates at EDM. It was evident once the initial results were computed that the hazard rate for the main chamber miter gates would be extremely low throughout the study period for each of the three projects. In reviewing the properties for the new gates, the team found the answer to why the hazard rate appeared to be so low. The new miter gates that were installed were vastly improved over the older design. The old miter gates were constructed of riveted, built-up plate beams and girders. For the limit states that we were investigating, these are the worst type of construction details for fatigue. The new gates (installed during the rehabilitation) were made of rolled wide flange sections. Additionally, the section modulus had been increased by over three times when compared to the original miter gate beams and girders.

Therefore, the model was giving correct values for the time dependent reliability of the vertically-framed miter gates for the selected limit states. The hazard rates were computed as zero for each of the main chamber miter gates. Without a hazard rate, the economists were not required to make an economic analysis of the vertically-framed miter gates, thus, an event tree was not required.

In conclusion, the replacement of the vertically-framed main chamber miter gates for the selected limit states is not justified during the study period at any of the three projects. This does not indicate that there will never be any problems associated with the miter gates. Operational problems will be encountered, but repairs are handled through normal and major maintenance.

5.3.6 References for Vertically-Framed Miter Gate Reliability Analysis

1. Ellingwood, B.R., Zheng, R., and Bhattacharya, B. (1996): "Reliability-based Condition Assessment of Steel Miter Gates." Report by Black & Veatch to U.S. Army Corps of Engineers.
2. Padula, J., Chasten, C., and Mlakar, P. (1995): Reliability of Hydraulic Steel Structures with Fatigue and Corrosion Damage. CESEC 1995.
3. EM 1110-2-2703 (1994): Lock Gates and Operating Equipment
4. Ellingwood, B.R. (1993) Load and Resistance Factor Design for Steel Miter Gates, CEWES Instruction Report ITL-93-4.
5. Commander, B.C., Schulz, J.X., Goble, G.G., and Chasten, C.P. (1993) Computer-Aided, Field-Verified Structural Evaluation, Report 3, Field Test and Analysis Correlation of a Vertically Framed Miter Gate at Emsworth Lock and Dam, CEWES Technical Report ITL-92-12.

5.4 HORIZONTALLY-FRAMED REVERSE TAINTER CULVERT VALVE RELIABILITY

Reverse tainter culvert valves at Ohio River projects are used to control the filling and emptying of lock chambers. All sites with the exception of the upper three (Emsworth, Dashields, and

Montgomery Locks and Dams) utilize reverse tainter culvert valves for the filling and emptying of the lock chamber. Emsworth, Dashields, and Montgomery (EDM) utilize butterfly valves for the operation of their filling and emptying systems. Butterfly valves are covered within the overall mechanical model. There are two types of reverse tainter culvert valves: horizontally-framed and vertically-framed. Separate reliability models had to be developed for each of these reverse tainter culvert valves.

Most Ohio River projects use vertically-framed reverse tainter culvert valves, however, there are several sites with horizontally-framed valves. In general, the older sites use horizontally-framed culvert valves. These include the valves at Pike Island, New Cumberland, Greenup, Meldahl, Markland, and the existing main chamber at McAlpine. The newer projects have vertically-framed valves. These sites include Willow Island, Belleville, Racine, Hannibal, R.C. Byrd, Cannelton, Newburgh, J.T. Myers, Smithland, and Olmsted. This section will focus on the horizontally-framed culvert valves. Section 5.5 of this appendix focuses on vertically-framed culvert valve reliability.

Most of the horizontally-framed reverse tainter culvert valves in use on the Ohio River have been in operation since the late 1950's to early 1960's. The design and construction technique for the main and auxiliary chamber valves at all the sites are the same, therefore, the same reliability model can be used for each chamber with chamber specific input for historical painting and operating cycles. Additionally, the culvert valves designs between projects with horizontally-framed culvert valves is similar enough that the same global finite element model was developed and used for all projects to determine load distributions, stress concentration factors, etc. It is important to note that the significance of an unsatisfactory performance of a reverse tainter culvert valve is quite different depending upon whether it occurs in the main or auxiliary chamber.

5.4.1 Main Chamber vs. Auxiliary Chamber

The main chamber at all sites, with the exception of EDM, has a total of four reverse tainter culvert valves for filling and emptying the lock, two filling and two emptying valves. One filling and emptying valve is in the middle wall and the other set is in the river wall. They can be operated independently. Therefore, a repair to one of the main chamber culvert valves does not necessarily close the chamber. It is possible to dewater the area around the valve only, thus, leaving the other filling and emptying set to operate the chamber. Filling and emptying time is roughly doubled over normal operation. Normal filling and emptying time for a typical 1200 foot lock on the Ohio River is approximately 8 minutes each.

For the auxiliary chamber, there are two valves to control filling and emptying operations. One filling and emptying valve each. Therefore, a problem with one of the valves on the auxiliary chamber closes the entire chamber while necessary repairs are made. The significance of closing the auxiliary chamber is considerably less than the main chamber, however, loss of navigation benefits associated with an extended auxiliary chamber closure can become large.

5.4.2 Description of the Horizontally-Framed Culvert Valves

The valves are termed horizontally-framed since the main load from the skin plate is transferred to large vertical plate girders by a series of horizontal girders. The large vertical plate girders transfer the load to a series of axially-loaded strut arms that connect the body of the valve to a pin plate casting, which transfers the load to the valve's trunnion beam. The trunnion beam then transfers the load to the concrete monolith. The valves act in tension since the tainter gate is reversed to the direction of flow. Photographs of the valves a typical Ohio River horizontally-framed reverse tainter culvert valve are shown in Figures ED 5-20 through ED 5-24.

Because of the complexity of these structures and the potential redundancy associated with them, a global finite element model for the Markland culvert valve was developed to determine areas

of high stress concentration. Again, this valve is typical of other Ohio River horizontally-framed culvert valves. Additionally, the problems associated with the miter gates at Markland caused concern for the valves since these structures also had large amounts of welding that may lock in residual stresses. For a more detailed description of the fatigue problems associated with residual stresses at Markland, refer to Section 5.2 of this appendix which covers the reliability modeling of the horizontally-framed miter gates.

It was determined from the finite element modeling of the horizontally-framed culvert valve that there were two areas of high stress concentration during normal operation. The two locations were where the strut arm transitions and connects to the pin plate casting. The other location was where the horizontal girders are connected to the vertical plate girders. It was decided to concentrate on the strut arm connection since there is little to no redundancy associated with this connection. Additionally, Louisville District Operations personnel familiar with the Markland culvert valves have stated that this connection has caused concern over the years.

Figure ED 5-20. Side View of Markland Reverse Tainter Culvert Valve

5.4.3 Finite Element Modeling of the Culvert Valves and Calibration

The same basic procedure and steps used to develop reliability models for fatigue cracking at welded connections for the miter gates were employed for the reverse tainter culvert valves. The differences are that, for the culvert valves, direct tensile loads act on structural members and connections, and that the impinging water loads are significant, both in amplifying the load and in area reduction due to erosion-corrosion effects (note pitting of strut arm in Figure ED 5-23). To compensate for these effects, the design of culvert valves use a much higher factor of safety by increasing load factors for design loads and reduced design stress allowables. The development of the reliability model requires the same basic steps of characterizing crack initiation, crack growth rate, and definition of the limit state but requires different criteria and methods.

Figure ED 5-21. Front View of Markland Reverse Tainter Culvert Valve.
Note surface deterioration of skin plate

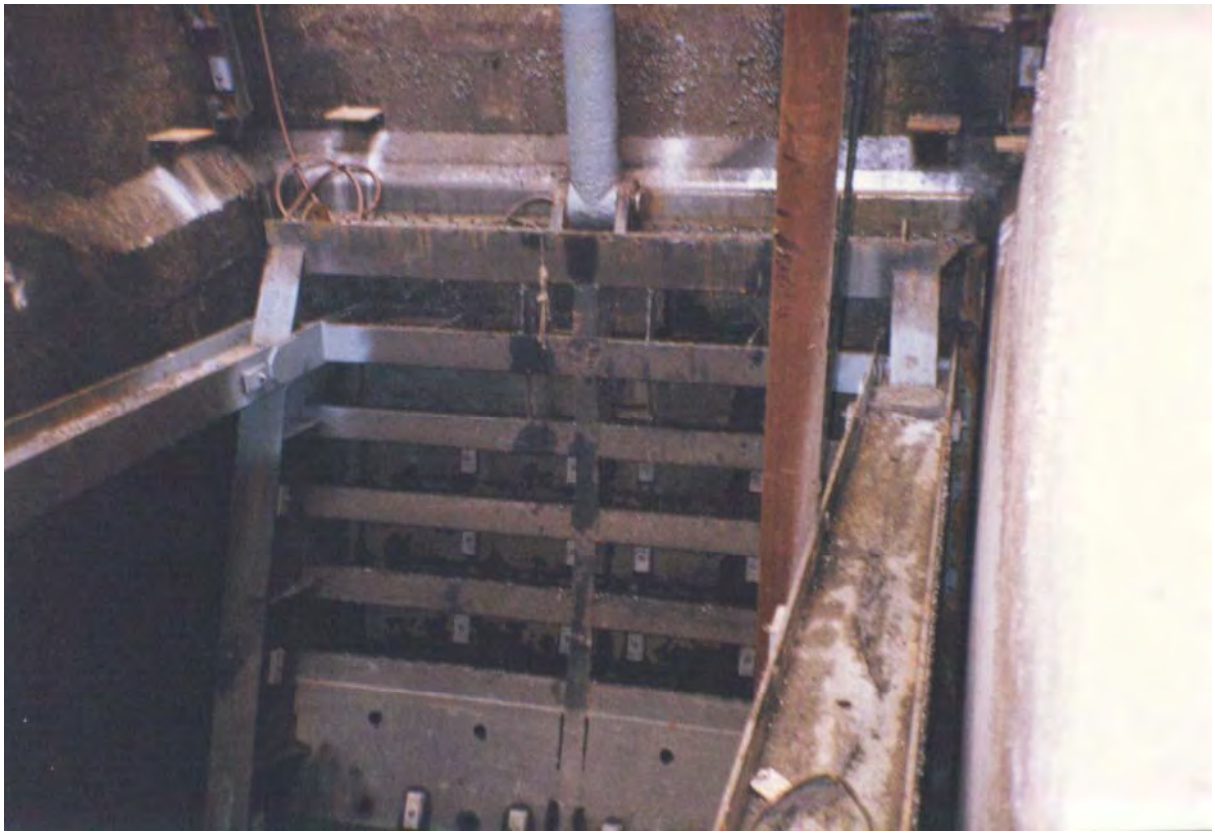


Figure ED 5-22. Markland Culvert Valve in the Pit
Note the corrosion of the valve relevant to the spot-painted areas

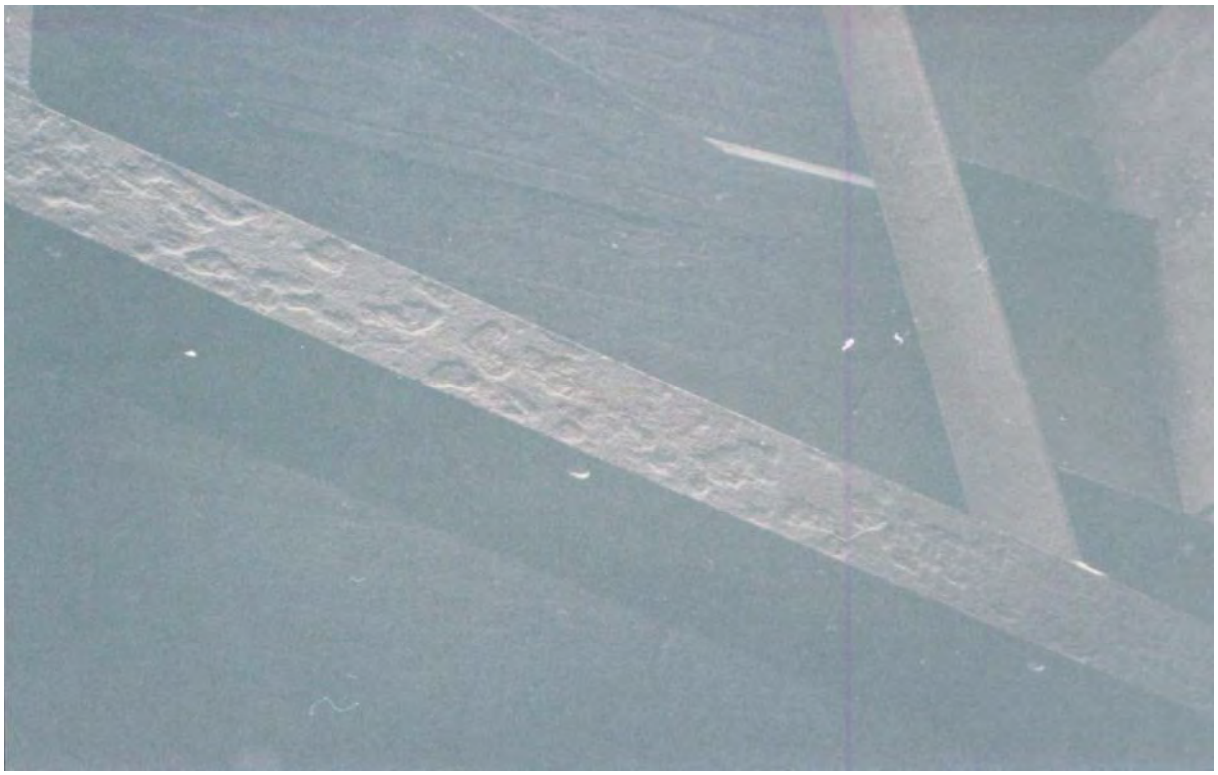


Figure ED 5-23. Markland Culvert Valve Strut Arm
Note heavy pitting and corrosion of strut arm

Figure ED 5-24. Markland Culvert Valve Bushing
Photograph depicts connection of valve body to pin plate casting

The first step is to evaluate the stress distributions in a global model of the culvert valve to identify locations where fatigue cracking can lead to reliability problems. A global model of a culvert valve was constructed using half symmetry, and areas of stress concentrations were evaluated for applied operating load conditions. Two areas showing the highest stress concentrations are identified, and refined meshes are incorporated into the global model for these areas. Figure ED 5-25 illustrates the global modeling for the culvert valve with the mesh refinement at the potential cracking areas. One area is the welded connection for the flange of the vertical load girder attached to the web of the strut arm. The other area for investigation is the welded connection of the strut arm flange to the trunnion pin casting. Global model calculations are conducted using a normal operating head of 30-ft (uniform pressure load) to determine the likely alternating stress ranges for crack initiation at these stress concentration areas. Adjusting for the nominal residual stress of 20 ksi tension at these connections gives alternating stress ranges of about 11 ksi at the girder flange to strut arm web connection and 9.5 ksi for the strut arm flange to trunnion pin block connection. Thus, cracking would initiate first at the girder flange to strut arm web connection. However, by considering the limit state involved at these two connections, it was determined by the engineering team that the strut arm connection to the trunnion pin block is the more critical for reliability.

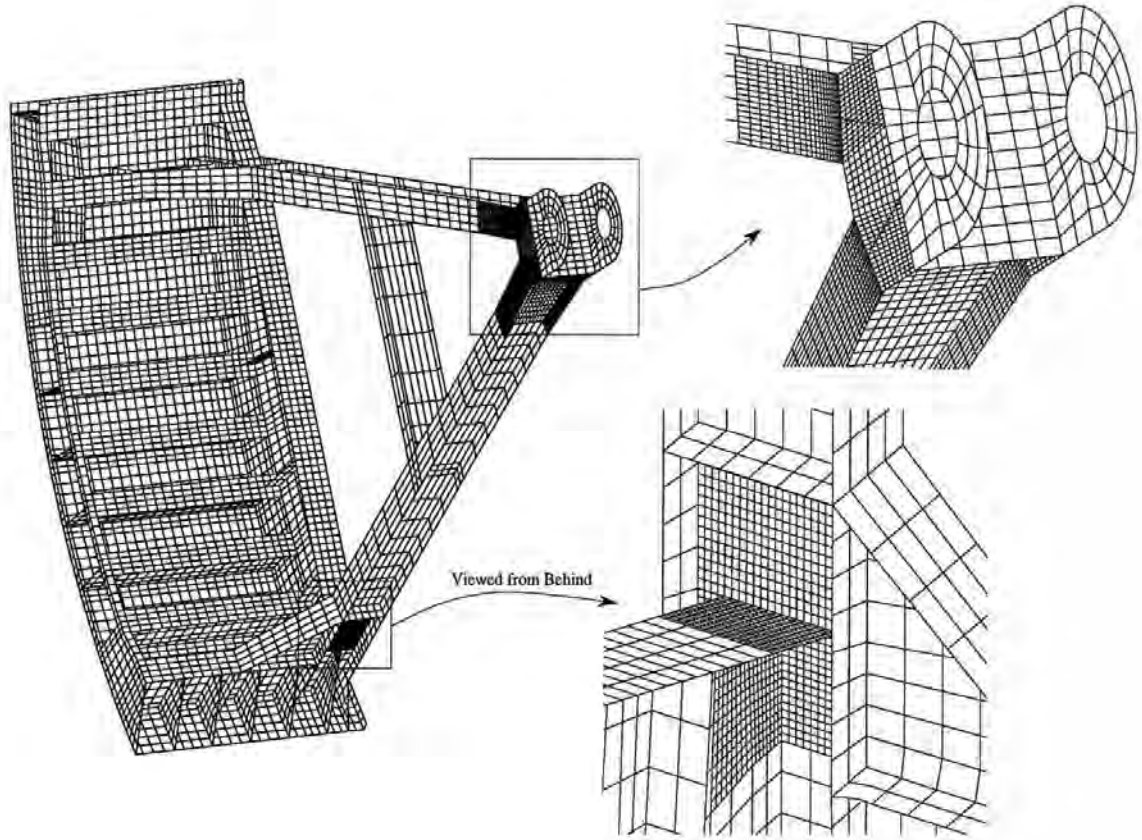


Figure ED 5-25. Global Finite Element of Horizontally Framed Culvert Valve

The engineering team then established the variables to characterize in the reliability model for fatigue cracking at the strut arm connection to the trunnion pin block. The residual stress at the welded connection is a function of the yield stress. Because of schedules and budget, detailed residual stress calculations of this connection were not employed. However, based on past experience, it is known that tensile residual stresses will develop during the welding of the connection. Since detailed calculations were not performed, a larger random variation is used for the residual stress as a function of yield stress. The operating loads develop tensile stress at this connection that will depend on the operating head and the amount of thickness reduction due to erosion-corrosion. Thus, a matrix of calculations were performed using head variations and thickness reduction of the strut arm flange to determine the maximum principal stress at the connection as a function of head (in feet) and thickness reduction (in inches) as shown in Figure ED 5-26. An equation was developed to fit this variation. For crack initiation, it is assumed that the valve open cycle produces a zero peak stress at the connection. The alternating stress is then determined from ½ of the maximum principal stress as a function of the random variables and adjusted for residual mean stress.

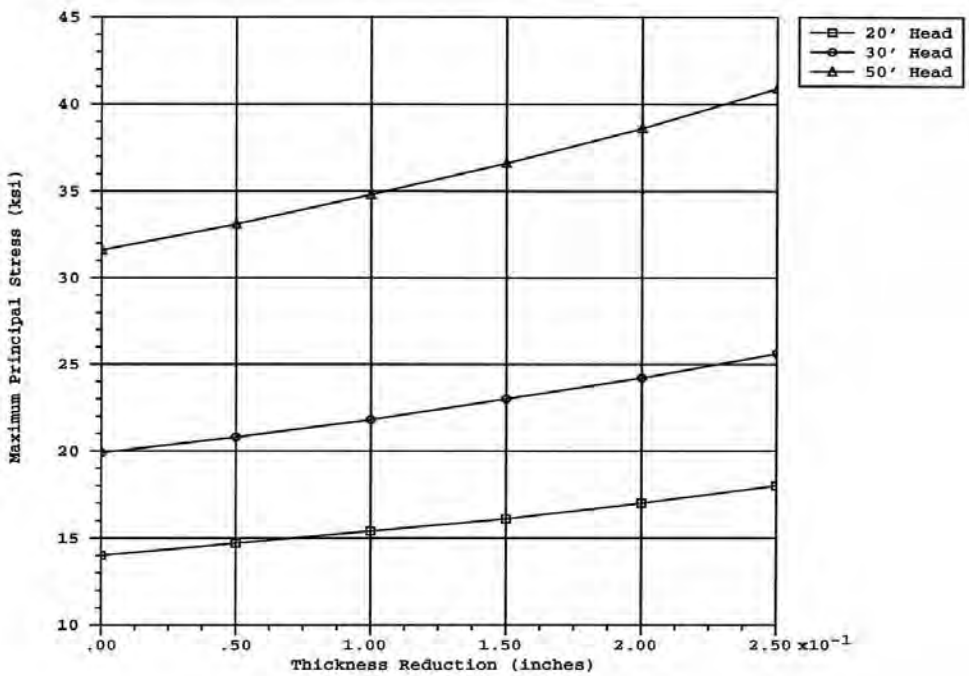


Figure ED 5-26. Maximum Principal Stress vs. Thickness Reduction as a Function of Head

The crack growth rate is now determined by extending a crack at the connection and calculating the stress intensity value versus crack length from the J-integral. Again, detailed residual stress calculations were not performed to establish the residual stress around the welded connection. However, because the crack is extending along the weld line for this case, it is assumed that the residual stress distribution is fairly constant along the path of the crack. Then, since fatigue crack growth is governed by the stress difference over the operating cycle, the residual stress will cancel out in determining the change in stress intensity. The magnitude of residual stress will affect the growth rate and this effect gets included in calculating the exponent on the change in stress intensity in the Paris relation. The fatigue crack growth rate is determined for a reliability model by conducting a matrix of analyses with variations in head and thickness reduction. For each combination, the crack is extended and the stress intensity computed for an open and closed valve condition. The resulting stress intensity versus crack length relation for that combination of variables is used to integrate the Paris relation to obtain number of cycles versus crack length as illustrated in Figure ED 5-27. An equation is then developed to fit this data that can return an increment in crack extension for a given increment in the number of cycles on a current crack length.

5.4.4 Limit State for Horizontally-Framed Reverse Tainter Culvert Valves

Once the crack initiation and fatigue crack growth rate are characterized, the limit state of the culvert valve must be established. The limit state is defined as the extent of fatigue cracking that will compromise the structural integrity of the culvert valve. As mentioned in the previous section, the first step was to determine which of the two areas identified for potential fatigue

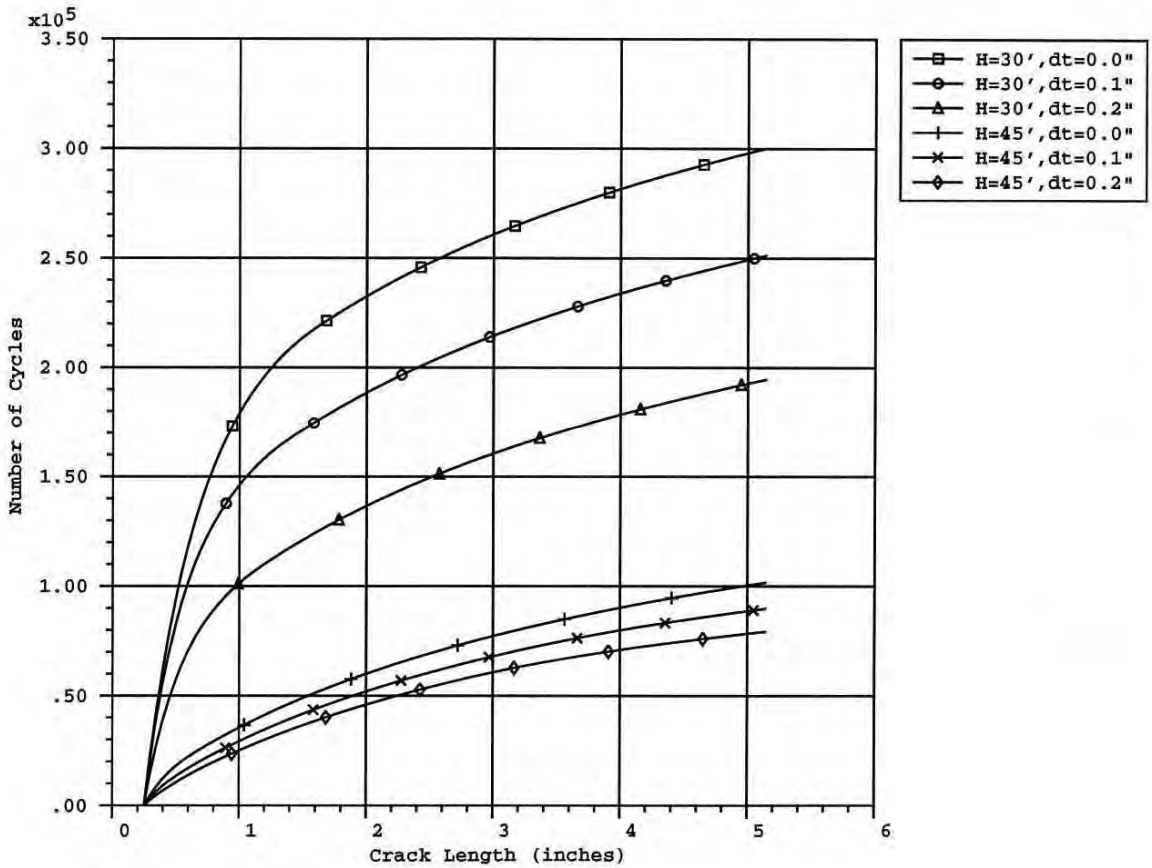


Figure ED 5-27. Crack Length vs. Number of Cycles as a Function of Head, Thickness Loss

cracking was the more critical for valve integrity under crack growth. To this end, extensive cracks were introduced in the finite element model at the two locations to evaluate the potential consequences. The top flange of the vertical load girder was completely disconnected from the welded attachment to the web of the strut arm. Under operating loads, the stress was redistributed to the web of the vertical load girder. Although stress concentrations were attracted to this new area, excessive deformations or stresses did not develop in the damaged area. This implies that cracking would continue to develop at this location, but that fairly extensive damage may be needed before the structural integrity is compromised. On the other hand, extending a crack in the flange of the strut arm connection to the trunnion pin block caused increased stress concentrations to develop ahead of the crack since a direct reduction of area on a tension member occurs. Thus, fatigue cracking here will undoubtedly progress into a failure of the valve. Therefore, this connection was judged by the engineering team to be more critical and was used to develop a reliability model.

The next step is to determine the extent of cracking that is considered the limit state for the valve. Since this connection is cycled from near zero load to tensile loads, buckling cannot be used to determine a limit state as was done for the miter gate flange connections. Linear elastic fracture mechanics formulas were considered for defining a critical crack length for brittle fracture. However, the size of the connection and the assumed fracture toughness for the material makes this connection very resistant to brittle fracture. Thus, criterion was established for the amount of plastic yielding ahead of the crack to determine the limit state. As the crack extends, the stress concentration increases at the crack tip and the amount of plastic yielding will steadily increase. A criterion was established

such that when yielding occurs throughout the thickness of the flange and about ½ the flange thickness in front of the crack, then a limit state is defined. Under these conditions, plastic ductile tearing will likely initiate rather than the fatigue cracking mechanism. The tensile load in the arm will then rapidly propagate the tearing until net section yield results.

This criteria means that the critical crack length or limit state is a function of the yield stress, the operating head, and the thickness reduction due to erosion-corrosion. For a given yield stress and operating head, the critical crack size will decrease as the corrosive environment reduces the thickness of the flange. Thus, a matrix of analyses was performed to find the crack length where the plasticity criteria is reached for variations of the three variables. For each combination of variables, a series of crack lengths are incorporated into the model, and the linear elastic stress distribution at the crack tip is evaluated with stress contour plots, as illustrated in Figure ED 5-28. When stresses greater than the yield stress are calculated throughout the flange thickness and for a region ahead of the crack, the corresponding crack length is established as the limit state for that combination of variables. An equation is then developed to relate the critical crack length to yield stress, operating head, and thickness reduction.

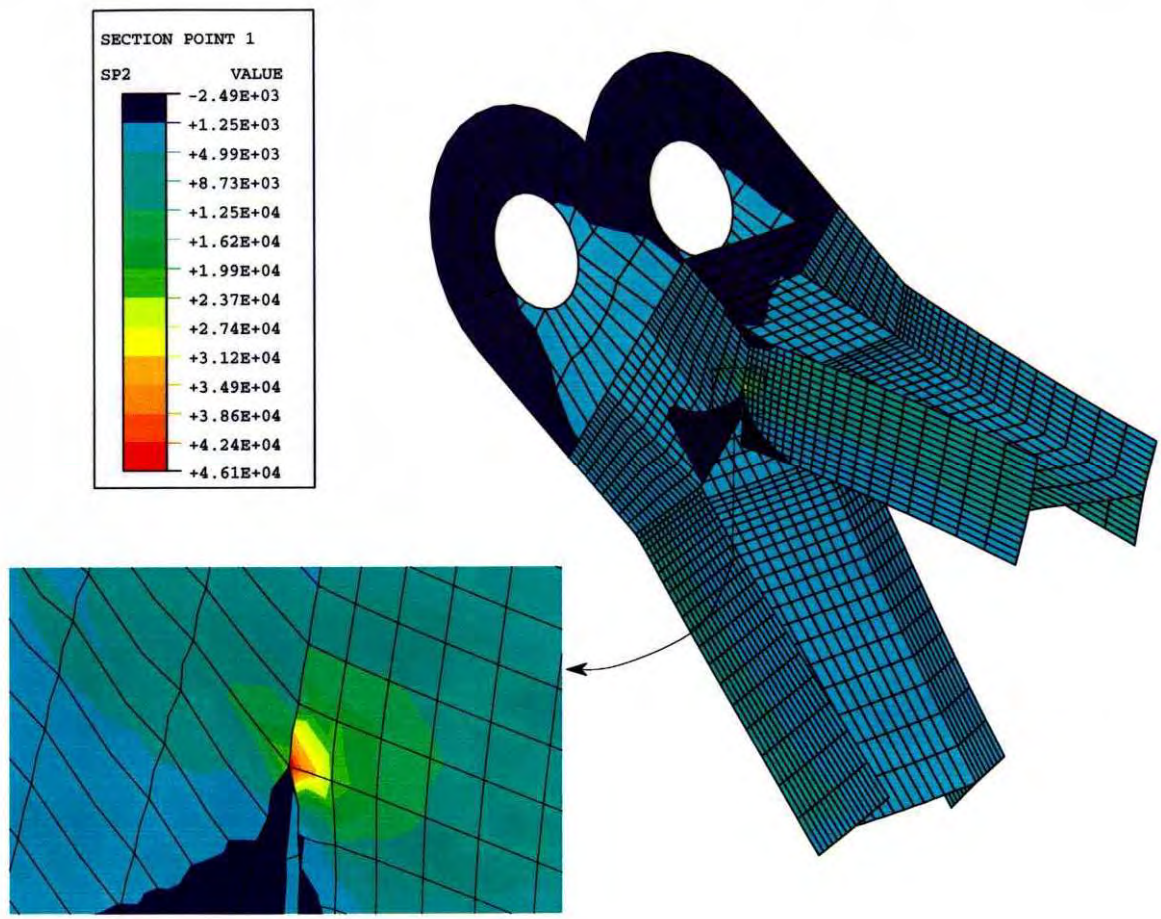


Figure ED 5-28. Linear Elastic Stress Distribution at Crack Tip

Finally, the influence of the hydrodynamic effects of the water impinging on the valve during the opening cycle must be addressed. This force will increase the loads in the structural components above the hydrostatic pressure head. For design, a "dynamic amplification load" of

1.5 to 2.0 times those due to the hydrostatic pressure is typically used. For the fatigue cracking reliability model, a realistic assessment must be determined in order to take any safety factors out of the analysis. As a method of determining this amplification factor on the operating head, a fluid flow analysis of the valve was conducted. The fluid flow calculation solves the Navier-Stokes equations for pressure gradients and fluid velocities using finite elements for the fluid filled regions. For this analysis, the valve was modeled as a smooth and rigid surface within the fluid flow region. Thus, no structural feedback is included. The fluid velocities and pressures are calculated for various gate open positions. The pressures calculated in the fluid at the gate surface are used to determine the likely factor for gate loads above the hydrostatic head applied in the structural calculations. Figure ED 5-29 illustrates the geometry, fluid velocities, and fluid pressure contours for this calculation. These calculations indicate a factor of 1.25 on the hydrostatic head is likely for hydrodynamic loads of opening the valve under a 30-ft. head differential.

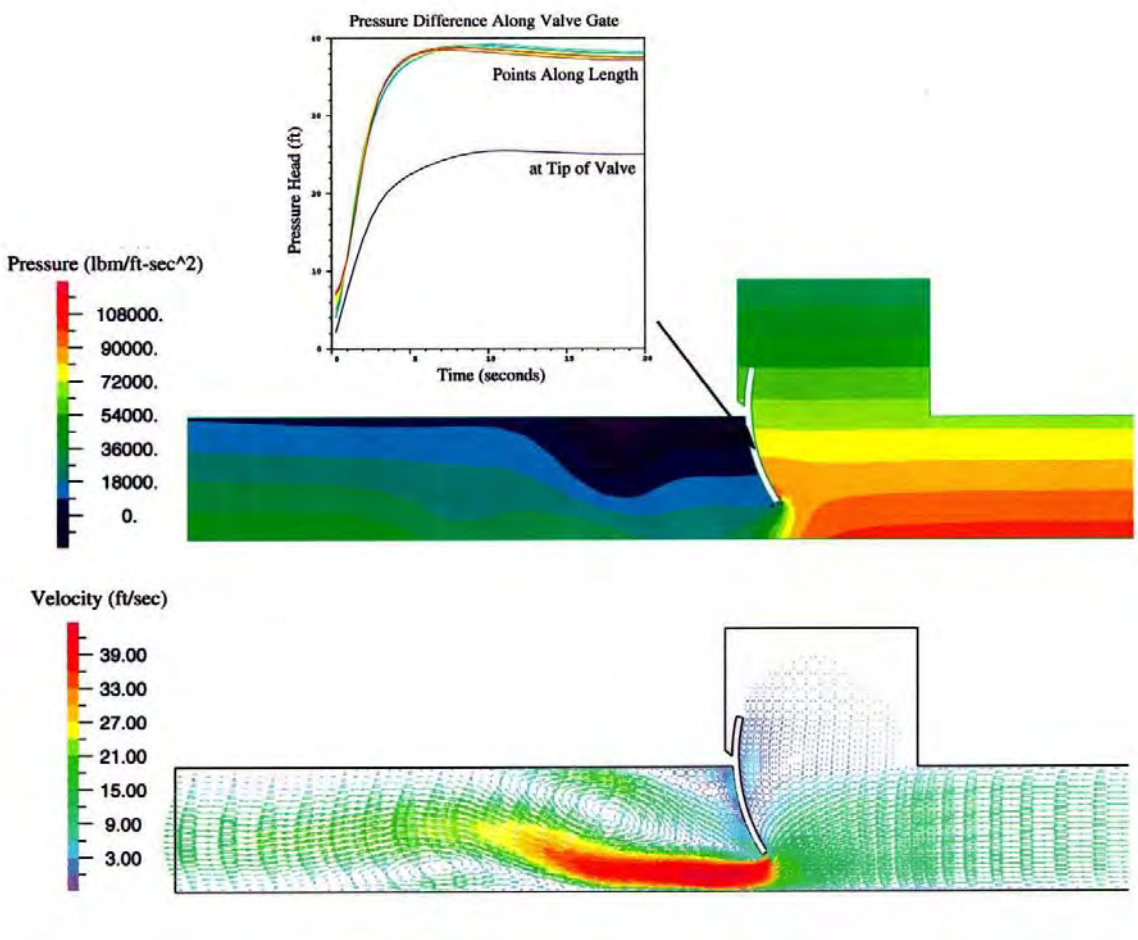


Figure ED 5-29. Fluid-Structure Interaction Diagrams and Contour Plots

5.4.5 Reliability Model Details

The reliability analysis for the horizontally-framed reverse tainter culvert valves was developed to measure the reliability associated with these type structures. In order to accomplish this effort, the team initially developed a spreadsheet model that investigated the typical analysis of the valves. The spreadsheet analysis included such items as fatigue associated with bending of the horizontal

beams that transfer load from the skin plate and also the bending of the main vertical girders. Additionally, axial force in the strut arms was checked over time with regard to fatigue and corrosion. The spreadsheet analysis showed no potential reliability problems with the valves *even after they would have been over 100 years old*. Neither the engineering team nor the operations personnel that work on the valves believed this to be an accurate representation of the reliability of the structure. This was due to the conservatism built into the design at the time of construction. However, it is known from reviewing operations records that repairs to the valves at all these Ohio River sites have caused significant chamber closures and costly repairs. Additionally, pitting and corrosion of the valves appears to be considerably greater for valves than other structures because of the turbulent water flowing across the structure associated with the opening and closing of the valve during chamber operation. Therefore, the engineering team decided that it would again be prudent to have a finite element analysis completed for the valves to investigate any potential problem areas. The engineering team decided to develop a Visual Basic coded model specifically for the ORMSS horizontally-framed reverse tainter culvert valves which was modeled after the one developed for the miter gates. The model was named HFCVWELD for horizontally-framed culvert valves. HFCVWELD was developed to investigate the reliability associated with the limit state described in Section 5.4.4 of this appendix.

HFCVWELD Reliability Model

The computer program HFCVWELD has been developed to complete a reliability analysis of the horizontally-framed culvert valves on the Ohio River system. The model was developed to measure the performance of the valves over time. Additionally, the model is used to determine if it is a better decision to replace the valves at some scheduled date as opposed to fixing them after they perform unsatisfactorily.

The basis of the model is that it is a time dependent reliability model for a structure subject to fatigue and corrosion. Therefore, input items such as paint history, corrosion rates, historical operating head with cycle information, and other variables are used in the model to determine the time dependent reliability of the structure.

Using the analysis and limit state information from the finite element modeling, HFCVWELD computes the time dependent reliability of the culvert valves given the input values. A critical crack length is input into the model as the limit state. For each iteration, the model determines the year in which a fatigue-related crack initiates and marks that year. Once the crack initiates, it is allowed to grow relative to the operating cycles within the histogram for each year after the time that it initiates. Once the crack reaches the limit state crack length, the year is tracked, recorded and marked as the year of unsatisfactory performance. This is done for each iteration and the results tabulated in a separate file.

The input menus associated with HFCVWELD look very similar to the ones for the miter gates. Input menus for things such as lock information, crack parameters, loading histograms, traffic cycles, etc. are input similar to the HWELD model for miter gates. In order not to repeat similar figures, please refer to the horizontally-framed miter gate model input narrative in Section 5.2.7 for figures depicting what the input menus look like.

1) Lock Information. The first portion of input is the project name and chamber that is being analy~~zed. For Markla~~nd and Greenup, the valves for both the main and auxiliary chambers are the same in terms of design and construction technique. However, operating cycles and age are different for the chambers and thus, each must be analyzed separately.

2) Crack Parameters. The initial crack length is set to a default value of 0.25 inches, the same a~~s the miter gate initial~~ crack length. The critical crack length is a function of other random

variables within the model and thus, is not input separately by the user. It is computed for each individual iteration within the model.

3) Head Histogram. The head histogram reflects the actual past distribution of head differential and hydraulic cycles for the reversed tainter valves. This distribution is based on true daily lockage cycles of each chamber available from the Lock Performance Monitoring System (LPMS) combined with the true head differential for each day. This distribution is very valuable in determining the fraction of annual cycles versus the expected head differential that can be used for fatigue analysis. The head histograms developed by WES are based on data collected and analyzed for approximately 12 years (1984–1995, inclusive) of lock operation. The HFCVWELD program allows the input of up to 20 different blocks for head (at specified midpoints) and fraction of cycles from the histograms. This histogram is used in HFCVWELD to parse the input annual cycles into the defined stress range blocks and number cycles for fatigue analysis.

4) Traffic Cycles. The number of operating cycles for the culvert valves are determined for each lock based on actual and predicted future cycles for the study period. The cycle information is used in fatigue analysis incorporated into the HFCVWELD program. The cycles are input from the start of operation to the end of the study period. Operating cycles from the origination of the each project through 1983 were determined by going through the log books to determine the number of lockages in each chamber. A ratio of lockages to operating cycles was determined and assumed to be the same in the past as well as for future projected cycles. Traffic cycles for 1984 through 2004 were determined on historical traffic using LPMS data. Future traffic projections for each of the five scenarios (Clear Skies, Modified Clear Skies, NAAQS, Utility Based, and Utility High) were provided by the ORMSS Economics Team.

Random Variables for HFCVWELD

The random variables incorporated into the HFCVWELD analysis are the yield strength of A36 steel, corrosion rate, residual stress factor, and the dynamic amplification factor. The values and ranges for the yield strength are the same as for the miter gates. The corrosion rate selected was for a structure subjected to wet/dry applications because the valves are constantly in and out of the water during operation. This rate is termed in the “splash” zone and has a higher corrosion rate than a submerged structure that was used for the miter gate analysis. Additionally, it was assumed that the valves only had an initial effective paint life of 5 years because of the turbulent water conditions impacting the valve during filling and emptying operations. This was based upon engineering judgment. However, sensitivity analyses were conducted varying the “effective” paint life from 0 to 20 years and it did not turn out to be a controlling variable. Therefore, the five-year life was used. Because a detailed residual stress analysis was not possible for this model due to funding and schedule constraints, a residual stress factor was created to attempt to measure the randomness associated with the residual stress analysis required for this model. The factor was based upon the residual stress analysis completed for the Markland miter gates. Finally, a dynamic amplification factor was needed to measure the increase in load on the valve due to the high velocities that occur during filling and emptying operations. This value (along with appropriate range) was determined by using a fluid flow analysis within the finite element model. This is described in Section 5.4.4. Again, all random variables were selected using Monte Carlo simulation.

1) Yield Strength. The distribution for yield strength is based on data from the published literature and previous Corps of Engineers reliability studies. The distribution is based on a truncated lognormal with a nominal yield stress of 38.88 ksi (i.e., mean yield strength times the

strength ratio) and a standard deviation of 5.44. The lower limit for truncation is based on one standard deviation below the nominal (33.44 ksi) and the upper limit is based on approximately two standard deviations above the nominal (51 ksi). The distribution and statistical moments for yield strength of the steel are the same as used for the miter gates.

2) Corrosion Rate. The distribution for corrosion is based on the data from the published literatur~~e and previous Co~~rps of Engineers reliability studies. Corrosion is based on a power law that has been fit to actual field data in various corrosive environments. The equation used for the corrosion is $C(t) = A*t^B$, where A is a random variable based on field measurements, B is generally a constant based on different corrosive environments and C(t) is the corrosion in micromils/yr. For this report, the mean value of A was selected based on submerged corrosion. This distribution used for A was a truncated lognormal with a mean value was 140 and standard deviation of 42. The upper limit of the distribution was taken at 224 and the lower limit at 56. The value for B was a constant of 0.667. These limits and constants are based on actual field measurement of hydraulic steel structures.

3) Residual Stress and Dynamic Amplification Factors. Two types of factors are utilized in HFCV~~WELD to account the major differences in stress values~~ between traditional hand calculations and the more sophisticated finite element analysis. The residual stress factor is for tensile stresses that are created during the heating and subsequent cooling of the welds at the time of construction. The second factor is the dynamic amplification factor, which represents increased load on the valve that is created by the vortex flow and pressure differential of the water around the valve upon opening. This quick change in pressure increases the stresses on the strut arms during valve operation. An extensive search for field measurement data on this subject was conducted, but did not turn up any definable results for forces on the valve. Therefore, these adjustment were determined based on a fluid flow finite element analysis to determine the range of values that may be exhibited in the valves.

The distribution for the residual stress model factors was considered to be normal since the limits were primarily defined as concentrated about a certain ratio. The mean value for residual stress was 0.35 with a standard deviation of 0.05. The dynamic amplification factor was determined to be a normal distribution with a mean of 1.25 (25% increase) and a standard deviation of 0.025 (2.5%).

5.4.6 HFCVWELD Reliability Model Results and Event Trees

The output from the HFCVWELD reliability model is an individual hazard function giving the overall probability of unsatisfactory performance of the culvert valve over time. The output is representative of a single valve at the project. Since the consequence event tree for the valves are developed around what response would be made if a single valve failed, then the overall reliability for all the culvert valves within the chamber need to be put in series. This will give the overall reliability for all four culvert valves within the main chamber. For the auxiliary chamber, this would require two valves being in series since there is only a single filling and single emptying valve. If historic repairs have been made to individual valves that improved the reliability performance, then the reliability of this individual valve was improved in the series system analysis.

MAIN CHAMBER HAZARD RATES AND EVENT TREE

Since there are several projects that have horizontally-framed culvert valves, the same type of process of selecting a single site as representative for the purposes of clearly describing the

process will be done for the valves. In order to depict different project features at different sites, the representative site for the horizontally-framed valves was selected as Greenup for the purposes of this narrative. As noted earlier, the HFCVWELD program produces a hazard rate for one valve per traffic projection. Three traffic projections (lowest, highest, and middle) are provided to the economists, along with a consequence event tree. Hazard rates for the valves were developed for the following traffic scenarios at Greenup: Clear Skies (lowest), Utility High (highest), and Modified Clear Skies (middle). A graphical representation of the calculated hazard rates for the main chamber valves at Greenup is shown in Figure ED-30.

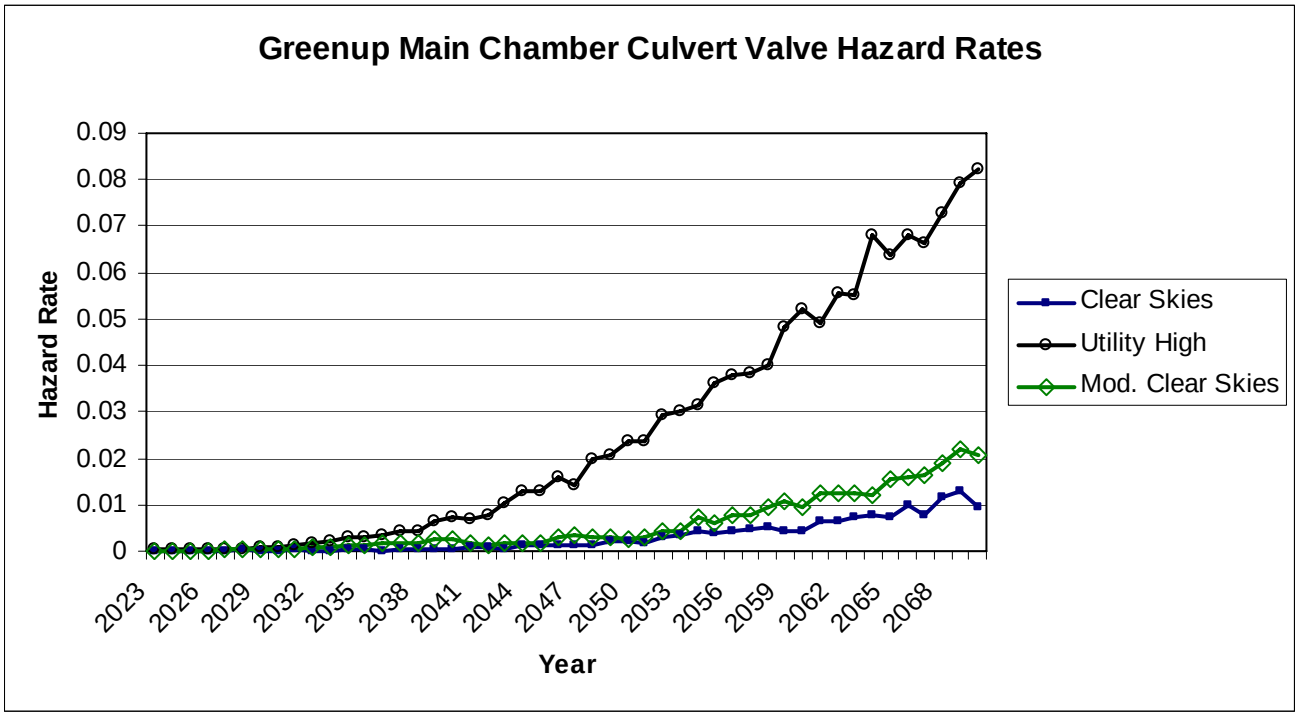


Figure ED 5-30. Greenup Main Chamber Culvert Valve Hazard Rates

The hazard rates shown in Figure ED 5-30 are for a single valve and were given to the economists along with chamber specific event trees. As illustrated in Figure ED 5-30, the Utility High forecast yields a hazard rate that is significantly higher than the middle (Modified Clear Skies) and low (Clear Skies) hazard rate. This is a function of the traffic forecast at Greenup. The event tree for the main chamber was formulated with the context of how historical repairs to valves have been made with the chamber operating at half filling/emptying speed. This is different than valve performance for Ohio River auxiliary chambers where there is only a single filling and single emptying valve used for the smaller 600-ft chamber. The doubling of filling and emptying time does not begin to compare to the navigation loss of benefits associated with having the main chamber closed and needing to move large tows through the smaller auxiliary chamber. Therefore, separate event trees were needed for the two chambers. The event tree for the main chamber is shown in Figure ED 5-31. A similar format as used for the miter gate event tree was used for the valves. Assuming an unsatisfactory performance of the culvert valve based upon the mode selected in the reliability model, three possible repair scenarios were chosen along with a replacement ahead of failure scenario which is used to time individual component replacements when economically justified. A breakdown of these repair scenarios for the main chamber culvert valves, along with their costs and closures are provided in Figure ED 5-31.

ANNUAL HAZARD RATE	LEVEL OF FAILURE & SUBSEQUENT REPAIR			CLOSURE TIME	CHAMBER @ 1/2 SPEED	REPAIR COST	DESCRIPTION OF REPAIR SEQUENCE	EFFECT ON FUTURE COMPONENT RELIABILITY
Annual Reliability Value (1 - Annual Hazard Rate)								
	Catastrophic Failure of a Single Valve. Close Chamber to Inspect/Repair Other Valves.	5%	0-30 years of service	5 days in year 1	180 days in year 1	Cost $6,074,627	Fleet on-site for a total of 5 days for closure and 45 days per valve for emergency repairs	Assume R = 1.0 for All Future Years
	Design New Valves. Operate Chamber @ 1/2 Speed Until New Valves Installed.	10%	31-50 years of service	0 days in year 2	365 days in year 2	Cost $2,000,000	Costs associated with design of new valves and fabrication cost	
	New Valves Fabricated and Installed in Chamber.	15%	Over 50 years of service	0 days in year 3	180 days in year 3	Cost $2,640,000	Fleet requires 120 days to install new valves (30 days per valve on average)	
Annual Hazard Rate	Major Repair Required but All Valves Still Serviceable for Immediate Future	75%	0-30 years of service	0 days in year 1	90 days in year 1	Cost $2,955,224	90 days to repair filling valves	Move Back 15 Years
		65%	31-50 years of service	0 days in year 2	90 days in year 2	Cost $2,955,224	90 days to repair emptying valves	
		55%	Over 50 years of service					
	Failure of a Single Valve. Close Chamber to Inspect/Repair Other Valves.	20%	0-30 years of service	1 days in year 1	180 days in year 1	Cost $5,943,284	Fleet on-site for a total of 1 days for closure and 45 days per valve for emergency repairs	Assume R = 1.0 for All Future Years
	Temporary Repairs Make Chamber Fully Operational. However, New Valves Required.	25%	31-50 years of service	0 days in year 2	0 days in year 2	Cost $2,000,000	Costs associated with design of new valves and fabrication cost	
	Design, Fabricate, and Install New Valves	30%	Over 50 years of service	0 days in year 3	180 days in year 3	Cost $2,640,000	Fleet requires 120 days to install new valves (30 days per valve on average)	

REPAIRS COST INFORMATION

$32,836	LRL Fleet Rate for Emergency Repairs to Valves (Factored Cost from ORMSS 1/2 Speed Historical Repair Work)
$200,000	Engineering Cost for Design of New Valves and Contract Award Effort (Markland Rehab Estimate)
$22,000	LRL Fleet Rate for Normal Valve Repairs (ORMSS Historical Database)
$1,800,000	Cost to Fabricate and Deliver 4 New Culvert Valves

REPLACEMENT OF MAIN CULVERT VALVES PRIOR TO FAILURE

Year 1 - Fabricate 2 Culvert Valves
Year 2 - Install 2 New Valves. Fabricate Other 2 Valves.
Year 3 - Install 2 Remaining Valves.

	Chamber 1/2 Speed	Cost of Repairs
Year 1	0	$900,000
Year 2	60	$2,220,000
Year 3	60	$1,320,000

There is no closure time required when valves are replaced ahead of failure.
With proper preparation, it will take about 30 days per valve to switch out the damage valve with the new one.

Figure ED 5-31. Main Chamber Culvert Valve Event Tree

Catastrophic Failure, Install 4 New Valves. This repair assumes the worst situation, a catastrophic failure of a culvert valve. It is assumed the damage and potential problems associated with the failure are enough to warrant a short closure of the main chamber to determine the problem and do a brief inspection of the other valves since they should all be of the same general condition. The duration of this closure is estimated to be 5 days and then the main chamber can be put back into service by operating at ½ speed. The overall repair effort is spread over 3 years since the damage caused by the failure is done during the first year and then four new valves are fabricated, delivered to the site and installed over the next two years. Future reliability is assumed to be equal to1.0 for the remainder of the study since new valves are installed. The repair cost associated with this repair is estimated at $10,714,660. The estimate is not accurate to that degree but the values are based upon average historical valve repair rates completed in the last 20 years by the Louisville District's repair fleet. There have been several emergency valve repairs made by LRL during this time frame and the average fleet rate for these repairs is $32,836 per day in FY05 dollars. The rate per day is lower because less personnel are required than full chamber dewaterings for miter gates where main chamber closure time must be kept to a minimum. It was also determined that a rate of approximately $22,000 per day is applicable for "normal" valve repairs from historic records. This rate will be used for work that can be planned in advance. A breakdown of the costs for this repair scenario is supplied below.

Repair Fleet Closes Chamber for 5 days for Inspection (Year 1):	$164,180 ($32,836/day for 5 days)
Full Inspection & Valve Repairs (45 days each valve, Year 1):	$5,910,480 ($32,836/day for 180 days)
Design, Fabricate and Delivery of 4 New Valves (Year 2):	$2,000,000
Installation of 4 New Valves in Chamber (Year 3):	$2,640,000 ($22,000k/day for 120 days)
Total for All Items for Catastrophic Repair:	**$10,714,660**

It is assumed that the chance of a catastrophic failure of this magnitude is quite low, therefore, it was decided to only place about a 5% chance of this occurrence in the first 30 years of service on this branch. This was increase to 10% for valves in service between 31 and 50 years, and finally, increased to a maximum of 15% for valve service life of over 50 years.

Temporary Repair with New Valves Following Year. This repair assumes that the major damage has occurred to at least one of the four valves such that it is out of service. The chamber is assumed to be shut down while engineers travel to the site to assess the situation. After a brief inspection, the chamber is opened back up for traffic but only at ½ speed while detailed inspection and repairs are made to all 4 valves. This would be done for each of the 4 valves. Emergency repairs would be made and then new valves would be designed and fabricated the following year. Installation of the 4 valves would occur in year 3 of the repair. Similar repair, fabrication, and installation times are assumed for this repair scenario as was done for the catastrophic repair. The only difference is the chamber is only closed 1 day in the year of the failure. The overall cost for this repair is estimated at $10,583,326 with chamber closure time of 1 day and total ½ speed time of roughly 2 years. Future reliability is assumed to be equal to 1.0 for the remainder of the study since new valves are installed the third and last year of this repair scenario. A breakdown of the costs for this repair is supplied below.

Repair Fleet Closes Chamber for 1 days for Inspection (Year 1):	$32,836 (emergency repair rate)
Full Inspection & Valve Repairs (45 days each valve, Year 1):	$5,910,480 ($32,836/day for 180 days)
Design, Fabricate and Delivery of 4 New Valves (Year 2):	$2,000,000
Installation of 4 New Valves in Chamber (Year 3):	$2,640,000 ($22,000/day for 120 days)
Total for All Items for Temporary Repair:	**$10,583,326**

It was agreed by the Engineering and Operations Team that this scenario was more likely to occur than the catastrophic repair scenario, however, it is not the most likely repair option. Thus, 20% was placed on this branch for up to 30 years of service, 25% between 31 and 50 years, and 30% for valves in service longer than 50 years. It is believed that the repair fleet would do everything possible to get the chamber operational again, however, major damage would prompt the district to obtain the funds to procure new valves.

Major Repair, Leave Existing Valves. This repair assumes the least damage to the culvert valves, such that they are repairable and can continue in service. For this situation, the main chamber does not require a closure, but is operated at ½ speed for repairs to each of the valves. It is estimated that each valve will require 45 days to repair. The cost associated with this alternative is estimated to be $5,910,480 over 2 years assuming a daily repair fleet rate of $32,836 per day for emergency valve repairs. It is assumed that the valves are repaired well enough that they can continue to provide adequate service in the future. Thus, the hazard rate after the repairs is lowered by "moving back" the hazard rate to a value to what it was 15 years prior to the failure and resetting the curve. Again, this is the easiest way to improve the reliability of a component after a repair in the economic model. A breakdown of costs associated with this repair is provided below.

Emergency Repairs to 2 Valves (45 days per valve, Year 1):	$2,955,240 ($32,836/day for 180 days)
Emergency Repairs to 2 Valves (45 days per valve, Year 2):	$2,955,240 ($32,836/day for 180 days)
Total for All Items for Major Repair:	**$5,910,480**

It was agreed that this scenario represented the most likely repair given the limit state modeled in the reliability analysis. Therefore, 75% was placed on this branch for valves with less than 30 years of service, 65% for valves with 31 to 50 years of service, and 55% for valves in service more than 50 years.

Scheduled Replacement of Culvert Valves. The other piece of information the economists need is the cost and chamber closure or filling/emptying effect associated with the scheduled replacement of the valves before failure. There are four valves for the main chamber and it can be operated at half-speed in the event of repair or replacement work to one of the valves. The simplifying assumption is made that new valves will be 100% reliable for this limit state for the remainder of the study period once they are installed. A well-planned and executed replacement should save considerable time when compared to the fix-as-fails scenarios evaluated with the hazard rate and event tree repair scenarios. Therefore, for this option is reduced to $4,440,000 and the total required time of the chamber operating at ½ speed is 120 days over a 2 year period. The cost and closure breakdown associated with a scheduled replacement of the main chamber culvert valves is provided below.

Fabrication of 2 New Valves (Year 1):	$900,000
Fabrication of Remaining 2 New Valves (Year 2):	$900,000
Installation of 2 New Valves (30 days per valve, Year 2):	$1,320,000 ($22,000/day for 60 days)
Installation of Remaining 2 New Valves (Year 3):	$1,320,000 ($22,000/day for 60 days)
Total for All Items for Replace Ahead of Failure:	**$4,440,000**

AUXILIARY CHAMBER HAZARD RATES AND EVENT TREE

As noted previously, the failure of a single culvert valve in a main chamber with 4 valves is considerably different that a failure of a single valve in an auxiliary chamber. The auxiliary

chambers on the Ohio River only have 2 valves (one filling and one emptying). Thus, a failure of an auxiliary chamber valve shuts that chamber down totally until the valve can be repaired. The same type of engineering reliability analysis is carried out for the auxiliary chamber culvert valves as was done for the main chamber culvert valves, however, chamber specific information such as operating cycles, paint history, etc. is applied to determine the hazard rate. Since the auxiliary chambers on the Ohio River are primarily used for recreational lockages and when the main chamber is closed for maintenance, they have seen significantly lower operating cycles to date. After conducting the engineering reliability analysis for the auxiliary chamber culvert valves, only one project (Markland) had enough operating cycles and stresses where predicted damage was high enough to generate a positive hazard rated during the study period. The analysis was carried out for the auxiliary chamber culvert valves, but no failures were encountered for the selected limit state. Since only one auxiliary chamber horizontally-framed culvert valve was analyzed in the economic analysis, no significant detail is provided on the event tree. However, the following general information applies. The same format was used, however, chamber closures were specified for each of the three levels of repair (catastrophic, temporary, and major) as opposed to ½ speed operating days for main chamber culvert valves. In addition, replacement costs are roughly ½ of the main chamber since there are only 2 valves for an auxiliary chamber.

5.4.7 Economic Results for Horizontally-Framed Culvert Valves

The Engineering Team provides both the hazard rates for the culvert valves, as shown in Figure ED 5-30 for Greenup, and the event tree shown in Figure ED 5-31 to the Economics Team for them to input into ORNIM. The other critical information for the main chamber culvert valves provided to the Economics Team was the replace ahead of failure costs and closures as outlined in Section 5.4.6 of this appendix. ORNIM was then used to compute average annual costs for two repair options (fix-as-fails or replace ahead of failure) for the main chamber culvert valves at Greenup. The average annual costs include both navigation delay and physical repair costs. Improved reliability after the repair is also included in the analysis, as noted in the event tree for differing levels of repairs. The costs of each alternative, fix-as-fails versus selected replacement dates, are compared to determine the most economic option. The replacement year with the lowest average annual cost sets the timed replacement of the culvert valves with fix-as-fails costs added to the economic analysis up to the year of scheduled replacement. Refer to the Economics Appendix for a more detailed description of how the ORNIM optimizes individual component replacements. If the lowest average annual cost is associated with the baseline condition (fix-as-fails), then the replacement of the culvert valves is not justified economically and the fix-as-fails costs are embedded into the overall economic analysis for every year of the study period. ORNIM produces a graphical output depicting the results and optimal timing of this process for each component and each traffic scenario. The ORNIM output for the Greenup main chamber culvert valves is shown for the Utility High traffic forecast in Figure ED-32.

As noted earlier, the culvert valves at Greenup were evaluated for each traffic scenario. Using the same methodology, optimized replacement dates were determined for each traffic scenario and are provided in the Economics Appendix.

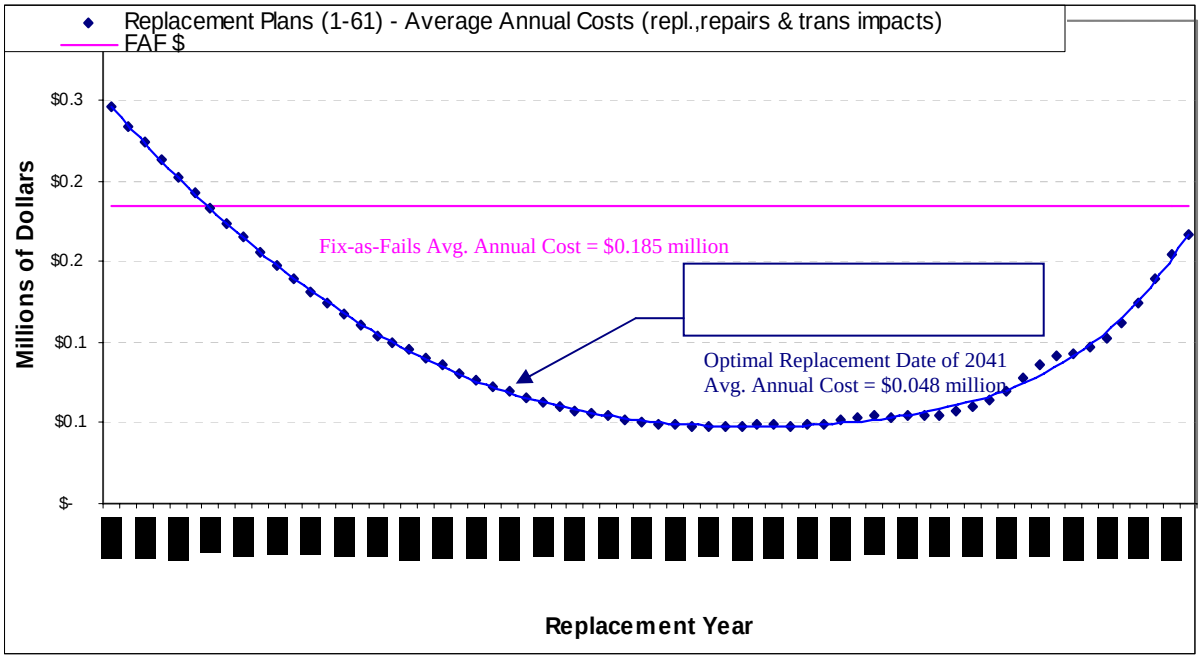


Figure ED 5-32. Greenup Main Culvert Valves Optimized Replacement Date (Utility High Traffic Scenario)

The lowest traffic scenario is the Clear Skies at Greenup. The other two lower scenarios, NAAQS and Modified Clear Skies, have only 12% and 13%, respectively, more cumulative projected traffic cycles between 2005 and 2070. However, the Utility Based and Utility High scenarios have 54% and 67%, respectively, more cumulative projected cycles than the Clear Skies scenario. For the culvert valves, this relates directly to the increased hazard rates for these traffic scenarios. This is more clearly depicted in Figure ED-30, which shows the hazard rates for the main chamber culvert valves at Greenup for the Clear Skies, Modified Clear Skies, and Utility High scenarios. The Utility High hazard rate is significantly higher than the other two scenarios in that graph. The much lower hazard rates combined with considerably less navigation delay consequences associated with operating at ½ speed compared to chamber closures is what causes the lower traffic projections to have "fix-as-fails" as the optimal economic solution for NAAQS, Modified Clear Skies, and the Clear Skies at Greenup.

Please refer to the tables in the Economics Appendix for the optimized replacement date of all horizontally-framed culvert valves across the Ohio River projects. These are given for each lock chamber by traffic scenario.

5.5 VERTICALLY-FRAMED REVERSE TAINTER CULVERT VALVE RELIABILITY

Reverse tainter culvert valves at Ohio River projects are used to control the filling and emptying of lock chambers. All sites with the exception of the upper three (Emsworth, Dashields, and Montgomery Locks and Dams) utilize reverse tainter culvert valves for the filling and emptying of the lock chamber. Emsworth, Dashields, and Montgomery (EDM) utilize butterfly valves for the operation of their filling and emptying systems. Butterfly valves are covered within the overall mechanical model. There are two types of reverse tainter culvert valves: horizontally-framed and vertically-framed. Separate reliability models had to be developed for each of these reverse tainter culvert valves. In general, the older sites use horizontally-framed culvert valves. These include the

valves at Pike Island, New Cumberland, Greenup, Meldahl, Markland, and the existing main chamber at McAlpine. The newer projects have vertically-framed valves. These sites include Willow Island, Belleville, Racine, Hannibal, R.C. Byrd, Cannelton, Newburgh, J.T. Myers, Smithland, and Olmsted. This section will focus on the horizontally-framed culvert valves. Section 5.4 focuses on horizontally-framed culvert valve reliability.

5.5.1 Main Chamber vs. Auxiliary Chamber

The same issues that apply main chamber versus auxiliary chambers for horizontally-framed culvert valves also apply to vertically-framed culvert valves on the Ohio River. There are 4 vertically-framed culvert valves for main chambers, the same as horizontally-framed culvert valves. Therefore, repairs can be made to vertically-framed valves while the lock continues to operate, although filling and emptying time is approximately doubled when compared to all valves operating properly. The auxiliary chambers on the Ohio River with vertically-framed valves are set up similar to the horizontally-framed culvert valves, two per auxiliary chamber. Thus, a repair to an auxiliary chamber vertically-framed valve requires a closure to the auxiliary chamber. However, the significance of closing the auxiliary chamber is considerably less than the main chamber where disbenefits associated with the closure can become large for extended closures.

5.5.2 Grouping of Vertically-Framed Reverse Tainter Culvert Valves

The valves are termed vertically-framed since the main load from the skin plate is transferred to large horizontal plate girders by a series of vertical curved ribs. The large horizontal plate girders transfer the load to a series of axially-loaded strut arms that connect the body of the valve to a pin plate casting, which transfers the load to the valve's trunnion beam. The trunnion beam then transfers the load to the concrete monolith. The valves act in tension since the tainter gate is reversed to the direction of flow. There are nine projects on the Ohio River system that utilize vertically-framed culvert valves. These valves can be broken into four separate groups. The groups are classified as follows:

Group 1. Group 1 vertically-framed culvert valves include those found at Willow Island, Belleville, Racine, and Hannibal Lock and Dams. These valves typically have curved vertical ribs that are approximately 11" deep and ½" thick. The flanges are roughly 6" wide and 1" thick. Most of the horizontal plate girders are 13 ½" deep by 1 ½" thick with flanges that measure 12" wide by 1 ¼" thick. Additionally, all four normally operate at a head of 20 to 22 feet.

Group 2. Sites considered for group 2 are Cannelton, Newburgh, and J.T. Myers. Each of these have vertical curved ribs that measure approximately 8" deep by ½" thick. The flanges typically measure 8" x 1". The horizontal girders measure approximately 28" deep by 5/8" thick. All these were built in the early 1970's.

Group 3. The valves at Smithland are the only ones in this group. This is mainly due to the small flange size on the vertical curved ribs. These ribs have flanges that measure only 4" wide by 1 ¼" thick. It should be noted that there was a major failure of one of the Smithland valves in 1998 at the connection of the vertical curved rib and lower horizontal girder. At the time of the failure, the other valves at Smithland were inspected and found to have the same deteriorated condition, thus, on the verge of failure.

Group 4. R.C. Byrd represents the only site with valves in this group. This is because the valves are the newest ones on the Ohio River system (1993) and do not fit well within other categories for member sizes.

Since all the vertically-framed valves on the Ohio River system are similar in construction type and operation, it was decided to develop the reliability model based upon field experience at Smithland. Therefore, global and local finite element models for the Smithland culvert valves were made in order to develop a time dependent reliability model for all Ohio River Mainstem Systems Study (ORMSS) vertically-framed valves. The limit state of the vertically-framed valves was centered around the type of failure that occurred at Smithland. From the Smithland global and local finite element models, appropriate adjustments were made to determine group specific load factors for such things as stress concentration factors associated with different member sizes.

Figure ED 5-33 shows the vertically-framed reverse tainter culvert valves being painted outside the chamber at Smithland. Note that all of the vertically-framed culvert valves are of similar general design and construction technique, thus, setting up the reliability model based upon experiences at Smithland is valid. Figures ED 5-34 through 5-38 depict the damage at Smithland from the 1998 failure and the limit state selected for the valves.

5.5.3 Finite Element Modeling and Calibration of Vertically-Framed Reverse Tainter Culvert Valves

Finite element modeling is used to develop reliability models for fatigue cracking at welded connections for vertically-framed culvert valves based on analyses and experience gained from reliability modeling for fatigue cracking at welded connections on miter gates and horizontally-framed culvert valves. In addition, recent field experience involving welded connection failures on a vertically framed culvert valves at the Smithland is used to guide the analysis and benchmark the reliability model. On each of these damaged culvert valves, the weld attaching a vertical rib to the main horizontal load beam failed, which separated the rib from the load beam. As the load transferred to adjacent connections, subsequent connections failed, both at the welded connections and from complete fracture through the vertical ribs.

This sequential failure at these connections is diagnosed to have progressed in a fairly rapid manner relative to a reliability study for fatigue cracking. Thus, once a crack initiated at the first welded connection, the operational failure of the valve developed within a relatively few additional cycles of operation. Therefore, for this reliability modeling, the limit state can be considered the initiation of fatigue cracking at the critical connection of the vertical rib to the horizontal load beam, and the finite element modeling concentrated on characterizing the fatigue failure of this connection.

A global model of half of the Smithland lock culvert valve, as illustrated in Figure ED 5-39, was developed to identify the local areas that are more susceptible to cracking due to elevated stress concentration factors. The Smithland design was used as a surrogate for the finite element modeling since field data was available for benchmarking and calibrating the reliability model. The global model indicated that the connection between the vertical rib and the horizontal load beam near the edge of the valve would develop the highest stress concentration under the normal operating head. This is the connection that was determined to have failed first in the Smithland culvert valve. More detailed modeling of this connection was then implemented into the global model, as illustrated in Figure ED 5-43, to characterize the fatigue cracking at this connection. At this type of connection, the top of the flange plate of the vertical rib is welded directly to the bottom of the flange plate on the horizontal load

Figure ED 5-33. Photograph of Smithland Culvert Valve Being Painted

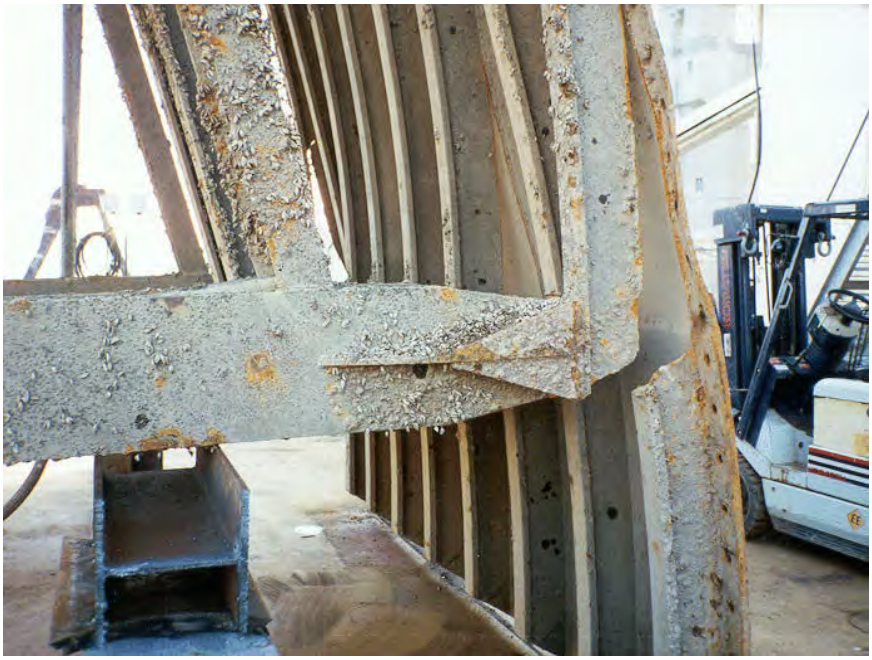


Figure ED 5-34. Side View of Failed Smithland Valve
Note sheared rib at strut arm and offset of curved ribs above and below horizontal girder.

Figure ED 5-35. Side View of Failed Curved Ribs at Bottom Horizontal Girder
Note the failure of the weld at horizontal girder in 2nd rib from end. Same weld failure occurred at 2nd rib from other end as well. All other ribs failed in shear.

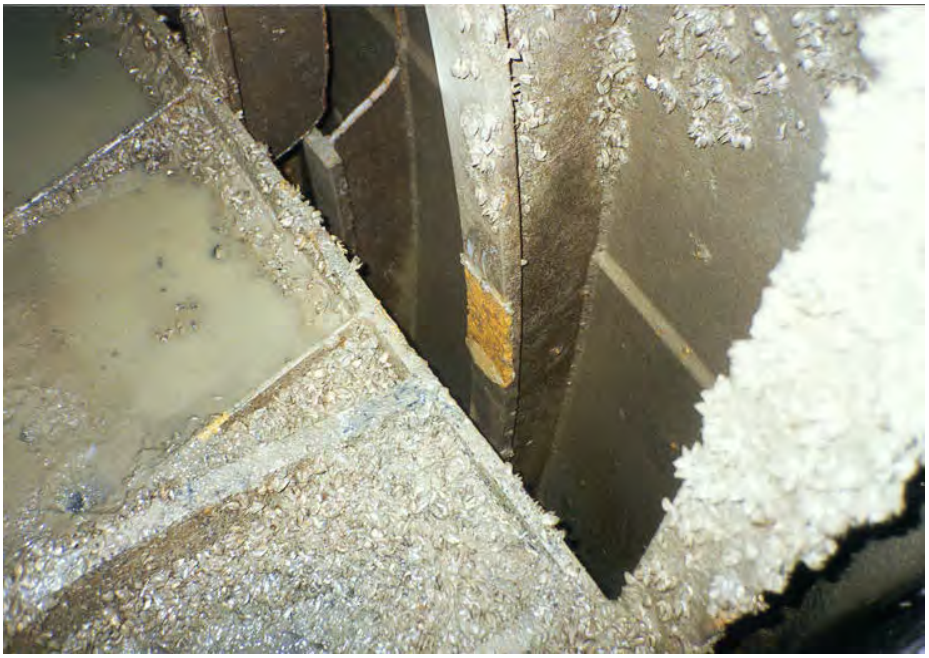


Figure ED 5-36. Failure of Weld at 2nd Vertical Rib
Note weld material left on rib after it separated from horizontal girder.

Figure ED 5-37. Shear Failure of Vertical Ribs in Middle of Valve
Note vertical rib on far right where initial weld failed.

Figure ED 5-38. Shear Failure and End Vertical Rib

beam using a fillet weld around the perimeter of the contacting plate areas. In the detailed modeling, the plate elements are constructed along the centerlines of the respective flanges. The two flanges are then connected together with plate elements around the perimeter representing the weld. The thickness of these weld elements is taken as the ligament thickness across the throat of the weld. The membrane stress in these weld elements, which acts through the depth of the weld, is used to establish the stress level for the fatigue cracking evaluations. Figure ED 5-40 also illustrates the maximum principal stress distribution in the weld at this connection due to the nominal operating head on the valve.

As in the reliability modeling for the horizontally framed culvert valves, a tensile residual stress is assumed to exist in the welded area. Because the connection failure is due to cracking along the weld, the residual stress can be assumed to be constant during the extension of the crack. This is consistent

with the field evidence that the fatigue crack extends relatively fast once it initiates. However, since limited funding and time constraints did not allow for detailed modeling of the distribution of residual

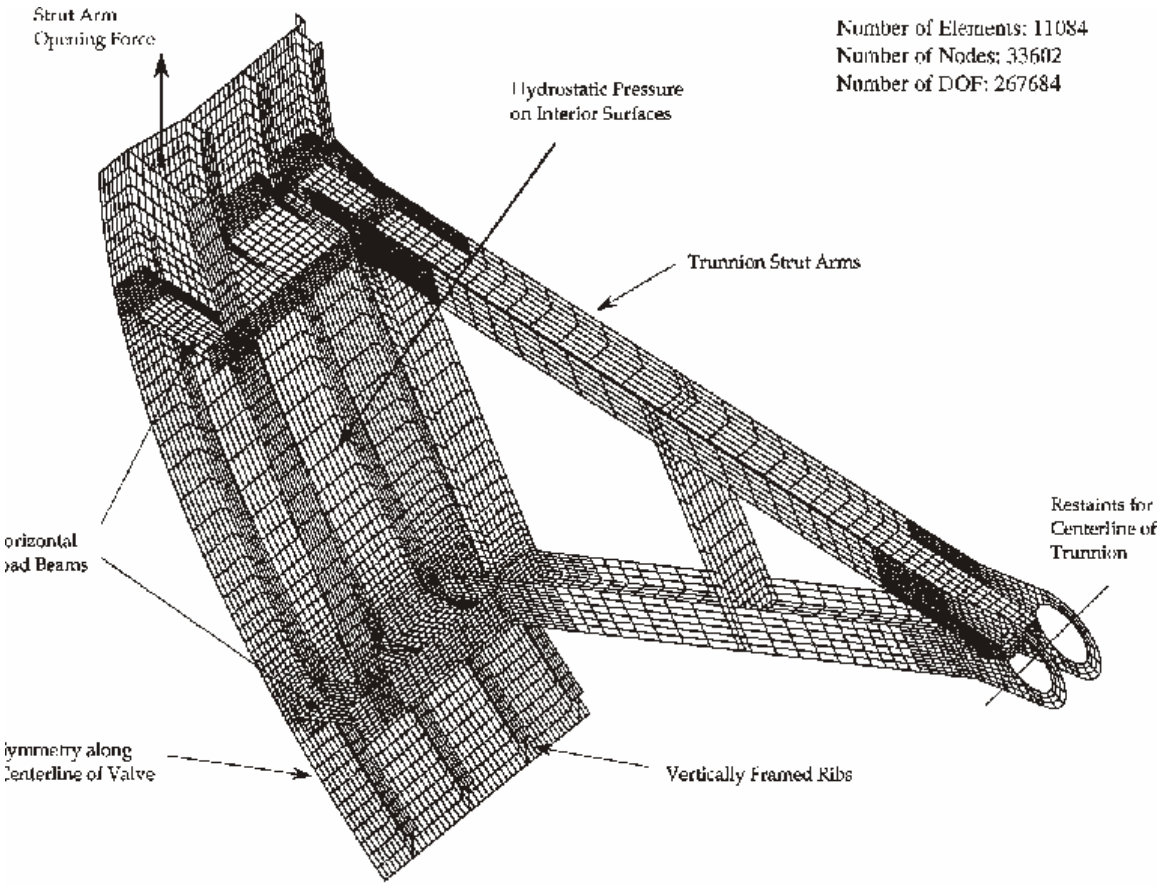


Figure ED 5-39. Global Finite Element Model of Smithland Culvert Valve

stresses, a larger variation for the level of residual stress is also assumed in the reliability calculations. The stress level calculated at the connection under the operational loads becomes the stress range for the fatigue cracking since these operational loads are imposed on top of the residual stresses. However, because the stress is cycling about a mean tensile value due to the residual stress, the effective alternating stress for determining the allowable fatigue cycles is adjusted using the Goodman relation.

The calculated peak membrane stress in the welded connection is used to establish a stress concentration factor that can be applied to the design based calculation for the average stress in the weld. The flange sizes are adjusted in the global model to account for the differences between site-specific culvert valve designs. For example, Figure ED 5-41 shows the principal stress contours for the geometry of Ohio River main chamber culvert valves (J.T. Myers is shown as an example in the Figure) to illustrate the stress concentrations present through the depth of the weld material. The stress concentration is then characterized for variations in operating head and thickness reduction due to corrosion.

The dynamic amplification factor of 1.3 on the nominal pressure head is also used to account for the hydrodynamic loading during opening of the valve. This factor was developed based on fluid flow modeling for a horizontally-framed culvert valve. Since this effect is a function of the general shape of the valve and culvert, rather than the details of the construction, this factor is also used for the vertically-framed culvert valve reliability model. For further details regarding the fluid-flow interaction, please refer to the horizontally-framed culvert valve narrative in Section 5.4 of this

appendix. Figure ED 5-42 illustrates the principal stress for crack initiation characterized as a function of head and thickness reduction developed for the reliability model.

As mentioned previously, the limit state of the vertically-framed culvert valve is defined to be the initiation of fatigue cracking at the welded connection between the vertical rib and the horizontal load beam. Field experience indicates that this cracking will rapidly propagate due to the reduction in area resisting the cyclic tensile loads. The cracking will completely separate the vertical rib from the horizontal load beam. As the load is transferred to the adjacent connections, similar failures will propagate until the valve has an operational failure. The failure hazard due to this limit state was benchmarked successfully with the Smithland and field experience. Thus, for this reliability modeling, the initiation of fatigue cracking at the first connection is considered sufficient to establish a failure of the valve.

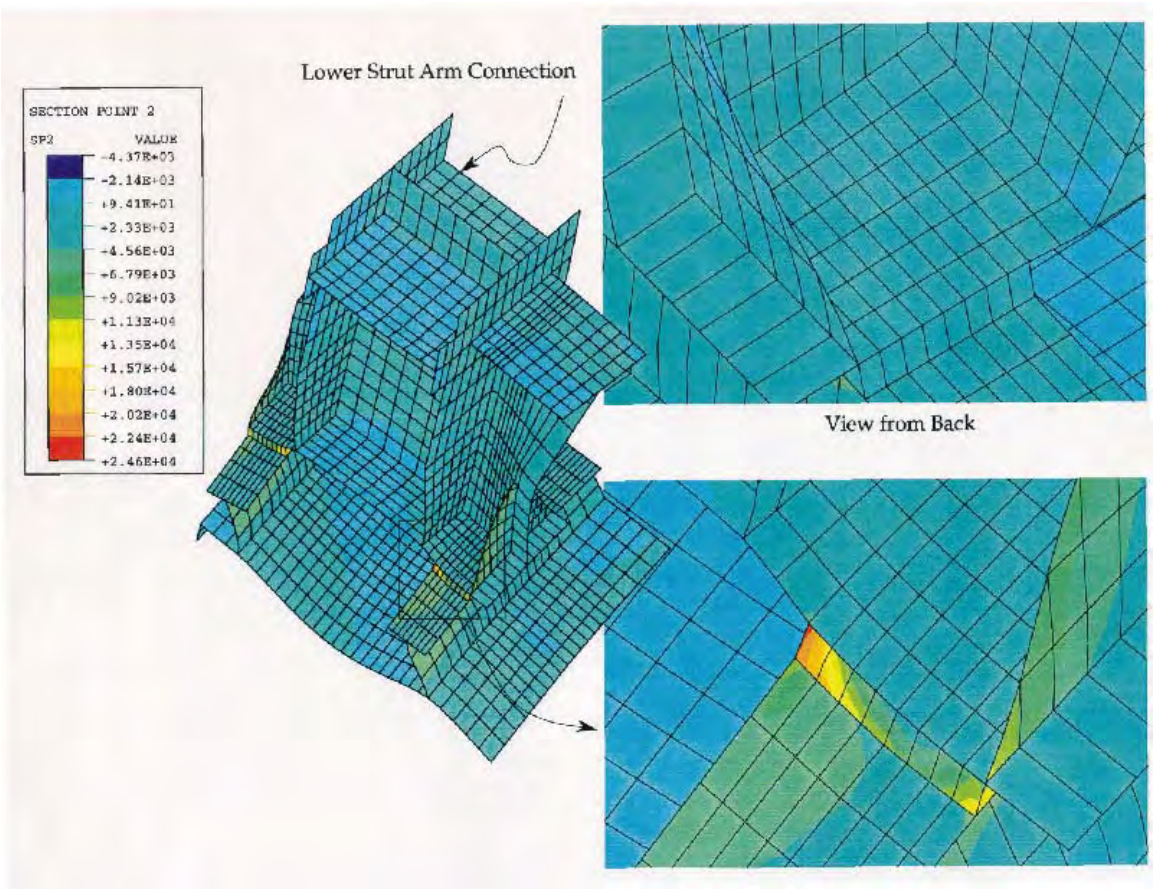


Figure ED 5-40. Maximum Principal Membrane Stress Refined Modeling of Welded Connection

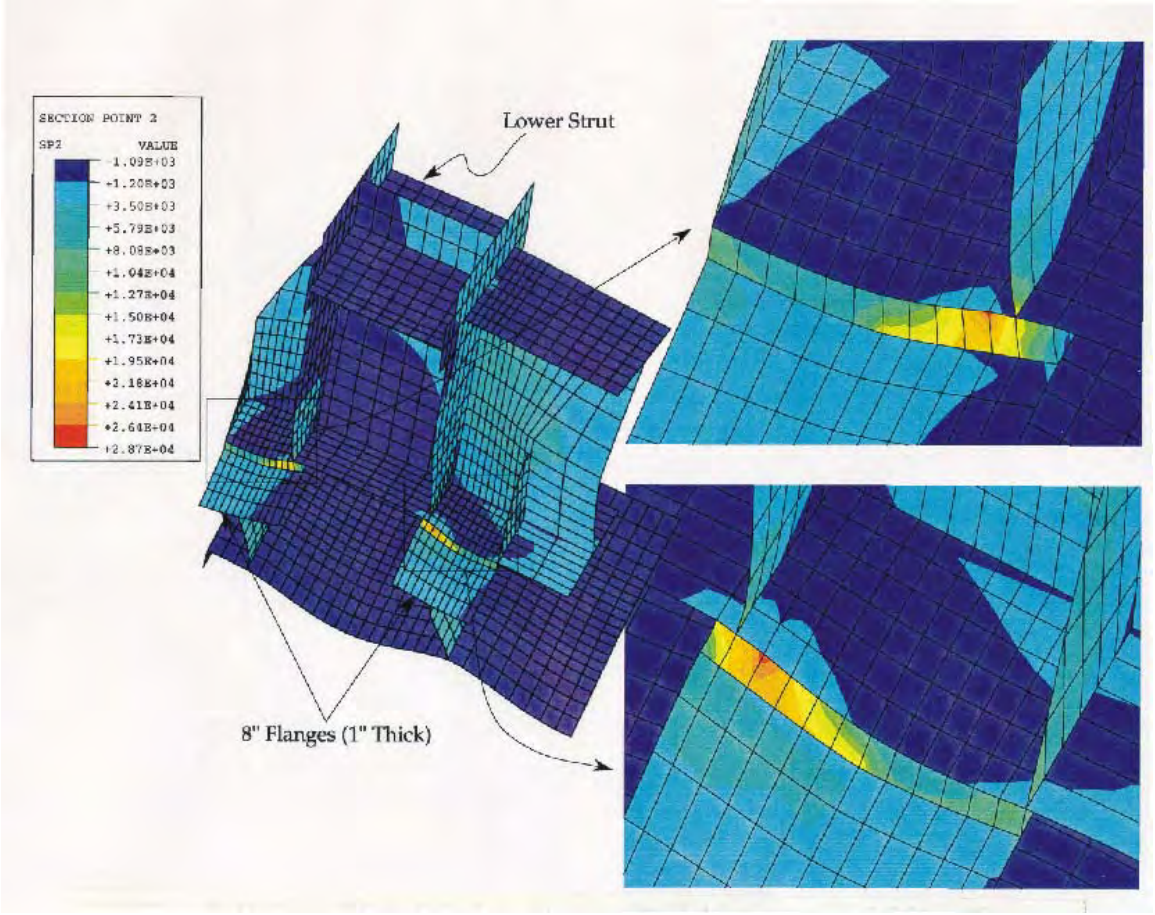


Figure ED 5-41. Maximum Principal Membrane Stress at Welded Connections for Ohio River Main Chamber Culvert Valves

5.5.4 Reliability Model Parameters

The time-dependent reliability analysis for the vertically-framed reverse tainter culvert valves was developed to estimate the hazard rate for these structures. Similar to the miter gate and horizontally-framed valve reliability models, the reliability analysis for vertically-framed valves incorporates both the fatigue and corrosion of the welds at the girder/rib connections of the valves. Additionally, the engineering team performed a range of 3-D finite element analyses of the valves to investigate the potential modes of failure of the valve, redistribution of loads upon failure, and the realistic values of stresses (both residual, static, and dynamic) to utilize into the reliability model. The limit state incorporated into the reliability model is based on the initiation of a crack at the girder/rib weld interface that causes a failure of the welds at the rib, which causes a redistribution of loads to the welds at the adjacent ribs. As evidenced from the valves at Smithland, actual field experience was used in the modeling effort to calibrate the timing of the limit state for the valves. For this model, the engineering team decided to develop a Visual Basic coded model specifically for the ORMSS vertically-framed reverse tainter culvert valves which was modeled similar to one developed for the miter gates and horizontally-framed culvert valves. The Visual Basic model was named VFCVWELD for the reliability of vertically-framed reverse tainter culvert valves.

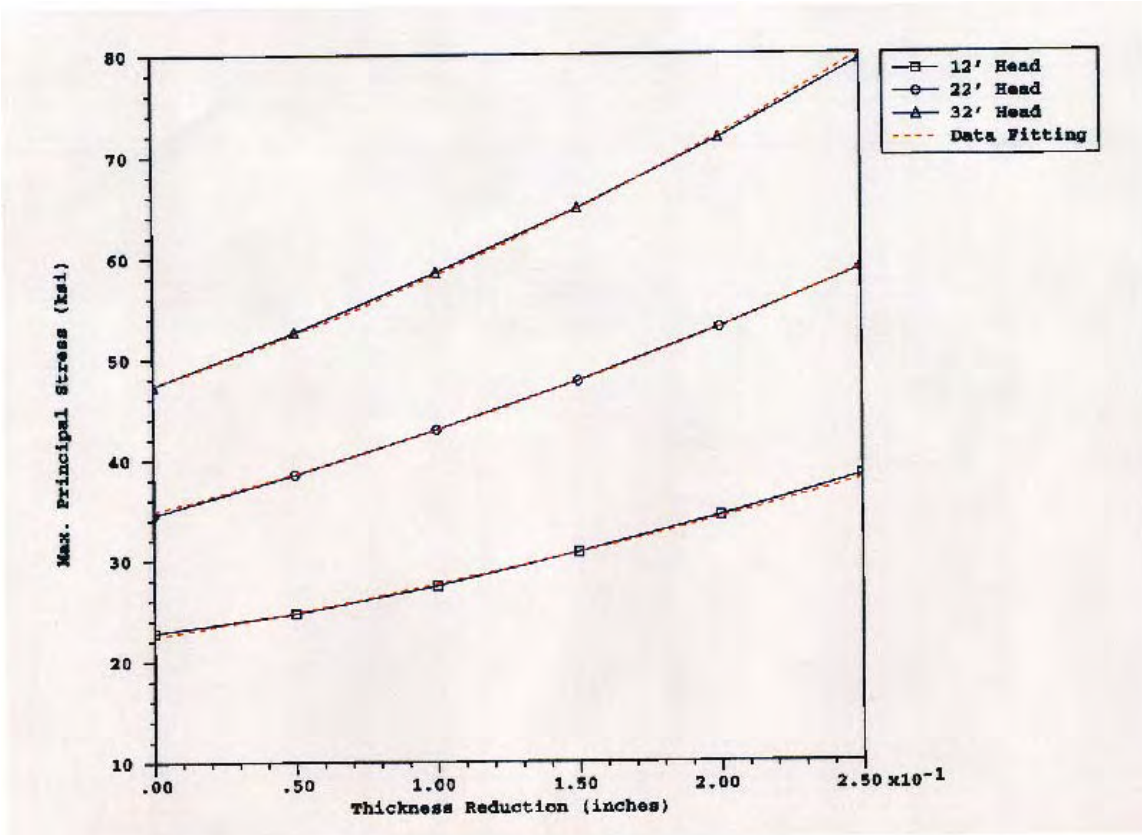


Figure ED 5-42. Principal Stress at Welded Connection as Function of Head and Thickness Reduction Due to Corrosion

VFCVWELD Reliability Model

The computer program VFCVWELD has been developed to complete a reliability analysis of the vertically-framed culvert valves for ORMSS lock projects. The model was developed to measure the future performance of the valves over time relative to the selected limit state. Additionally, the model is used to determine if it is a better decision to replace the valves at some scheduled date as opposed to fixing them after they perform unsatisfactorily.

The basis of the model is to determine the time dependent reliability for the valve structure subjected to fatigue and corrosion. Therefore, input items such as paint history, corrosion rates, historical operating head with cycle information, and other random variables are used in the model to determine the time dependent reliability of the structure. Using the analysis and limit state information defined from the finite element modeling, VFCVWELD computes the time dependent reliability of the vertically-framed culvert valves given the input parameters. For each iteration, the model determines the year in which a fatigue-related crack initiates and marks that year as the time of unsatisfactory performance. This is done for each iteration and the results are tabulated for the hazard function in a separate file.

Lock Information. The first portion of input is the project name and chamber that is being analyzed. For each of the ORMSS locks, both the main chamber and auxiliary chamber valves are of the same design and construction technique. However, operating cycles and age are different for the chambers and thus, each must be analyzed separately. The input menu from VFCVWELD for the lock information is to specify the district, lock project, and chamber that is being analyzed.

Rib/Girder Properties. The VFCVWELD program requires the input of rib and girder properties for the valve. Since the original model was calibrated to the performance at Smithland, most of the figures will reference Smithland vertically-framed valve properties. The input menu for the valve properties includes the vertical spacing between ribs, the length of the valve, the top dimension distance to the horizontal girder which defines the positions of both the top and bottom girders on the vertical ribs (for simplicity, the top and bottom ribs were assumed to be equidistant from both ends since all differences are very minor), the rib flange width, the horizontal girder flange width, and finally both the horizontal and vertical weld thickness at the rib/flange connection. The input for these properties in VFCVWELD for the Smithland valves are shown in Figure ED 5-43.

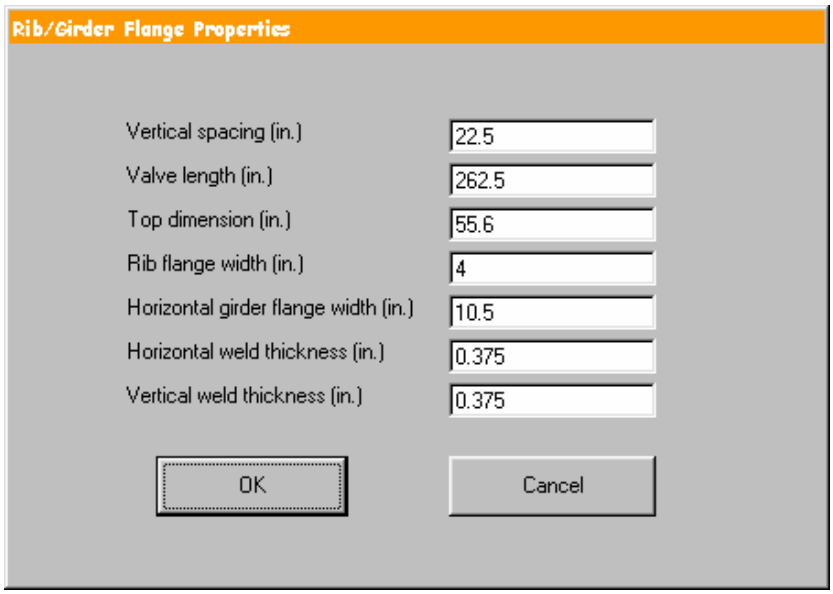


Figure ED 5-43. Rib/Girder Flange Properties Input Menu

Crack Parameters. The only crack parameter required for the VFCVWELD is the initital crack length. This is because the reliaibility model only accounts for the crack initiation and not crack propogation because of the anticipated brittle failure mode that was evidenced at Smithland. The initial crack length is set to a default value of 0.25 inches, the same as the miter gate initial crack length.

Head Histogram. The head histogram reflects the actual past distribution of head differential and hydraulic cycles for the reverse tainter valves. This distribution is based on true daily lockage cycles available from the Lock Performance Monitoring System (LPMS) combined with the true head differential for each day. This distribution is very valuable in determining the fraction of annual cycles versus the expected head differential that can be used for fatigue analysis. The head histograms developed by WES are based on data collected and analyzed for approximately 21 years inclusive (1984–2004) of lock operation. The VFCVWELD program allows the input of up to 20 different blocks for head (at specified midpoints) and fraction of cycles from the histograms. This histogram is used in VFCVWELD to parse the input annual cycles into the defined stress range blocks and number cycles for fatigue analysis. An example head histogram is shown in Figure ED 5-44 for Markland Lock and Dam (even though Markland valves are horizontally-framed, the histograms are similar in nature).

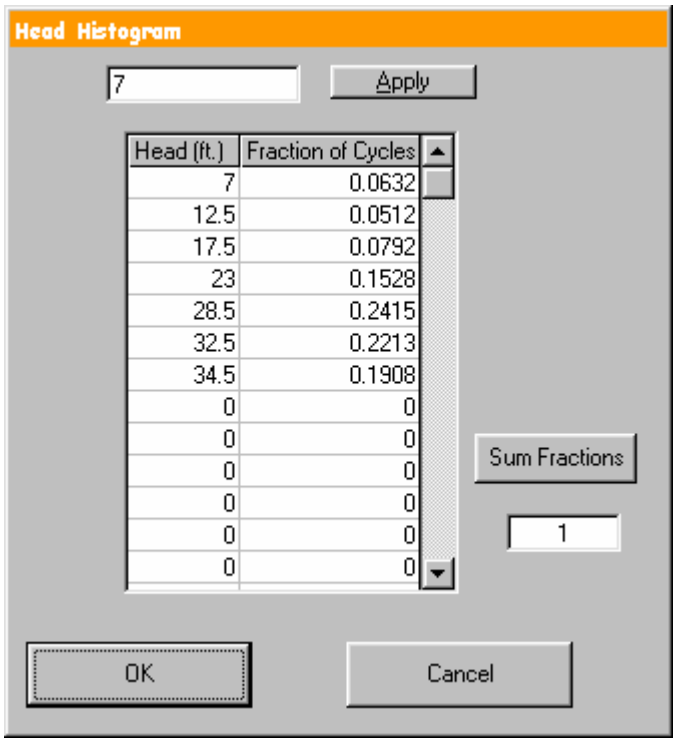
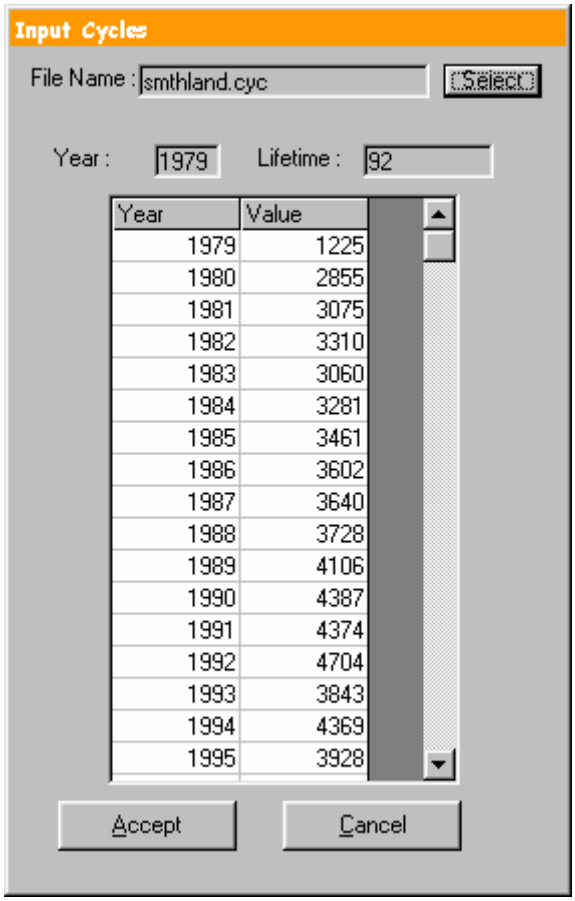


Figure ED 5-44. Example of Head Histogram

Traffic Cycles. The number of operating cycles for the vertically-framed valves is determined for each lock based on actual and predicted future cycles for the study period. The cycle information is used in fatigue analysis incorporated into the VFCVWELD program. The cycles are input from the start of operation to the end of the study period. Operating cycles from the origination of the project through 1984 were determined by going through the log books at various ORMSS sites to determine the number of lockages in each chamber. From the LPMS data from 1984 through 2004, a ratio of lockages to operating cycles was determined and assumed to be the same in the past as well as for future projected cycles. Traffic cycles for 1985 through 2004 were determined using LPMS data. Finally, projected traffic through the end of the study period was determined by LRD's Navigation Center in Huntington, WV. The input traffic cycles for one of the Smithland 1200-ft chambers are shown in Figure ED 5-45.

Random Variables Used in VFCVWELD

The random variables incorporated into the VFCVWELD analysis are the yield strength of A36 steel, corrosion rate, residual stress factor, stress concentration factor, and the dynamic amplification factor. The values and ranges for the yield strength used for the vertically-framed valve analysis are the same as applied to the miter gates and horizontally-framed culvert valves. The corrosion rate selected was for a structure subjected to wet/dry applications because the valves are constantly in and out of the water during operation, again the same as the horizontally-framed culvert valves. This rate is termed in the "splash" zone



Year	Value
1979	1225
1980	2855
1981	3075
1982	3310
1983	3060
1984	3281
1985	3461
1986	3602
1987	3640
1988	3728
1989	4106
1990	4387
1991	4374
1992	4704
1993	3843
1994	4369
1995	3928

Figure ED 5-45. Example Input Traffic Cycles

and has a higher corrosion rate than a submerged structure. Additionally, it was assumed that the valves only had an initial effective paint life of 5 years because of the turbulent water conditions impacting the valve during filling and emptying operations. This was based upon engineering judgment. However, sensitivity analyses were conducted varying the "effective" paint life from 0 to 20 years and it did not turn out to be a controlling variable. Therefore, the five-year life was used to be consistent with the analysis for the horizontally-framed culvert valves. Because a detailed residual stress analysis was not possible for this model due to funding and schedule constraints, a residual stress factor and stress concentration factor was created to attempt to measure the randomness associated with the residual stress analysis required for this model. The factor was based upon the residual stress analysis completed for the Markland miter gates. This is also consistent with the analysis for the horizontally-framed culvert valves. Finally, a dynamic amplification factor was needed to measure the increase in load on the valve due to the high velocities that occur during filling and emptying operations. This value (along with appropriate range) was determined by using a steady state fluid-structure interaction finite element model. This model is described in the horizontally-framed valve narrative. Again, all random variables were selected using Monte Carlo simulation techniques.

Yield Strength. The distribution for yield strength is based on data from the published literature and previous Corps of Engineers reliability studies. The distribution is based on a truncated lognormal with a nominal yield stress of 38.88 ksi (i.e., mean yield strength times the strength ratio) and a standard deviation of 5.44. The lower limit for truncation is based on one standard deviation below the nominal (33.44 ksi) and the upper limit is based on approximately two standard deviations above the nominal (51 ksi). The distribution and statistical moments for yield strength of the steel are the same as used for the miter gates and horizontally-framed culvert valves.

Corrosion Rate. The distribution for corrosion is based on the data from the published literature and previous Corps of Engineers reliability studies. Corrosion is based on a power law that has been fit to actual field data in various corrosive environments. The equation used for the corrosion is $C(t) = A*t^B$, where A is a random variable based on field measurements, B is generally a constant based on different corrosive environments and C(t) is the corrosion in micromils/yr. For this report, the mean value of A was selected based on "splash zone" corrosion. This distribution used for A was a truncated lognormal with a mean value was 140 and standard deviation of 42. The upper limit of the distribution was taken at 224 and the lower limit at 56. The value for B was a constant of 0.667. These limits and constants are based on actual field measurement of hydraulic steel structures.

Residual Stress, Stress Concentration, and Dynamic Amplification Factors. Three types of factors are utilized in VFCVWELD to account the major differences in stress values between traditional hand calculations and the more sophisticated finite element analysis. The residual stress factor represents the tensile stresses that are created during the heating and subsequent cooling of the welds at the time of construction. The second factor is the dynamic amplification factor, which represents increased load on the valve that is created by the vortex flow and pressure differential of the water around the valve upon opening. This quick change in pressure increases the stresses on the strut arms during valve operation. The third factor is the stress concentration factor that tries to account for local stress increases to due fabrication confinements that occur in welded structures. An extensive literature search for field measurement data on these factors was conducted. No data is available to assist in better defining any these parameters for the reliability of the valve. Therefore, these adjustments were determined based on various finite element analysis to determine the range of values that may be exhibited in these random variables.

The distribution for the residual stress model factors was considered to be a Gaussian distribution since the limits were defined by a concentration about a certain percent ratio. The mean value for the residual stress was 0.35 with a standard deviation of 0.05. The dynamic amplification factor was also determined to be a normal distribution with a mean of 1.25 (25% increase) and a standard deviation of 0.025 (2.5%). As an example, the stress concentration factor for the Group 2 valves was determined to be a uniform distribution with an upper limit of 2.1 and a lower limit of 1.5.

5.5.5 VFCVWELD Reliability Model Results and Event Trees

The output from the VFCVWELD reliability model is a hazard function giving the annual probability of unsatisfactory performance of the culvert valve over time. For simplicity, it was decided to look only at the reliability associated with a single valve as compared to numerous ones for the main chamber. The consequence event tree is structured around the failure of a single valve and how repairs would be initiated following a valve failure.

Main Chamber Results and Event Tree

Similar to other sections, a single project site (Cannelton in this case) will be detailed to clearly illustrate the process of modeling carried out for vertically-framed culvert valves and the subsequent output. As an example of the output provided by the VFCVWELD program, the hazard rates for the vertically-framed culvert valves of the Cannelton main chamber are shown in Figure ED 5-46 for the high (NAAQS), middle (Utility High) and low (Clear Skies) future traffic projections. As shown in Figure ED 5-46, the variability between the hazard rates for the main chamber vertically-framed culvert valves does not vary greatly. This is primarily due to the fact that the cumulative future traffic cycles are fairly similar across all traffic scenarios, unlike the large difference between the utility-based scenarios and the other three scenarios at Greenup. This was detailed in the horizontally-framed

culvert valve reliability analysis in Section 5.4 of this appendix. For example, at Cannelton the difference between the lowest traffic scenario (Clear Skies) cumulative traffic cycles and the highest scenario (NAAQS) was roughly 23%. However, at Greenup this difference was 67% between the lowest and highest. This relative difference is directly related to the hazard functions for the culvert valves.

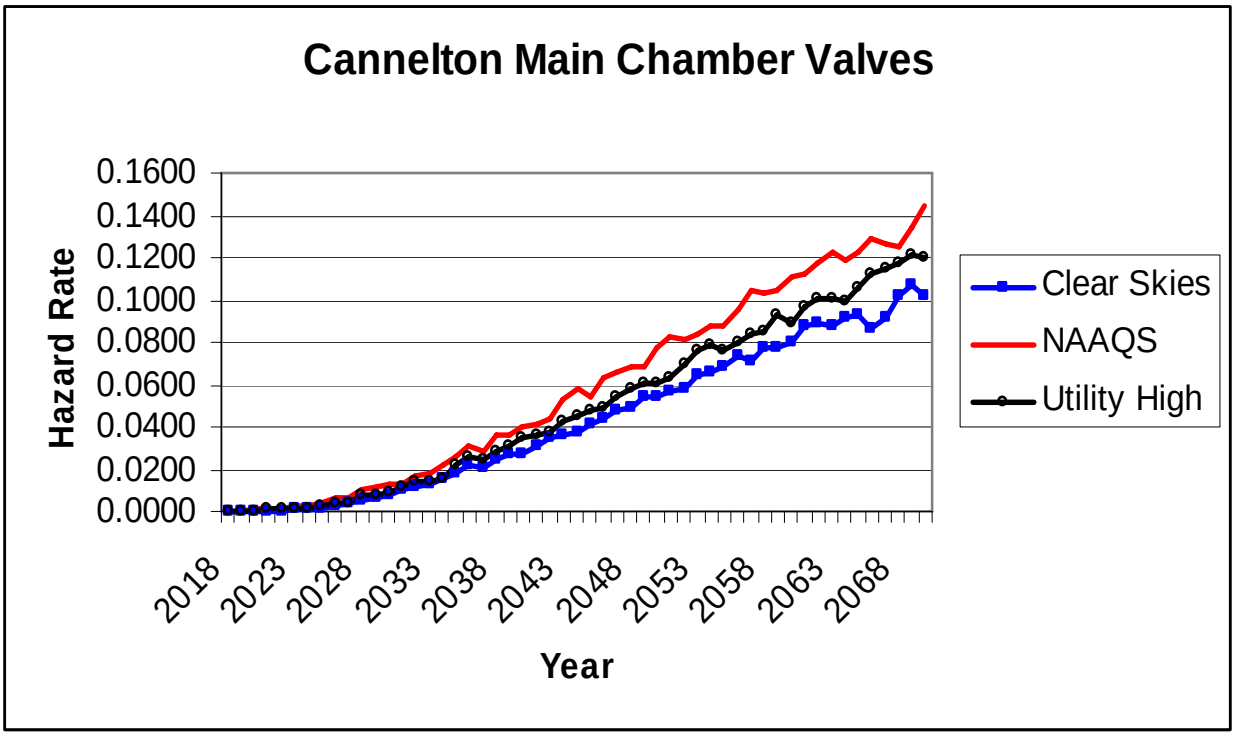


Figure ED 5-46. Cannelton Vertically-Framed Culvert Valve Hazard Rates

5.5.6 Economic Results for Vertically-Framed Culvert Valves

The hazard rates shown in Figure ED 5-46 are combined with consequence event trees for the vertically-framed culvert valves. It is important to note that the same event trees for the main chamber vertically-framed culvert valves are applicable for the horizontally-framed culvert valves. Although there are structural differences between the two types of valves, they are not great enough to warrant using different event trees. The details associated with the event trees for culvert valves, both main and auxiliary chambers, are described in Section 5.4.6 of this appendix.

ORNIM was then used to compute average annual costs for two repair options (fix-as-fails or replace ahead of failure) for the main chamber culvert valves at Cannelton. The average annual costs include both navigation delay and physical repair costs. Improved reliability after the repair is also included in the analysis, as noted in the event tree for differing levels of repairs. The costs of each alternative, fix-as-fails versus selected replacement dates, are compared to determine the most economic option. The replacement year with the lowest average annual cost sets the timed replacement of the culvert valves with fix-as-fails costs added to the economic analysis up to the year of scheduled replacement. Refer to the Economics Appendix for a more detailed description of how the ORNIM optimizes individual component replacements. If the lowest average annual cost is associated with the baseline condition (fix-as-fails), then the replacement of the culvert valves is not justified economically and the fix-as-fails costs are embedded into the overall economic analysis for

every year of the study period. ORNIM produces a graphical output depicting the results and optimal timing of this process for each component and each traffic scenario. The ORNIM output for the Cannelton main chamber culvert valves is shown for the Utility High traffic forecast in Figure ED 5-47.

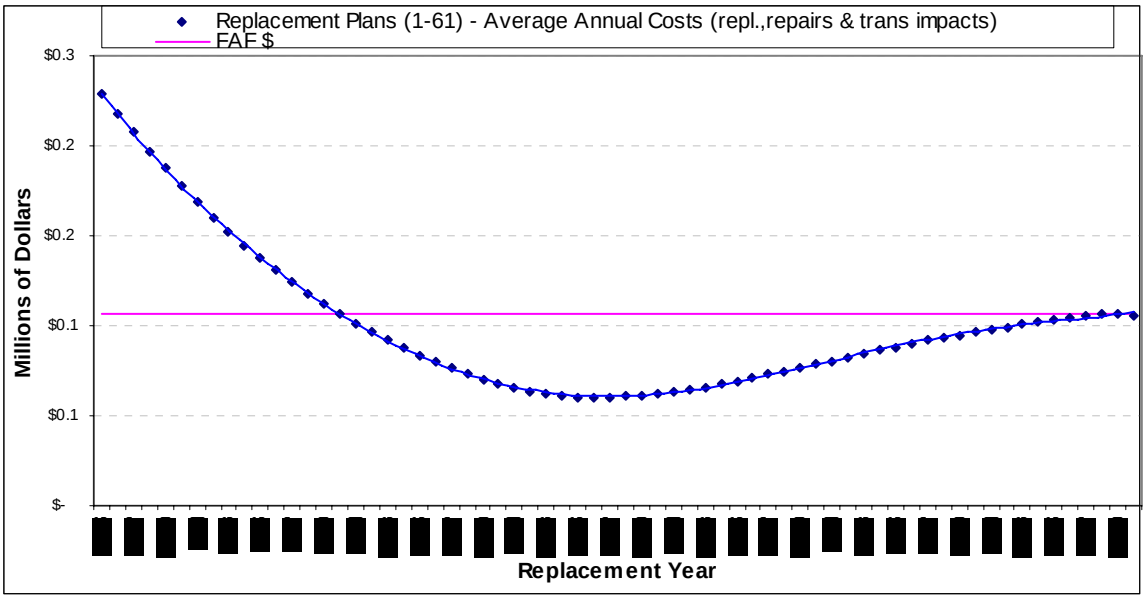


Figure ED 5-47. Economic Results for Cannelton Main Valves for Utility High Forecast

As noted earlier, the culvert valves at Cannelton were evaluated for each traffic scenario. Using the same methodology, optimized replacement dates were determined for each traffic scenario. The projected replacement dates for each traffic scenario are provided in the Economics Appendix.

As shown in Figure ED 5-46, there is a relatively small difference in the hazard rates between all three traffic scenarios for the main chamber culvert valves at Cannelton. Thus, the replacement dates only will vary slightly across the different traffic projections for this particular component.

Please refer to the tables in the Economics Appendix for the optimized replacement date of all vertically-framed culvert valves across the Ohio River projects. These are given for each lock chamber by traffic scenario.

5.6 ELECTRICAL SYSTEM RELIABILITY FOR THE LOCK

The electrical system for the lock essentially is made up of a series of individual components that work in series and parallel to operate the lock. Included in this list of components are items like commercial power source, diesel generator, fuses, motors, controllers, solenoids, etc. The electrical model was kept a single model in that the team decided not to try to develop separate hazard rates for each specific component. Since the vast majority of the system operates in series, a failure of any single item, with the exception of the possibly the commercial power supply or a diesel generator, would shut the lock down until repairs were made. Therefore, a single overall lock model was set up for the development of one hazard rate per lock chamber with a single event tree to reflect failures and repairs.

Many of the lock electrical systems are set up with similar systems. There are various changes to the lock electrical system as different pieces are parallel and in series from one project to another. These changes make each lock electrical model unique. The other thing that makes each unique is that

each lock chamber sees a different number of operating cycles each year. This section of the Engineering Appendix will discuss the lock electrical reliability model in a general nature to give the reader a feel of how the model is set up and calibrated versus field conditions.

5.6.1 Assessment of Reliability for Electrical System of the Lock

The electrical reliability assessment is based in principle on procedures defined by ETL 1110-2-549, Engineering and Design, RELIABILITY ANALYSIS OF NAVIGATIONAL LOCK AND DAM MECHANICAL AND ELECTRICAL EQUIPMENT. However, it should be noted that the failure rates and other relevant information listed in the ETL is for electrical equipment is not necessarily from locks and dams. Therefore, careful consideration was given when using select failure rates and other information from this ETL. Calibration with field conditions was used to the best extent possible. The following paragraphs document the assumptions, current conditions and provide the results of the reliability assessment.

5.6.2 Component Condition Investigations

For the purposes of this report, the lock electrical systems at Newburgh will be detailed to show how the electrical model was set up and developed for each project. Newburgh has two locks, a main, 1200-ft. lock, and an auxiliary, 600-ft. lock, which is typical for most Ohio River projects. Newburgh became operational in 1974. Each lock has four miter gates that are operated by hydraulically driven sector gears. The electrical power is provided by the local utility, with backup power provided by a diesel generator. Most of the electrical equipment, excepting that replaced during regular maintenance, is the original equipment at both projects. This is similar to all other projects except EDM, which had the electrical systems upgraded as part of major rehabilitation projects in the mid to late 1980's. The lock electrical systems at EDM are considered new with the major rehabilitation projects.

5.6.3 Condition States of the Electrical System

The reliability, R(t), for each component and for the system as a whole, was calculated for every year of operation from installation through the year 2070. The limit state was defined as the Mean Time to Failure (MTF) for the expected useful life of the components being analyzed. The hazard rate of any system is defined by the following relationship to be the probability of unsatisfactory performance, provided the component or system has not failed until the time of assessment: $h(t) = f(t)/R(t)$. The general reliability block diagram and one-line of the basic electrical system for Newburgh is shown in Figure ED 5-48.

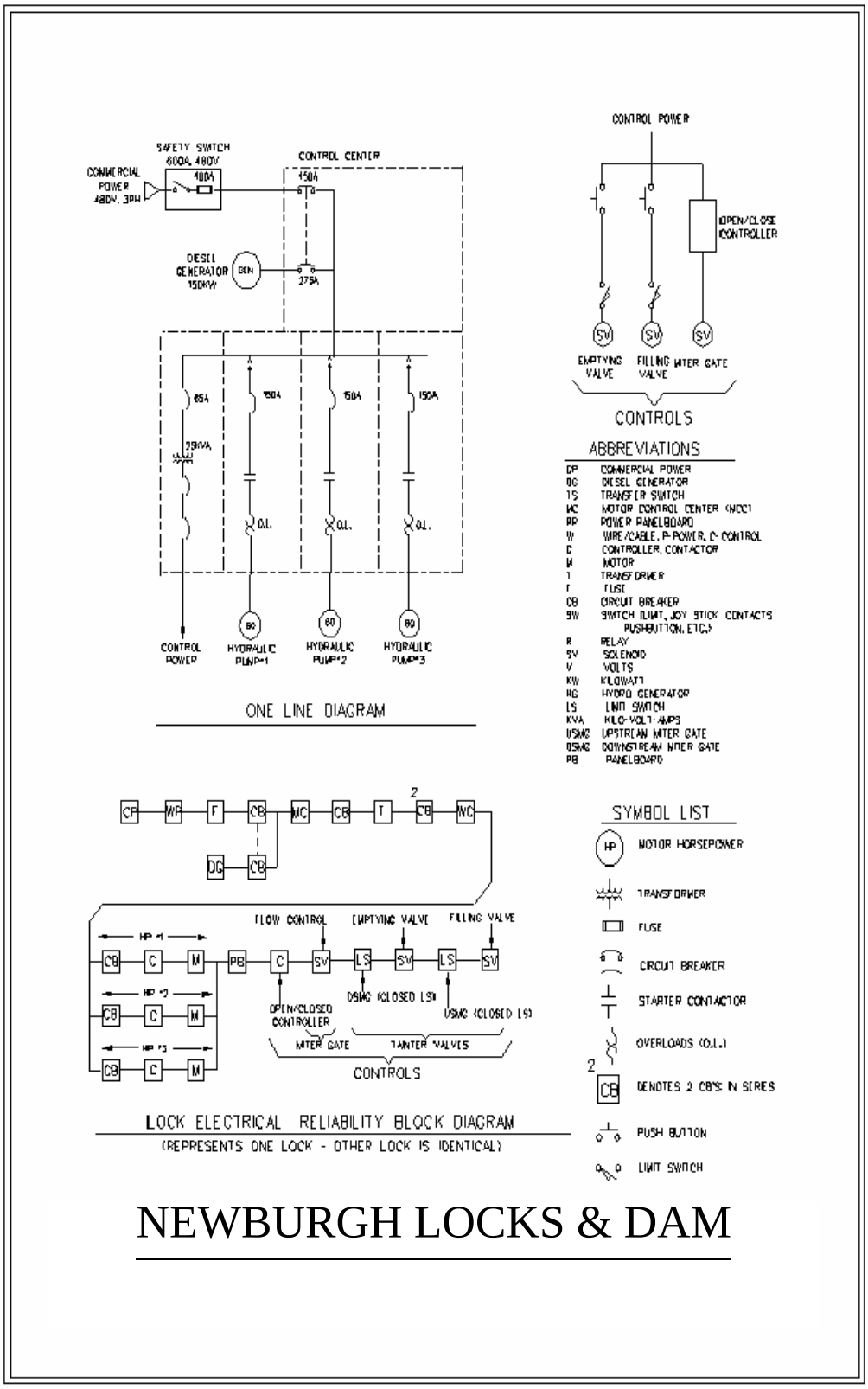


Figure ED 5-48. Newburgh One Line Diagram for Lock Electrical System

5.6.4 Failure Rate of Electrical Components

The environmental conditions were considered for the ambient service of the electrical equipment. Lambda, λ, represents the number of failures per 1×10^6 operating hours. The values were based on data from equipment similar in nature, but not necessarily associated with locks and dams. Therefore, the failure rates of all applicable equipment were based on available data and engineering judgment based on repair history. Also, the length of time parts are generally readily available for a given serviceable component also figured into failure rates for electrical components.

5.6.5 Failure Types

In this analysis, electrical equipment comes to the end of its "useful life" by one of three types of failures. These are termed the *Duty Cycle Failure*, *Environmental Conditions/Entropy*, and *Obsolescence*. Each is described within this sub-section.

Duty Cycle Failure

This type of failure is based on the amount of time that the component is operated or how many cycles it has to go through multiplied by the time per cycle. Since the equipment does not operate continually, the total mission time is determined with a duty cycle factor. The duty cycle factor is the ratio of actual time the equipment is energized by voltage and/or current to the total mission time, t. The example from ETL 1110-2-549 states that the equation $R(t) = e^{-\lambda td}$ is a constant failure rate component with a duty factor d. The lock equipment in the example had an average number of 13,148 open/close cycles per year. Assuming the operating time of an open/close operation is 120 seconds (or 240 seconds per open/close cycle) and using a total mission time of equal to the study period for the economic analysis, which happens to be 50 years in this example. Therefore, the calculation is as follows for a 50-year study period:

Operating time = (240*13,148)/3600
= (877 operational hours/year)*(50 years)
= 43,850 hours = 5 years

For t = 50 years,

d = 5/50 = 0.10

This analysis uses the past and projected cycles as a key input to this analysis. To determine the duty cycles for each component, see Figure ED 5-49, which shows some of the model computations for the main chamber electrical system for Newburgh. The first page of the model for Newburgh main chamber is provided in this report only since all the computation sheets are similar for all projects. The total number of cycles for each lock is divided by the total number of years of operation to come up with the average cycles per year. Electrical equipment, which is normally energized 100% of the calendar year, has a duty cycle of 1.0.

Environmental Conditions and Entropy

This type of failure relates to components such as a wire, which has insulation that degrades over time, whether it has current flow or not. In this case, historic replacement information is used. For example, several locks have installed new wiring after approximately 50 years of operation. While this replacement was more of a preventative measure than a repaired failure, it does define the "useful

Duty Cycle				Com.Power	Diesel Genset	X-fer Switch	MCC	Panel Board	Wire,power	Wire,control	Controller	Motor	Xfmr,power	Xfmr,lv	Fuse
	Avg. # of open/close cycles per yr.			NA	NA	NA	NA	NA	NA	NA	7194	7194	NA	NA	7194
	time for open/close cycle, sec			NA	NA	NA	NA	NA	NA	NA	1200	1200	NA	NA	1200
	Avg. operating time, hrs. per year			8760	36	8760	8760	8760	8760	8760	2398.141	2398.141	8760	8760	2398.141
	Mission time, t, years			98	98	98	98	98	98	98	98	98	98	98	98
	Mission time, t, 1E6 hrs.			0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848
	d, duty factor			100.00%	0.41%	100.00%	100.00%	100.00%	100.00%	100.00%	27.38%	27.38%	100.00%	100.00%	27.38%
Failure Rate															
	Lambda, L, failures/1E6 oper.hrs.			0.019	7.65	4.55	3	3	1	1	3	10	1	1	12.1
	(Yrs. To failure)			6008.17	3631.08	25.09	38.05	38.05	114.16	114.16	139.00	41.70	114.16	114.16	34.46
	Value for L=C if life calc,D if data			D	D	D	D	D	D	D	C	C	D	D	C
	MTTF = 1/L , E6hrs.			52.63158	0.13072	0.21978	0.33333	0.33333	1.00000	1.00000	0.33333	0.10000	1.00000	1.00000	0.08264
	Beta			1	1	1	2.5	2.5	1	1	2.5	2.5	1	1	1
	Alpha=MTTF*Beta, E6 hrs.			52.63158	0.13072	0.21978	0.83333	0.83333	1.00000	1.00000	0.83333	0.25000	1.00000	1.00000	0.08264
	Alpha, yrs.			6008.17	14.92	25.09	95.13	95.13	114.16	114.16	95.13	28.54	114.16	114.16	9.43
Weibull Reliability Function															
	R(t)=exp[-(td/Alpha)**Beta]			98.38%	97.34%	100.00%	34.06%	34.06%	42.38%	42.38%	95.86%	42.45%	42.38%	42.38%	100.00%
	(at t = 50)														
	(at t = 1)			99.98%	99.97%	100.00%	100.00%	100.00%	99.13%	99.13%	100.00%	100.00%	99.13%	99.13%	100.00%
	Year Completed -		1971												
	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Project Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Com.Power	99.98%	99.97%	99.95%	99.93%	99.92%	99.90%	99.88%	99.87%	99.85%	99.83%	99.82%	99.80%	99.78%	99.77%	99.75%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Diesel Genset	99.97%	99.94%	99.92%	99.89%	99.86%	99.83%	99.81%	99.78%	99.75%	99.72%	99.70%	99.67%	99.64%	99.62%	99.59%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
X-fer Switch	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
MCC	100.00%	99.99%	99.98%	99.96%	99.94%	99.90%	99.85%	99.80%	99.73%	99.64%	99.55%	99.44%	99.31%	99.17%	99.02%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Panel Board	100.00%	99.99%	99.98%	99.96%	99.94%	99.90%	99.85%	99.80%	99.73%	99.64%	99.55%	99.44%	99.31%	99.17%	99.02%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Wire,power	99.13%	98.26%	97.41%	96.56%	95.71%	94.88%	94.05%	93.23%	92.42%	91.61%	90.81%	90.02%	89.24%	88.46%	87.69%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Wire,control	99.13%	98.26%	97.41%	96.56%	95.71%	94.88%	94.05%	93.23%	92.42%	91.61%	90.81%	90.02%	89.24%	88.46%	87.69%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Controller	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	99.99%	99.99%	99.99%	99.99%	99.98%	99.98%	99.97%	99.97%	99.96%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Motor	100.00%	99.99%	99.99%	99.97%	99.95%	99.92%	99.88%	99.84%	99.78%	99.72%	99.64%	99.55%	99.45%	99.34%	99.22%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Xfmr,power	99.13%	98.26%	97.41%	96.56%	95.71%	94.88%	94.05%	93.23%	92.42%	91.61%	90.81%	90.02%	89.24%	88.46%	87.69%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Xfmr,lv	99.13%	98.26%	97.41%	96.56%	95.71%	94.88%	94.05%	93.23%	92.42%	91.61%	90.81%	90.02%	89.24%	88.46%	87.69%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fuse	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Circuit Bkr.	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Switch	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Relay	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Solenoid	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Figure ED 5-49. Example Reliability Model Computations for Newburgh Main Chamber Lock Electrical System

life" that was utilized from the component and provides a guide for subsequent replacements. In this analysis, useful life is equal to characteristic life, α.

Obsolescence

Components such as the motor control center (MCC) and transfer switches usually reach the end of their "useful life" when repair parts and other relative hardware cease to be available from the manufacturer. These components will usually require repair/service before they become obsolete, but this analysis does not consider them failed until parts are not readily available. Historic precedent and engineering judgement must be used for the values of these components.

5.6.6 Model Distribution

The modes of failure for electrical equipment are very complex (i.e. they involve a wide variety of distresses such as temperature, vibration, mechanical stresses, etc.) resulting in extreme difficulty or inability to select β values for a Weibull distribution. Since the values were not known, an initial value of 1.0 was used as recommended by ETL 1110-2-549. Using an initial value of 1.0 tends to reduce the Weibull distribution equation to an exponential distribution for the computation of the reliability value. After initial results indicated exceedingly high hazard rates, it was decided that other β values would provide a more sensible answer based upon historical performance. During model calibration, it was agreed by the engineering team to use a value of 2.5 for the motor control center, panel board,

controller, and motors. This combination of β values seemed to give the proper range of values for the overall hazard rate. The exponential reliability equation is:

$$R(t) = e^{-\lambda' t'}$$

where,

λ' = adjusted failure rate, failures/year
t'= adjusted time variable (operation time), years

One other key item to note is that several "small" components such as fuses, solenoids, switches, and circuit breakers were set to be 100% reliable for the entire study period. Because these components could be repaired without closing the chamber, and at a very minor cost, the team decided to "eliminate" these from the failure calculations and assume they were always working properly. Making these "minor failures" part of the overall calculation tended to yield a very high hazard rate that did not seem realistic when determining the long-term reliability of the electrical system. Another reason that these values were selected was the overall reliability process agreed by the team. The team believed the better option for all of the reliability models (miter gates, culvert valves, etc.) was to investigate significant type of limit states, thus, ones that caused extended chamber closures and had high repair costs. All the components that were made 100% reliable for this study would cause neither an extended chamber closure nor costly repair if they failed to perform satisfactorily.

5.6.7 Lock Electrical Sub-Components Analyzed

The overall system analyzed was the provision of power to operate the lock. The overall system was modeled by the process as described by ETL 1110-2-549, but calibrated to give reasonable results. There is no recorded historical data available regarding the lock electrical components or system reliability. Much of the reliability information for the electrical components was readily available in published sources, which was also referenced by ETL 1110-2-549. However, some of the published reliability information was not based on operating conditions or environments similar to the sites conditions associated with locks and dams. Therefore, the team used varying β values and made minor components 100% reliable as part of the calibration process to get results that seemed reasonable based upon historical observations.

The lock electrical service for Newburgh is comprised of two power sources, the electric utility service entrance, (CP, commercial power), and the standby diesel generator, (DG) with wire (WP, wire, power), fuses, (F), and circuit breakers (CB) which feed the motor control center (MC). The power sources are "stand-by redundant" because the system continues to operate successfully if either of the sources operate and as long as power is transferred successfully. The Newburgh electrical distribution subsystem diagram for power to the project is organized as shown in Figure ED 5-50.

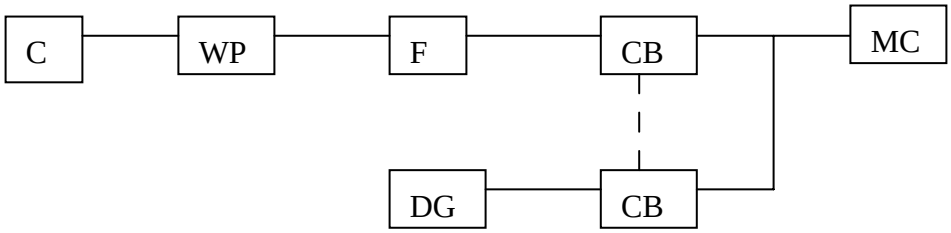


Figure ED 5-50. Newburgh Lock Electrical Service Block Diagram

Duty Cycle				Com.Power	Diesel Genset	X-fer Switch	MCC	Panel Board	Wire,power	Wire,control	Controller	Motor	Xfmr,power	Xfmr,lv	Fuse
	Avg. # of open/close cycles per yr.			NA	NA	NA	NA	NA	NA	NA	7194	7194	NA	NA	7194
	time for open/close cycle, sec			NA	NA	NA	NA	NA	NA	NA	1200	1200	NA	NA	1200
	Avg. operating time, hrs. per year			8760	36	8760	8760	8760	8760	8760	2398.141	2398.141	8760	8760	2398.141
	Mission time, t, years			98	98	98	98	98	98	98	98	98	98	98	98
	Mission time, t, 1E6 hrs.			0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848	0.85848
	d, duty factor			100.00%	0.41%	100.00%	100.00%	100.00%	100.00%	100.00%	27.38%	27.38%	100.00%	100.00%	27.38%
Failure Rate															
	Lambda, L, failures/1E6 oper.hrs.			0.019	7.65	4.55	3	3	1	1	3	10	1	1	12.1
	(Yrs. To failure)			6008.17	3631.08	25.09	38.05	38.05	114.16	114.16	139.00	41.70	114.16	114.16	34.46
	Value for L=C if life calc,D if data			D	D	D	D	D	D	D	C	C	D	D	C
	MTTF = 1/L , E6hrs.			52.63158	0.13072	0.21978	0.33333	0.33333	1.00000	1.00000	0.33333	0.10000	1.00000	1.00000	0.08264
	Beta			1	1	1	2.5	2.5	1	1	2.5	2.5	1	1	1
	Alpha=MTTF*Beta, E6 hrs.			52.63158	0.13072	0.21978	0.83333	0.83333	1.00000	1.00000	0.83333	0.25000	1.00000	1.00000	0.08264
	Alpha, yrs.			6008.17	14.92	25.09	95.13	95.13	114.16	114.16	95.13	28.54	114.16	114.16	9.43
Weibull Reliability Function															
	R(t)=exp[-(td/Alpha)**Beta]			98.38%	97.34%	100.00%	34.06%	34.06%	42.38%	42.38%	95.86%	42.45%	42.38%	42.38%	100.00%
	(at t = 50)														
	(at t = 1)			99.98%	99.97%	100.00%	100.00%	100.00%	99.13%	99.13%	100.00%	100.00%	99.13%	99.13%	100.00%
	Year Completed -		1971												
	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Project Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Com.Power	99.98%	99.97%	99.95%	99.93%	99.92%	99.90%	99.88%	99.87%	99.85%	99.83%	99.82%	99.80%	99.78%	99.77%	99.75%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Diesel Genset	99.97%	99.94%	99.92%	99.89%	99.86%	99.83%	99.81%	99.78%	99.75%	99.72%	99.70%	99.67%	99.64%	99.62%	99.59%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
X-fer Switch	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
MCC	100.00%	99.99%	99.98%	99.96%	99.94%	99.90%	99.85%	99.80%	99.73%	99.64%	99.55%	99.44%	99.31%	99.17%	99.02%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Panel Board	100.00%	99.99%	99.98%	99.96%	99.94%	99.90%	99.85%	99.80%	99.73%	99.64%	99.55%	99.44%	99.31%	99.17%	99.02%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Wire,power	99.13%	98.26%	97.41%	96.56%	95.71%	94.88%	94.05%	93.23%	92.42%	91.61%	90.81%	90.02%	89.24%	88.46%	87.69%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Wire,control	99.13%	98.26%	97.41%	96.56%	95.71%	94.88%	94.05%	93.23%	92.42%	91.61%	90.81%	90.02%	89.24%	88.46%	87.69%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Controller	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	99.99%	99.99%	99.99%	99.99%	99.98%	99.98%	99.97%	99.97%	99.96%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Motor	100.00%	99.99%	99.99%	99.97%	99.95%	99.92%	99.88%	99.84%	99.78%	99.72%	99.64%	99.55%	99.45%	99.34%	99.22%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Xfmr,power	99.13%	98.26%	97.41%	96.56%	95.71%	94.88%	94.05%	93.23%	92.42%	91.61%	90.81%	90.02%	89.24%	88.46%	87.69%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Xfmr,lv	99.13%	98.26%	97.41%	96.56%	95.71%	94.88%	94.05%	93.23%	92.42%	91.61%	90.81%	90.02%	89.24%	88.46%	87.69%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fuse	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Circuit Bkr.	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Switch	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Relay	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Solenoid	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
---age, yrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Figure ED 5-49. Example Reliability Model Computations for Newburgh Main Chamber Lock Electrical System

life" that was utilized from the component and provides a guide for subsequent replacements. In this analysis, useful life is equal to characteristic life, α.

Obsolescence

Components such as the motor control center (MCC) and transfer switches usually reach the end of their "useful life" when repair parts and other relative hardware cease to be available from the manufacturer. These components will usually require repair/service before they become obsolete, but this analysis does not consider them failed until parts are not readily available. Historic precedent and engineering judgement must be used for the values of these components.

5.6.8 Model Distribution

The modes of failure for electrical equipment are very complex (i.e. they involve a wide variety of distresses such as temperature, vibration, mechanical stresses, etc.) resulting in extreme difficulty or inability to select β values for a Weibull distribution. Since the values were not known, an initial value of 1.0 was used as recommended by ETL 1110-2-549. Using an initial value of 1.0 tends to reduce the Weibull distribution equation to an exponential distribution for the computation of the reliability value. After initial results indicated exceedingly high hazard rates, it was decided that other β values would provide a more sensible answer based upon historical performance. During model calibration, it was agreed by the engineering team to use a value of 2.5 for the motor control center, panel board,

5.6.9 Electrical System Event Tree

The event tree for the electrical system is set up slightly different than that of the structural components. An extra branch on the event tree was added to differentiate between minor and major types of failures of the significant electrical components. Thus, there are many more failure options evaluated for the electrical system. The failure rates from the manuals reflect mainly wear-and-tear type of failures such that most repairs would be minor in nature. Therefore, the first branch of the event tree is the hazard rate for the electrical system. The second branch delineates between major and minor failures. Like the structural components, the event tree for the electrical system also has a sliding scale used for the major and minor branches related to service age of the system. For lock electrical systems with less than 30 years of service, 25% was used for major branch and 75% of the minor branch. This relationship changes to 35% major/65% minor for lock electrical systems between 31 and 50 years of service, and finally an even 50% split for lock electrical systems in service over 50 years. The event tree used for the lock electrical system is shown in Figure ED 5-53. A cost and closure breakdown for each of the major and minor types of repairs is supplied for the event tree.

Major Failure Branch

There are three branches off of the major failure branch portion of the event tree. These are catastrophic failure with a new, unplanned electrical system, a major overhaul of the electrical system, and finally, replacing one major component. Each of these is detailed below.

~~*Major Failure, Unplanned New Electrical System*~~. This assumes a total failure of the electrical system. The failure is assumed to be non-repairable such that a new, unplanned electrical system is required for the lock. It is estimated that the electrical system would cost $4,00,000 to replace under emergency conditions. The cost of this was provided by electrical engineers in consultation with operations personnel. The lock is assumed to be closed for 365 days under this scenario. This is due to the fact that this would be an unscheduled closure and a replacement system would need to be designed and procured. Because this is the least likely repair method, a small chance was assigned to this level. This will vary according to service life of the electrical system. For the first 30 years of service life, a 2.5% chance of occurrence is derived from taking the 10% assigned to the branch multiplied by the 25% associated with the major failure branch. Future reliability of the electrical system once it is replaced is assumed to be 1.0 for the purposes of this study.

~~*Major Failure, Major Overhaul of Electrical System*~~. This assumes numerous failures to the electrical system such that an upgrade of several major components is required, but not a full replacement of the entire electrical system. Parts that are not replaced are assumed to be in good condition and provide continued adequate service. The estimated cost of this repair scenario is $750,000 and was provided by ORMSS electrical engineers in consultation with operations personnel. Since this also repsents a “reactive” repair, an extended closure of 90 days was estimated to be required to procure replacement parts, install them, and get the chamber serviceable again. The team developing this information estimated that these parts and the parts not replaced would provide about 20 years of adequate service, thus, the “effective” improvement in reliability following the repair was to slide back the hazard rate by 20 years. A 7.5% chance was assigned to this repair level for the first 30 years of service life by taking the 30% for the repair level multiplied by the 25% for the major failure branch. Therefore, it is assumed that this is not a likely repair scenario given a failure of the electrical system.

The resulting reliability equation for this segment of the Newburgh electrical distribution system is:

$R(t)_{JTMyers}$ = [1-[[1-CP(t)*WP(t)*F(t)*CB(t)]*[1-DG(t)*CB(t)]]][MC(t)]

Lock Electrical Distribution, Power to Hydraulic Pumps

Three hydraulic pumps in parallel provide hydraulic power for the gates. Each of these circuits is comprised of a controller/contactor (C), a circuit breaker (CB), and the motor (M) and can operate independently of the other two. The diagram of the resulting electrical subsystem is organized as follows in Figure ED 5-51.

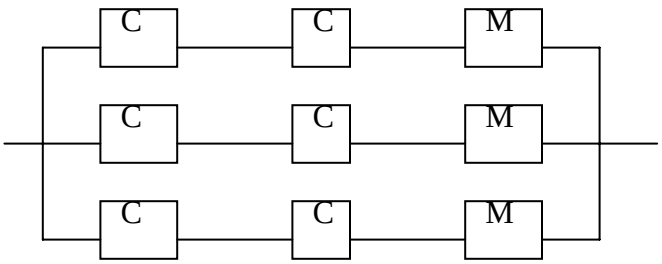


Figure ED 5-51. Block Diagram for Power to the Three Parallel Hydraulic Pumps

Each of the pump motors (M) is fed from a circuit breaker (CB) through a controller/contactor (C). The resulting reliability equation for this segment of the electrical distribution system is:

$R(t)_{Figure3}$=[1-[1-[CB(t)*C(t)*M(t)]]^3]]

Lock Electrical Distribution, Control Power

Power for the Newburgh controls are stepped down with a control transformer (T), that is fed from a circuit breaker (CB). The control power feeds through the control wiring (WC), two circuit breakers (CB), and a panelboard (PB). This control power feeds the open/closed controller (C) which directs the power through the limit switches (LS) to the respective emptying\filling valve (SV).

The diagram of the resulting electrical subsystem at Newburgh is organized as follows in Figure ED 5-52.

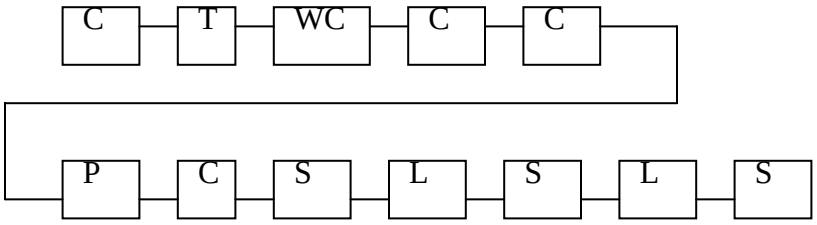


Figure ED 5-52. Newburgh Block Diagram for Power to the Controls

The resulting reliability equation for this segment of the Newburgh electrical distribution system is:

$R(t)_{JTMyers}$=[$CB(t)^3$*T(t)*WC(t)*PB(t)*C(t)*$SV(t)^3$*$LS(t)^2$]

Major Failure, Replace Single Component. This assumes that only a single major component needs to be replaced and all others are in good condition. It is assumed that the part requires a special order and will cost roughly $250,000. Chamber downtime is estimated at 15 days, but would vary according to the part that needs to be replaced. The electrical system is assumed to be in relatively good condition other than the major part that needs to be replaced. It is assumed replacing the the failed component effectively improves the reliability by 15 years. This is considered to be the most likely repair level under the major failure branch of the event tree. An 15% chance was assigned to this repair for the first 30 years of service life by taking the 60% multiplied by the 25% for the major failure branch.

Minor Failure Branch

There are two branches off of the minor failure portion of the event tree. These are a major overhaul of the electrical system and replacing a single component. An unplanned, new electrical system was left out of this branch since than can not be considered a minor failure. Each of these "minor" failures is detailed below.

Minor Failure, Overhaul of Electrical System. This assumes numerous failures to the electrical system such that an upgrade of several electrical components is required, but not a full replacement of the electrical system. Parts that are not replaced are assumed to be in good condition. The difference between this repair and the major overhaul for the major failure branch is the assumption that the diagnosis of the problem and repair time takes less time than under the other major failure branch. Thus, for this repair scenario, replacement parts are readily available and/or already on-hand. Therefore, only 5 days of chamber closure is required for this closure. The cost for this option was estimated at $225,000 by ORMSS electrical engineers and operations personnel. A 22.5% chance was assigned to this repair level for the first 30 years of service life by taking the 30% for the repair level multiplied by the 75% for the minor failure branch. With a overhaul, not all parts are new, however, the major components would be new and thus, the reliability is assumed to be upgraded to what it was 10 years previous to the failure.

Minor Failure, Replace Single Component. This assumes that only a single component needs to be replaced and all others are in good condition. However, it is assumed replacing the component only has a minimal effect of improving the overall reliability of the electrical system (effective 5 years). A chamber closure of 1 day is assumed for this repair, thus, the replacement part essentially must be on-site and ready to install following a failure. As opposed to the major failure branch, it is assumed that the single component is cheaper and a smaller crew would be required to install it for the minor failure branch. A cost of $75,000 is assumed for this repair. This is considered to be the most likely repair level in the entire event tree. A 52.5% chance was assigned to this repair for the first 30 years of service life by taking the 75% multiplied by the 70% for the minor failure branch.

5.6.10 Hazard Rates and Calibration of Model

One of the first revisions required once the initial model was developed was to attempt and calibrate to a combination of historical performance at typical Ohio River lock projects and the engineering team's judgment. Immediately it was evident that several minor components were controlling the hazard rates in the results. These components were items such as fuses, switches, circuit breakers, relays, and solenoids. The team agreed that since these parts were easily replaceable and spares were readily available any chamber down time or repair cost would be insignificant in the overall economic analysis. Therefore, for the purposes of this study, it was assumed that all fuses,

circuit breakers, switches, solenoids, and relays were 100% reliable so they did not affect the overall electrical system hazard rate.

As noted previously, the failure rates for the different components are pulled from data books for the electrical systems as outlined in ETL 1110-2-549. Therefore, the failure rates from the data books lead to an overall electrical system hazard rate that is much smoother and always increasing when compared to the capacity versus demand hazard rates for structural components. The hazard rate for the main chamber electrical system at Newburgh is shown in Figure ED 5-53 for the high (NAAQS), middle (Utility High), and low (Clear Skies). The hazard rates for main and auxiliary chamber are only slightly different even though the operating cycles on the main chamber are considerably higher. This is due to the fact that the majority of the components in the system are operational all the time and not just when lockages occur. The panel board, wires for power and control, transformers, and commercial power are more a function of age because they are continually charged. The ages of the main and auxiliary chamber are essentially the same. Therefore, the difference between the two chambers is primarily due to only two components, the controller and motor. These two components are a function of the number of operating cycles. The other components that are a function of the operating cycles were the minor components that were assumed 100% reliable because they were insignificant in terms of repair cost and chamber down time.

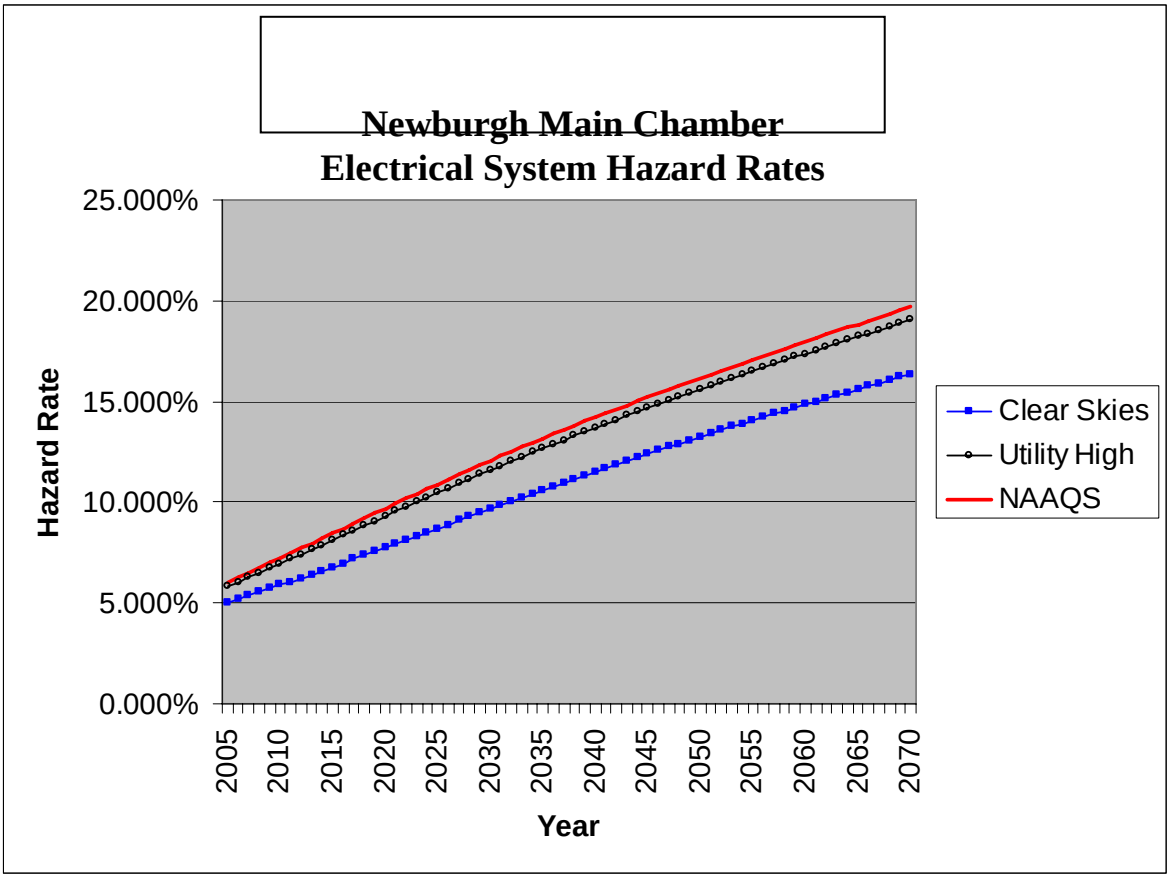


Figure ED 5-53. Newburgh Main Chamber Electrical System Hazard Rate

5.6.11 Economic Results for Main Chamber Electrical Systems

The hazard rates for the electrical systems for all Ohio River locks, along with the event tree shown in Figure ED 5-52, were provided to the economists to determine if a scheduled replacement of

the electrical system for the lock was economically justified for replacement ahead of reaching a level of unsatisfactory performance as outlined in the modeling setup, as well as determine the average annual costs associated with the fix-as-fails scenario. It should be noted that the same event tree was used for the both the main and auxiliary lock chambers since essentially all the electrical components are the same with a few minor differences. However, the auxiliary chamber hazard rates are lower than the main chamber since less traffic locks through the auxiliary. In addition, a closure of the auxiliary is much less critical than a closure to a main chamber. As noted earlier, only a few components within the same chamber tend to cause significant variance in the hazard rates between difference traffic scenarios. Thus, the hazard rate differences between the lowest (Clear Skies) and highest (NAAQS) scenarios for the main chamber electrical system does not vary greatly due to this and the fact that projected cumulative traffic cycles between these scenarios varies only by 26% at Newburgh, which is considerably less that the difference at some of the other Ohio River sites. Higher hazard rates earlier are encountered for the electrical system compared to the structural components, however, the required closure time is considerably less than those provided in the miter gate event tree. As expected, the relatively tight band on the hazard rates for the main chamber electrical system at Newburgh yields projected replacement dates that are close to one another across all traffic scenarios. The optimized replacement dates were determined by ORNIM for the main chamber are provided in the Economics Appendix.

A reliability analysis for the Newburgh auxiliary chamber was also completed for the electrical system and it was determined that the fix-as-fails is the most economical solution. This is not surprising given the fact that the auxiliary chamber is primarily used for recreational vessels and its hazard rates are lower than those on the main chamber. For the summarized results (replacement dates and/or fix-as-fails selection) for all electrical system reliability analyses of all Ohio River lock chambers, refer to the Economics Appendix.

5.7 MECHANICAL SYSTEM RELIABILITY FOR THE LOCK

The mechanical systems for the lock essentially are made up of three major components: miter gate machinery, culvert valve machinery, and the supporting hydraulic system. Because each of these components has different failure conditions and subsequent repairs with differing consequences, each component was independently tracked in the overall mechanical model. Therefore, hazard rates and separate event trees were developed for each of the three components in both chambers. The reliability analyses for the mechanical components at each site were completed as part of the overall analysis. For the purposes of this report, only the mechanical system reliability analysis for Belleville Locks and Dam will be shown for clarity sake.

5.7.1 Assessment of Reliability for Mechanical System

The mechanical reliability assessment is based in principle on procedures defined by ETL 1110-2-549, Engineering and Design, RELIABILITY ANALYSIS OF NAVIGATIONAL LOCK AND DAM MECHANICAL AND ELECTRICAL EQUIPMENT. However, it should be noted that the failure rates and other relevant information listed in the ETL is for mechanical equipment is not necessarily from locks and dams. Therefore, careful consideration was given when using select failure rates and other information from this ETL. Calibration with field conditions was used to the best extent possible. The following paragraphs document the assumptions, current conditions and provide the results of the reliability assessment.

5.7.2 Component Condition Investigations

The Belleville project has two lock chambers. The main chamber for each site is 110 feet wide by 1,200 feet long. The auxiliary chamber at each site is 110 feet wide by 600 feet long. The main chamber has an upper and lower set of miter gates and two filling and two emptying reverse tainter gate style culvert valves. The auxiliary chamber has an upper and lower set of miter gates and one filling and one emptying reverse tainter gate style culvert valve. Each miter gate and culvert valve is operated by a hydraulic cylinder connected to a central pump system. Three main pumps and one small pump operate the hydraulic system for the entire locks. The lock machinery at both projects is the original equipment installed when the project was completed. Periodic inspections and review of the original lock design drawings were conducted to assist in finding the current condition of the mechanical systems.

5.7.3 Selected Limit States for the Mechanical System

The probability of unsatisfactory performance (PUP) was computed from time of installment through the year 2070. It was computed in increments of years between these times to provide a trend of unsatisfactory performance. The limit state was defined as the "meanlife" or Mean Time to Failure (MTTF) of the components analyzed.

5.7.4 Lock Mechanical Systems and Subsystems Analyzed

For this analysis, each of the four mechanical gate systems and each of the valve systems were considered separate models. The diagram is shown in Figure ED 5-54. The valve machinery systems diagram for Belleville is shown in Figures ED 5-55. Finally, the hydraulic system line diagram for the Belleville project is shown in Figures ED 5-56.

5.7.5 Reliability Block Diagram Formulation

This analysis and the formulation of the system reliability block diagrams (RBD) are in accordance with ETL 1110-2-549. The machinery functions to operate the miter gates and reverse tainter culvert valves. The major components required for mission success are defined and organized into an RBD. For the miter gate subsystems for the main chamber, if one component does not function, then the entire system for that chamber will not function. On the auxiliary chamber, if one of the culvert valves or miter gate systems does not operate then the entire system will not function. There are no parallel or redundant items, therefore, the mission and basic block diagrams are arranged as series system models. In this analysis, the structural supports and anchorages are not included in the model. They are unique to the system and there is no published failure rate data available.

5.7.6 Subsystem Reliability Calculation

a. Duty Cycle. The miter gate equipment was considered to have a negligible failure rate during periods ~~of non-operat~~ion (ignoring barge impact). The failure rate can be modified by a duty cycle factor. The duty cycle factor is the ratio of actual operating time to total mission time, t. The lock equipment operates a certain number of open/close cycles per year depending upon the traffic projection scenario. The same process is used to determine the duty cycle for the other lock chambers by using the appropriate values for other lock chambers and corresponding traffic scenarios.

b. Environmental Conditions. The environmental conditions were defined for the ambient service of the lock equipment as an outdoor marine environment. The environmental K factors were selected from Table C-l of ETL 1110-2-549. For this analysis, a K_l factor of 2.0 is used and K_2 and K_3 are 1.0.

c. Lock Equipment Reliability. The Weibull distribution was used to perform the reliability analysis for each component in the block diagram. The shape parameter values for b were selected from the values given in Table C-6 of the ETL, by choosing a dominant failure mode for each component. The characteristic life parameter *a* was determined from the failure rate data using the methods presented in the ETL. The failure rates for the lock mechanical components were selected from Table C-7 of the ETL. These failure rates were multiplied by the K factor to obtain a final adjusted failure rate. The parameter *alpha* was determined as follows:

$$\alpha = \frac{\gamma}{\lambda}$$

Where,

γ = (α/MTTF ratio from Table C-2 of ETL 1110-2-549)
λ = Adjusted failure rate = SK

The Weibull reliability function for the components becomes:

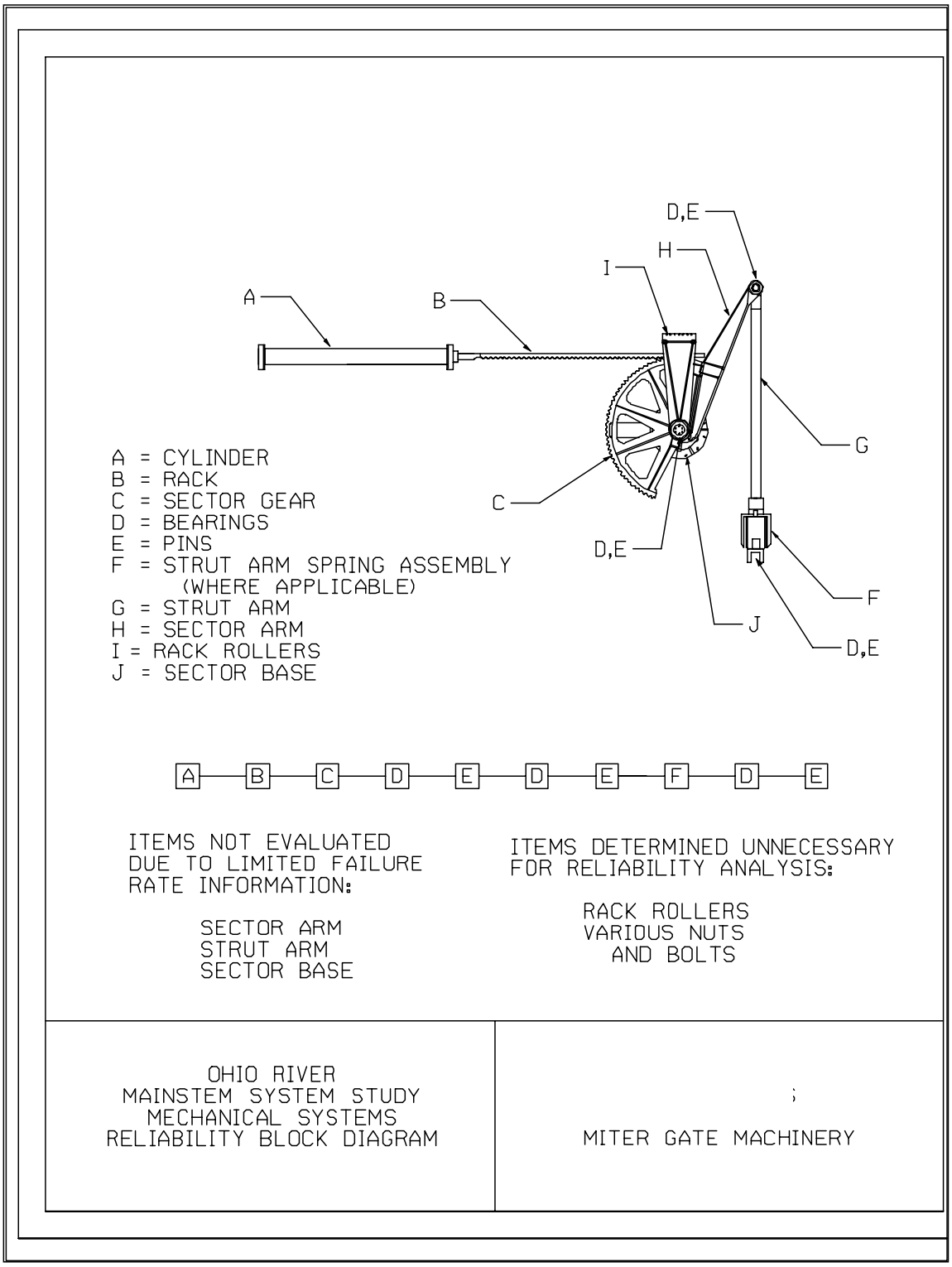
$$R(t)= \exp [-(td/\alpha)^{\beta}] \qquad \text{where t is in years}$$

MITER GATE MACHINERY RELIABILITY

Where the shape parameter (b) is equal to 1.0, the Weibull distribution reduces to the Exponential distribution. The miter gate mechanical subsystem was considered to begin at the first gearset. The subsystem reliability at both projects for the miter gate machinery model in Figure ED 5-62 at time *t* is determined from the individual reliability of each component as follows:

$$R_{MGMachinery}(t) = R_A(t) * R_B(t)* R_C(t) * R_D(t)^3 * R_E(t)^3 * R_F(t)$$

Where,
$R_A(t)$ = Reliability of the cylinder
$R_B(t)$ = Reliability of the rack
$R_C(t)$ = Reliability of the sector gear
$R_D(t)$ = Reliability of the bearings
$R_E(t)$ = Reliability of the pins
$R_F(t)$ = Reliability of the strut arm spring assembly



ED 5-54. Belleville Miter Gate Machinery System

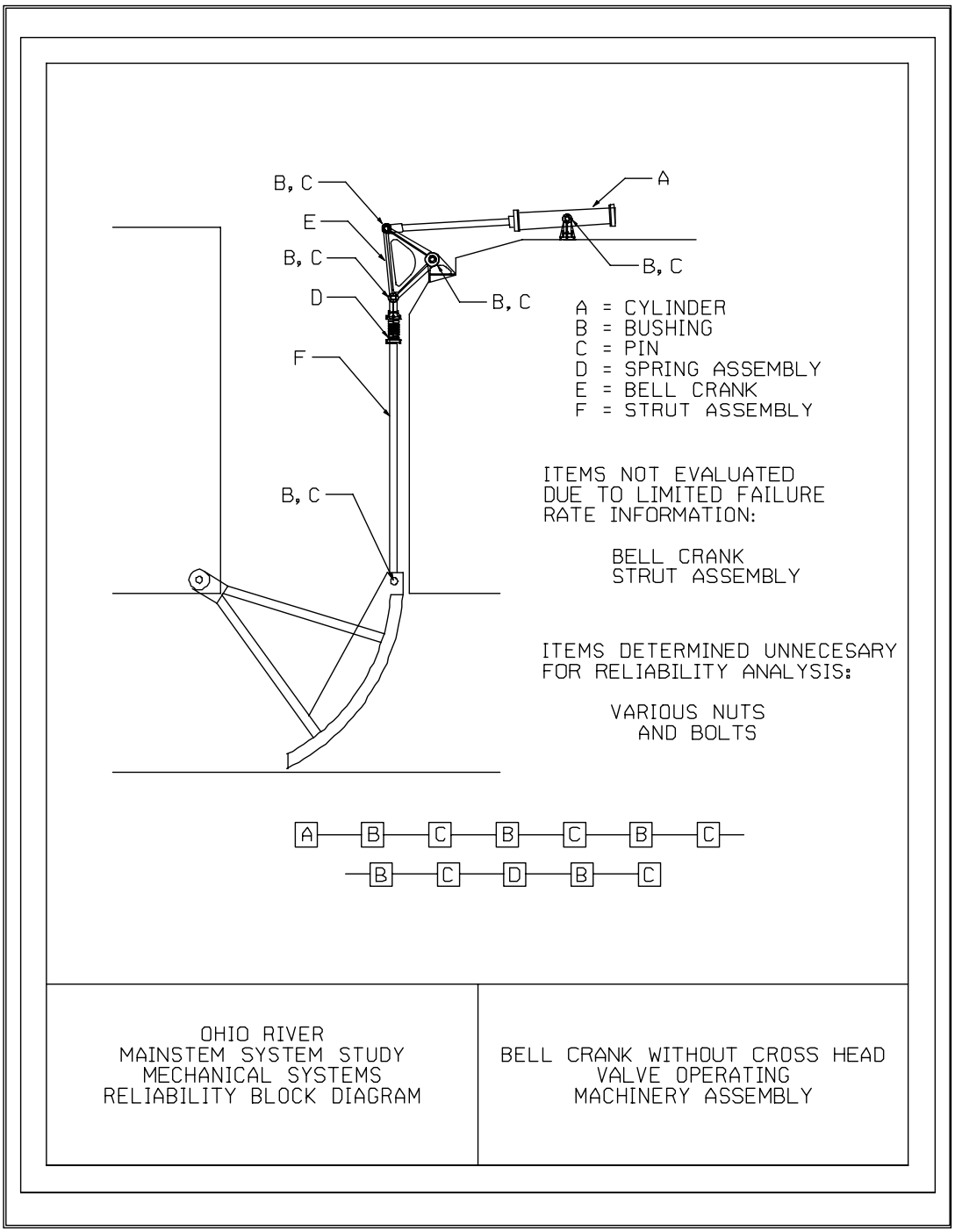


Figure ED 5-55. Belleville Culvert Valve Machinery System

CULVERT VALVE MACHINERY RELIABILITY

The culvert valve mechanical subsystem was considered to begin at the first coupling. The subsystem reliability for the culvert valve machinery model at Belleville (See Figure ED 5-55) is calculated as:

$R_{BellevilleCVMachinery}(t) = R_A(t) * R_B(t)^5 * R_C(t)^5 * R_D(t)$

Where,
$R_A(t)$ = Reliability of the cylinder
$R_B(t)$ = Reliability of the bushing
$R_C(t)$ = Reliability of the pin
$R_D(t)$ = Reliability of the spring assembly

HYDRAULIC SYSTEM RELIABILITY

$R_{HYDRAULIC}(t) = R_{PUMP}(t) * R_{PIPE}(t) * R_{CVHYDR}(t) * R_{MGHYDR}(t)$

Hydraulic Pump System Reliability

$R_{PUMP}(t) = R_C(t) * R_J(t) * [1 - (1 - (R_C(t)^2 * R_F(t) * (1 - (1 - R_B(t))(1 - R_J(t)))))]*[1 - (1 - R_C(t))^2]$

Where,
$R_C(t)$ = Reliability of shutoff valve
$R_J(t)$ = Reliability of filters/strainer
$R_F(t)$ = Reliability of pump
$R_B(t)$ = Reliability of check valve

Culvert Valve Machinery Hydraulic System Reliability

$R_{CVHYDR}(t) = [1 – (1 - R_C^3)(1- R_C*R_G)] * R_C * [1 – (1 – R_{L1})(1 – R_{L2})(1 – R_{L3})]$

Where,
$R_C(t)$ = Reliability of shutoff valve
$R_G(t)$ = Reliability of manual control valve
$R_J(t)$ = Reliability of filters/strainer
$R_H(t)$ = Reliability of solenoid control valve
$R_I(t)$ = Reliability of flow control valve
$R_B(t)$ = Reliability of check valve
$R_K(t)$ = Reliability of the cylinder
$R_{L1} = R_C(t)^2 * R_J(t)$
$R_{L2} = R_H(t)^2 * R_C(t) * [1 – (1 – R_I(t))(1 – R_B(t)))]$
$R_{L3} = R_B(t) * R_H(t) * R_D(t)^2 * R_I(t)^2 * R_K(t) * R_C(t)^4$

Miter Gate Hydraulic System Reliability

$R_{MGHYDR}(t) = R_I * R_C * [1 – (1 – R_C^2*R_G)^2] * [1 – (1 – R_K)(1 – R_B^2)(1 – R_D^2)] *$
$[1 – (1 – R_I)^2]$

Where,
$R_C(t)$ = Reliability of shutoff valve
$R_G(t)$ = Reliability of manual control valve
$R_I(t)$ = Reliability of flow control valve
$R_B(t)$ = Reliability of check valve
$R_K(t)$ = Reliability of the cylinder

x

$R_D(t)$ = Reliability of relief valve

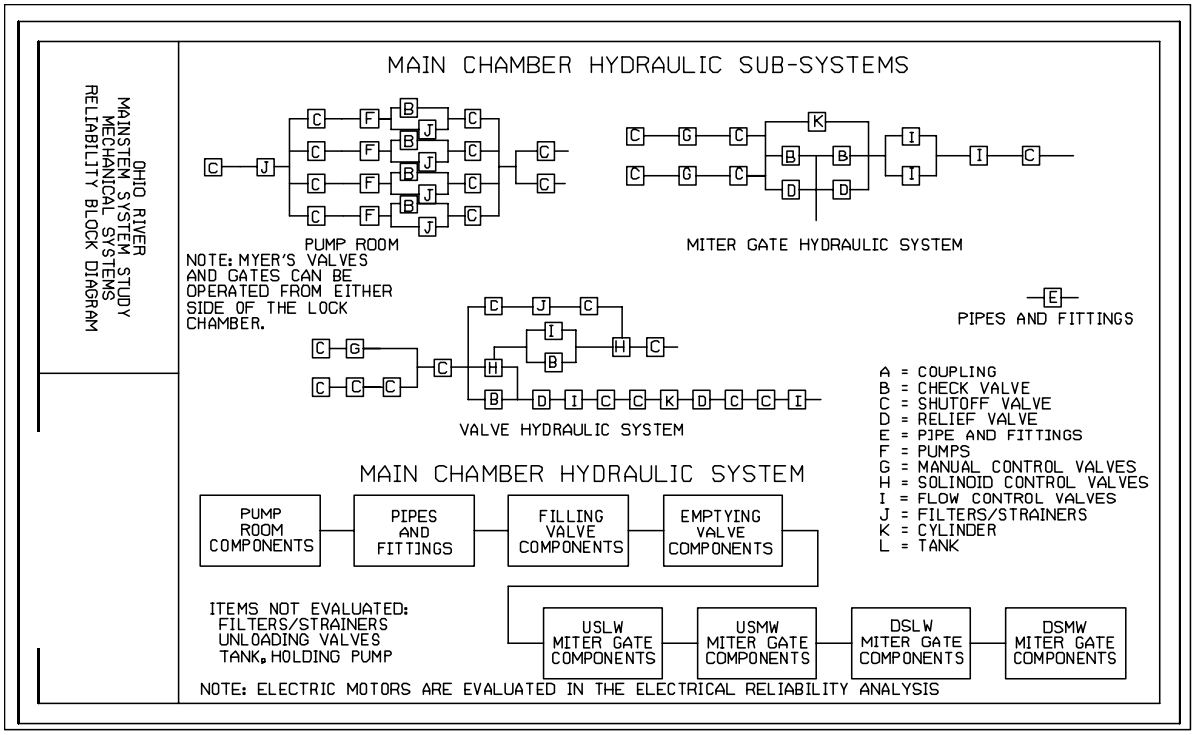


Figure ED 5-56. Belleville Hydraulic System Line Diagram and RBD

5.7.7 Hazard Calculation for the Mechanical System

The Weibull hazard function was used to determine the hazard rate of each component. The Weibull hazard function is:

$$h(t) = \frac{\beta\,[td]^{\beta-1}}{(\alpha)(\alpha)}$$

The subsystem hazard rates for the miter gate and culvert valve models were calculated from the hazard rates of the individual components using the following relationship:

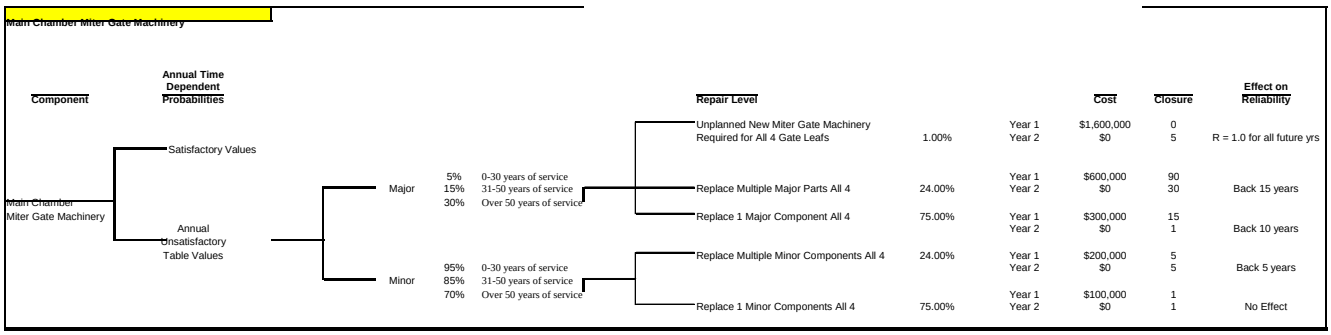
$$h_{subsys}(t) = \sum h_i(t)$$

Where,

$h_i(t)$ = Hazard rate for the individual components
i = 1,n

5.7.8 Mechanical System Event Trees

The event trees for the mechanical systems (miter gate machinery, culvert valve machinery, and hydraulic systems) are set up similar to the electrical system. An extra branch on the event tree was added to differentiate between minor and major types of failures for each of the mechanical components. Thus, there are many more failure options evaluated for the mechanical systems when compared to the structural components. The failure rates from the manuals reflect mainly wear-and-tear type of failures such that most repairs would be minor in nature. Therefore, the first branch of the event tree is the hazard rate for the component (miter gate machinery, culvert valve machinery, or hydraulic system). The second branch delineates between major and minor failures. Like the structural components, the event tree for the miter gate machinery system also has a sliding scale used for the major and minor branches related to service age of the system. These sliding values vary according to service life of the component. The event tree used for the lock miter gate machinery system is shown in Figure ED 5-57. The event tree used for the culvert valve machinery is shown in Figure ED 5-58. Note that ½ speed operation, and not closure time, is the primary chamber performance measure for this component besides repair costs. Finally, the event tree for the hydraulic system is shown in Figure ED 5-59. As was the case with the electrical system event tree, approximate costs and closure times for each branch was determined by ORMSS mechanical engineers in consultation with operations personnel familiar with repairs to these particular components.



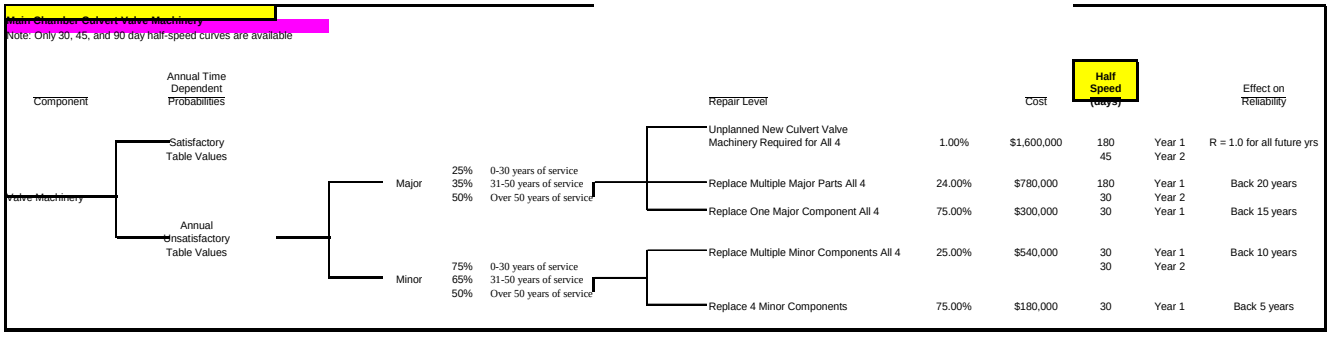
REPAIR COST INFORMATION

$15,000	LRL Fleet Cost for MG Machinery Emergency Repairs
$10,000	LRL Fleet Historical Cost for MG Machinery Repairs
$400,000	Cost to Fabricate One New Set of Miter Gate Machinery
$75,000	Cost of Major Component to Replace
$25,000	Cost of Minor Componet to Replace

REPLACEMENT OF MAIN CHAMBER MITER GATE MACHINERY PRIOR TO FAILURE

Time	Chamber Closure	Cost	Description
Year 1	30	$1,900,000	Procure material in preparation of replacement. Roughly 1 week per leaf to replace machinery. Future reliability assumed to be 1.0 for all years after replacement.

Figure ED 5-57. Miter Gate Machinery Event Tree



REPAIR COST INFORMATION

$15,000	LRL Fleet Cost for CV Machinery Emergency Repairs
$10,000	LRL Fleet Historical Cost for CV Machinery Repairs
$250,000	Cost to Fabricate One New Set of Culvert Valve Machinery
$60,000	Cost of Major Component to Replace

REPLACEMENT OF MAIN CHAMBER CULVERT VALVE MACHINERY PRIOR TO FAILURE

Time	Chamber 1/2 Speed	Cost	Description
Year 1	30	$1,300,000	Procure material in preparation of replacement. Roughly 1 week per valve to replace machinery. Future reliability assumed to be 1.0 for all years after replacement.

Figure ED 5-58. Main Chamber Culvert Valve Machinery Event Tree

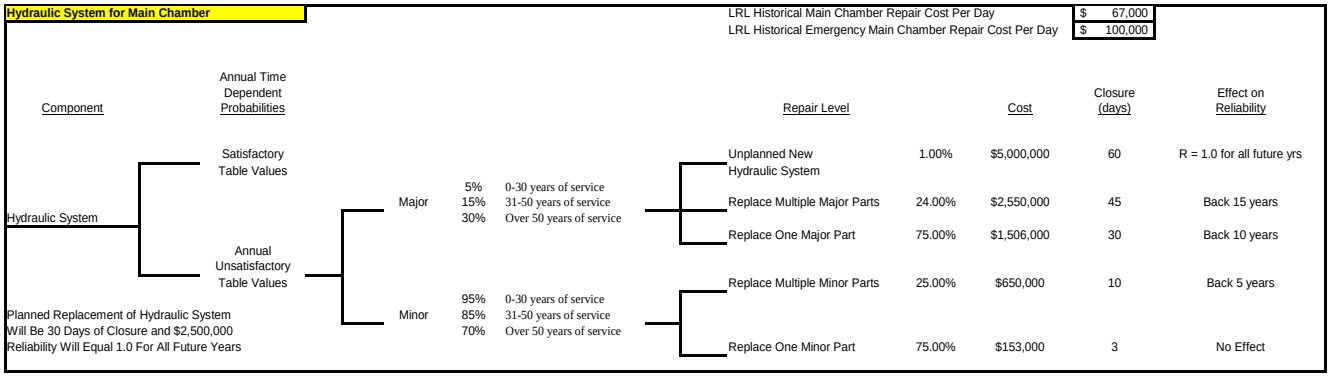


Figure ED 5-59. Lock Hydraulic System Event Tree

5.7.9 Mechanical System Hazard Reliability Model Results

As noted previously, the failure rates for the different components are pulled from data books for the mechanical systems as outlined in ETL 1110-2-549. Therefore, the failure rates from the data books lead to an overall hazard rate that is much smoother and always increasing when compared to the capacity versus demand hazard rates for structural components. The hazard rate for the main chamber miter gate machinery system at Belleville is shown in Figure ED 5-60 for the high (Modified Clear Skies), middle (Utility High), and low (Clear Skies). As shown in Figure ED 5-60, the hazard rates for the miter gate machinery at Belleville do not vary greatly between the low and high scenarios since many features of the miter gate machinery system reliability analysis is age based. However, operating cycles are a contributing factor that makes up part of the difference. The hazard rates for main and auxiliary chamber are only slightly different even though the operating cycles on the main chamber are considerably higher. Similar notes to those described for miter gate machinery hazard rates are applicable to the hazard rates for culvert valve machinery and hydraulic systems. The variation in hazard rates between these components is based upon the failure rates used in the analysis for each of these components from the guidance. The hazard rates for the low, high, and middle traffic projections are shown in Figures ED 5-61 and ED 5-62 for the culvert valve machinery and hydraulic system, respectively.

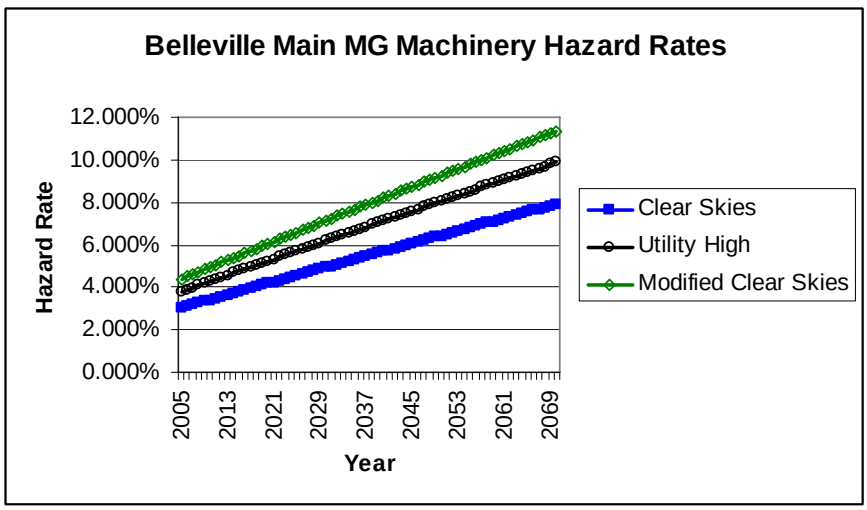


Figure ED 5-60. Belleville Main Chamber Miter Gate Machinery Hazard Rates

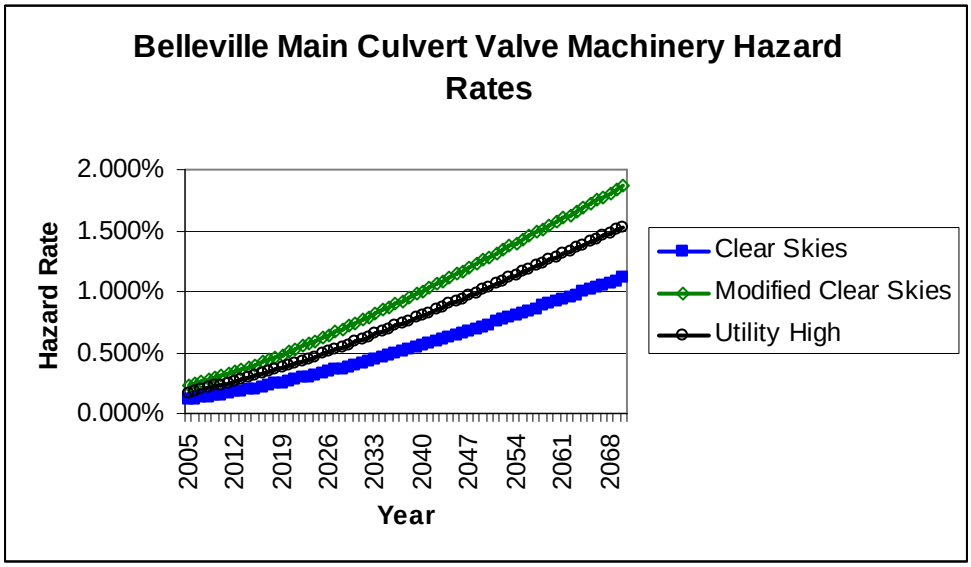


Figure ED 5-61. Belleville Main Chamber Culvert Valve Machinery Hazard Rates

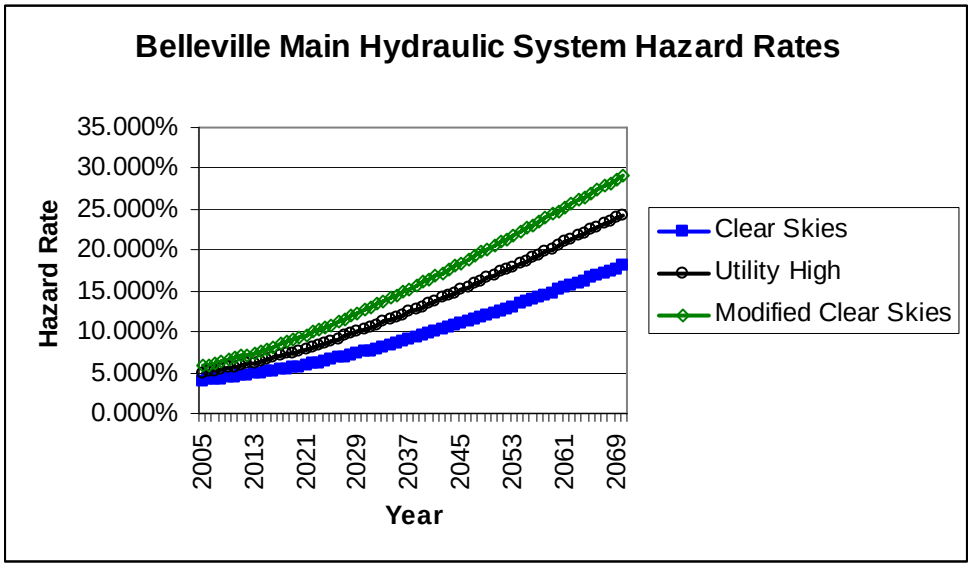


Figure ED 5-62. Belleville Main Chamber Hydraulic System Hazard Rates

5.7.10 Economic Results for Mechanical Systems

The hazard rates for the various mechanical components systems for all Ohio River locks, along with the event trees shown in Figures ED 5-57 through ED 5-59, were provided to the economists to determine if a scheduled replacement of any of the mechanical operation machinery was economically justified for replacement ahead of reaching a level of unsatisfactory performance as outlined in the

modeling setup, as well as determine the average annual costs associated with the fix-as-fails scenario. The same event tree for the miter gate machinery was used for the main and auxiliary chambers. Different event trees for the hydraulic system and culvert valve machinery were used between the main and auxiliary chamber, however, these differences made little difference in the economic results. The differences are mainly driven by the fact that auxiliary chambers are not used for most commercial lockages in addition to the having lower hazard rates compared to the main chamber. As noted earlier, the hazard rates between the low (Clear Skies) and high (Modified Clear Skies) traffic scenarios at Belleville did not vary greatly even though traffic levels are considerably different. This is a function of the failure rate type of analysis applied with the ETL. Future work in this area will be directed towards a capacity versus demand type of analysis like what is done for structural components. If these models can be developed through research and development efforts, they would add great benefit to the Corps risk-based applications.

Using the event trees and hazard rates of the mechanical components at Belleville, the replacement dates for each main chamber component are shown in the Economics Appendix. Graphical representation of the Belleville miter gate machinery, culvert valve machinery, and hydraulic system ORNIM output is shown in Figures ED 5-63, 5-64, and 5-65, respectively, for the Utility High traffic scenario.

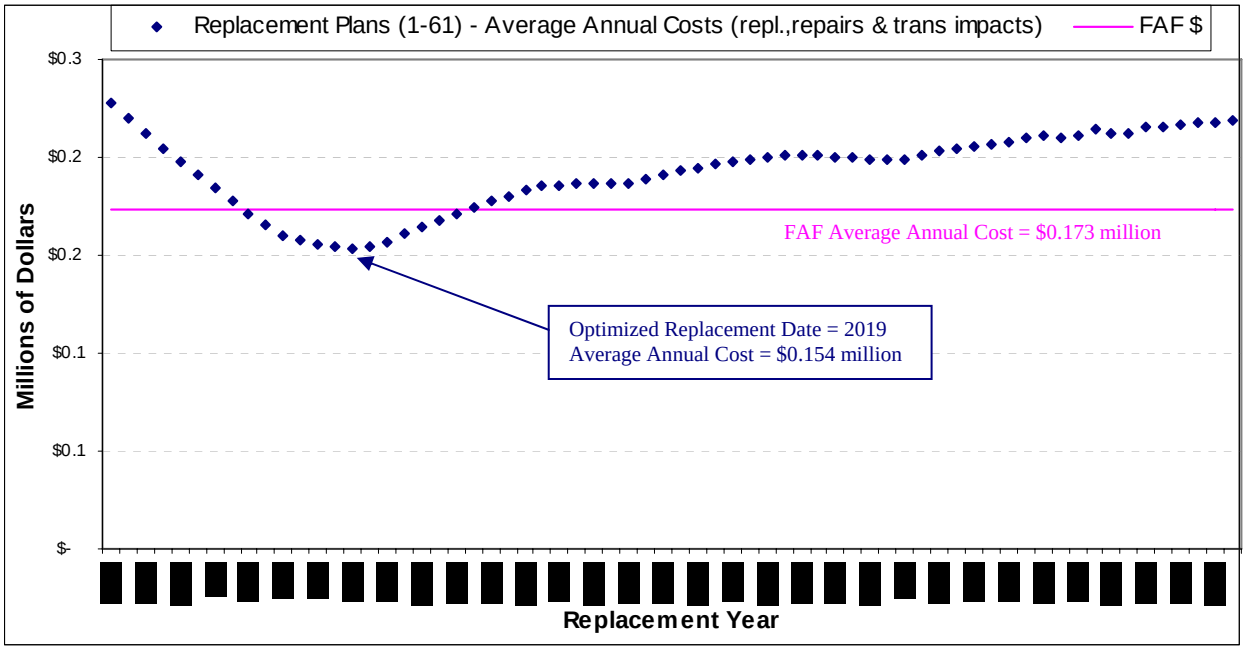


Figure ED 5-63. Economic Results for Belleville Main Chamber Miter Gate Machinery

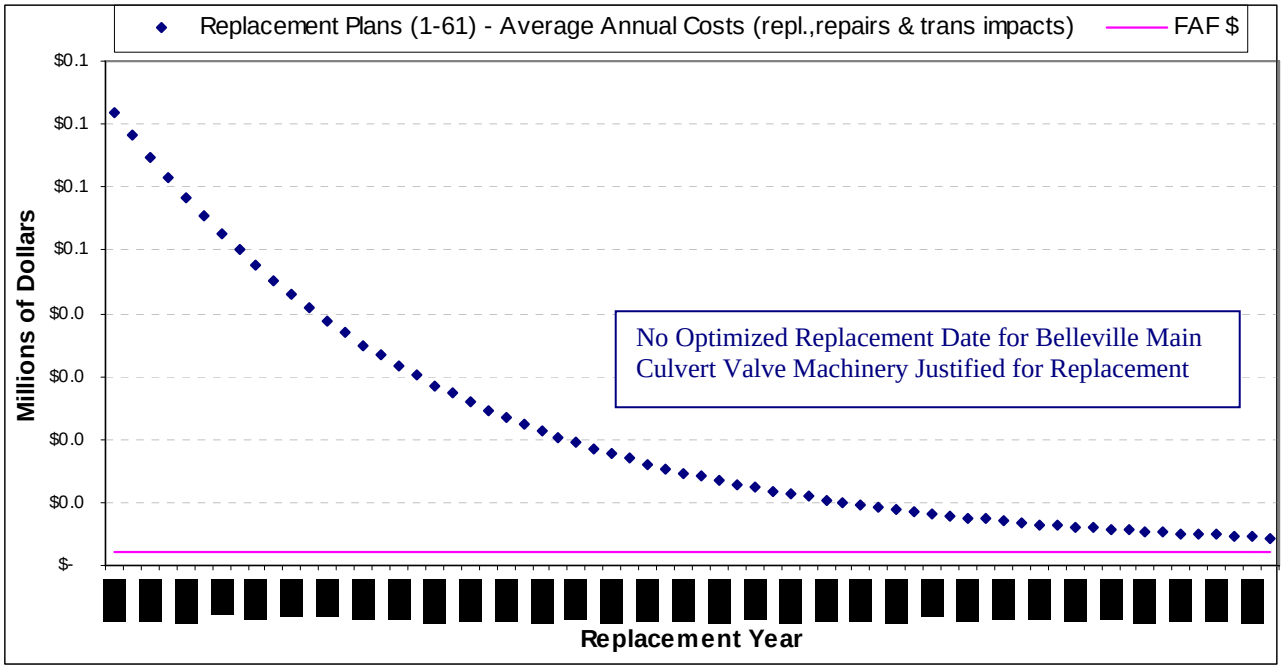


Figure ED 5-64. Economic Results for Belleville Culvert Valve Machinery

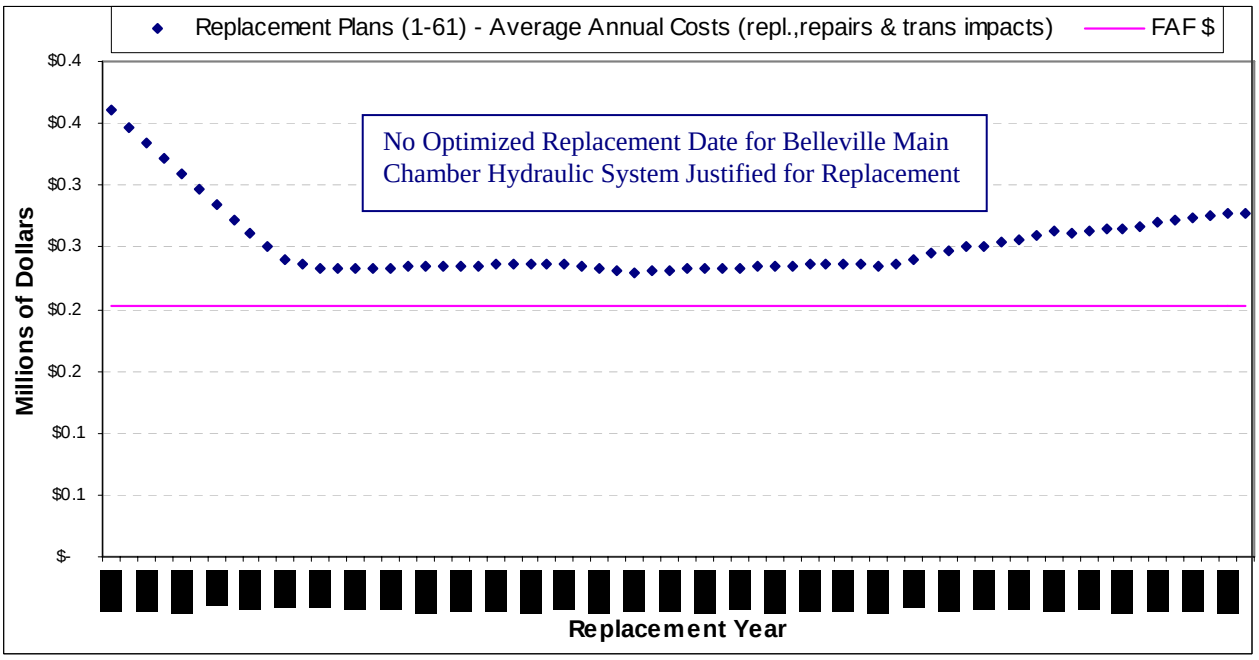


Figure ED 5-65. Economic Results for Belleville Hydraulic System

5.8 GRAVITY MONOLITH RELIABILITY

There are two basic types of concrete gravity monoliths on the Ohio River system, unanchored concrete gravity monoliths and anchored concrete monoliths. The unanchored concrete monoliths are not considered to be time dependent from a reliability standpoint since the ORMSS Engineering Team was not evaluating "return period" types of loads such as earthquakes and floods as part of this evaluation. The anchored concrete monoliths are considered to be time dependent (reliability changes with time) because the anchors are subjected to fatigue and corrosion. There are only three sites on the Ohio River that have anchored concrete monoliths. These are Emsworth, Dashields, and Montgomery (EDM) Locks and Dams in the Pittsburgh District. All other remaining sites have unanchored concrete gravity monoliths for lock walls. As stated previously, their reliability is not assumed to change with time because the structure does not significantly degrade with time. In addition, the reliability analysis did not consider extreme or unusual loads as part of the analysis, as directed by HQUSACE guidance.

Within the unanchored concrete gravity monolith category, there are various types of monoliths that have been analyzed for reliability. These include "typical" land wall, middle wall, and river wall monoliths within the lock chamber. Stability for approach walls was also analyzed for ORMSS. Additionally, the lower, middle wall auxiliary chamber miter gate monolith was analyzed. The engineering team chose this miter gate monolith at each site since it generally experiences the highest uplift, particularly in the maintenance case. Since the uplift has proven to be the most critical load on concrete gravity structures, the team chose to look at this particular monolith.

All of the unanchored monolith sections analyzed are concrete gravity structures founded on rock. Olmsted was not considered because of it was recently constructed and designed with current criteria for uplift, seismic, and safety factors. The same is true for the new lock chamber at McAlpine, which is currently under construction. All of the monoliths analyzed are concrete structures founded on rock and are not stabilized with active or passive rock anchors with the exception of EDM. There are three walls made of individual concrete, gravity monoliths that form the lock chamber. The land wall and one side of the middle wall form the auxiliary chamber. The river wall and other side of the middle wall form the main chamber. Since the time or funding was not sufficient to investigate every possible monolith cross-section for reliability analyses, a typical monolith was selected to be representative for each wall at each project.

5.8.1 Load Cases for Lock Wall Reliability

Because the structures are massive concrete structures without anchors, they are not subject to fatigue and corrosion associated with steel structures. As a result, no significant deterioration over the operational life of the structure is considered to threaten the overall stability of the structure and the reliability is assumed to be independent of time. The exception is at EDM, where significant deterioration of the internal mass concrete is a major reliability concern. The EDM reliability analysis for lock wall stability had to be meshed with the expert elicitation in order to be used in ORNIM. For all other sites besides EDM, the reliability is assumed to be constant over the study period. This is consistent with HQUSACE reliability guidance for unanchored concrete gravity monolith structures. Since the reliability of the structure is based on limit states and not design values, unsatisfactory performance modes considered for the gravity monoliths are overturning, sliding, and bearing of the rock foundation **without any safety factors applied to the analysis**. The limit states established for the unsatisfactory performance modes are as follows: overturning – a negative effective base in compression, sliding – the driving horizontal forces exceed the resisting horizontal forces, and bearing – the resultant monolith toe bearing pressure exceeds the maximum peak bearing strength of the foundation rock or subjacent rock.

In general, calculations were based on current Corps of Engineers lock design criteria. Two loading conditions are considered for the unanchored lock wall monoliths: the normal operating condition and the maintenance condition. The normal operating condition represents the usual daily

cyclic loads experienced by the lock monoliths. Dewatering the chamber is the maintenance condition. As has been the case for all other components, a single site has been selected for the typical analysis of the component. The Markland project is being detailed for lock wall stability.

Table ED 5-5 depicts the loading conditions for both situations for all three types of monoliths at Markland. Normal upper pool at Markland is elevation 455.0. This generally does not vary significantly and therefore is assumed to be constant in the model. Normal lower pool elevation is 420.0; however, the lower pool fluctuates and is a random variable in the reliability analysis. The major external loadings experienced by a land wall are lateral earth pressure, hydrostatic pressure due to the saturation level of the backfill, uplift, hawser pull, and the fluctuating pool elevation in the lock chamber. The middle and river walls are subjected primarily to uplift, hawser pull, and fluctuating pool elevations in the chambers or river. The miter gate monolith is also subjected to hydrostatic effects, but also the miter gate loads. Barge impact is excluded from the analysis since the lock chamber monoliths are not part of the navigational approach system. Barge impact loads were included in the approach wall stability analysis.

Monolith	Load Case	
	Normal Operating Condition	Maintenance Condition
Land	Backfill saturated to EL. 455.0 and fluctuating lower pool in main chamber.	Backfill saturated to EL. 455.0 and the main chamber dewatered, EL. 398.0.
Middle	Main chamber at upper pool, EL. 455.0 and auxiliary chamber at fluctuating lower pool.	Main chamber at upper pool, EL. 455.0 and auxiliary chamber dewatered, EL. 398.0.
River	Auxiliary chamber at upper pool, EL. 455.0 and the river at fluctuating lower pool.	River at fluctuating lower pool (<EL 431.08) and auxiliary chamber dewatered, EL 398.0.

Table ED 5-5. Load Cases for Lock Wall Monoliths (Markland Example)

For the analysis of all gravity structures, an external force resisting overturning was added to the model to account for rock embedment where appropriate. If the embedment was minimal, this external force was neglected in the analysis. The model calculates this force as the passive crossbed shear resistance of the rock wedge on the down stream face of the monolith. For the miter gate monoliths, the analysis included no resistance from the adjacent miter gate sill or adjacent monoliths.

5.8.2 Loading Assumptions

The gravity loads considered in the analysis are due to the weights of the water and soil above the monolith, water within the culvert, and the concrete monolith. For an example of model input, the soil/rock random variables and constant values for the Markland project are provided in the Tables ED 5-6 and ED 5-7, respectively. For the case where the moist soil unit weight exceeds the saturated soil unit weight, the moist soil unit weight is made equal to the saturated soil unit weight in the stability analysis. Lateral earth pressure of the backfill is computed using the full at-rest pressure coefficient (K_o) that is calculated from Jacky's Equation, since the lock monoliths are founded on rock[1,2]. For Markland, the saturation level in the backfill is assumed to be constant and equal to the normal upper pool elevation EL 455.0. Uplift is assumed to be acting on the entire base of the monolith. The uplift pressure values are based on the varying lower pool elevation, constant upper pool elevation, and/or the saturation level in the backfill. The distribution of the uplift pressure was calculated using a derived closed-form solution for uplift that is a function of the overturning and resisting moments, uplift pressures at the toe and heel of the structure, and the resultant vertical load. It is assumed that a uniform uplift pressure equivalent to the maximum hydrostatic pressure at the heel of the base acts on the portion of the base not in compression. A hawser pull is applied to a structure under the normal operating condition for 20

percent of the Monte Carlo trials [typically 10,000 trials] [3]. The hawser pull-force value normal to the face of a monolith is established from the guidance in ETL 1110-2-321 and the point of application is assumed to be 5 feet above the pool elevation[4,5]. Vertical shear (downdrag), acting along the wall-soil interface due to differential settlement of the backfill, is available in the model but was not utilized in the stability analyses since the lock monoliths are completely stable for both normal operating and maintenance conditions.[2,5]

For the miter gate monolith analysis, full hydrostatic head was applied to the upstream and downstream faces and uplift on the base of the structure varies linearly from 100% of headwater to 100% of tailwater with no effect from foundation drains. In the case of the base not being entirely in compression, it was assumed a tension crack is formed and 100% of headwater pressure was applied along the length of the crack then the uplift varies linearly to tailwater from that point. For the normal condition, the hydrostatic and uplift pressures upstream of the centerline of the pintle were based on the upper pool level in the auxiliary chamber, and those downstream were based on lower pool level. All sites with unanchored concrete gravity monoliths have miter gates that are horizontally framed. Therefore, the miter gates transfer the load produced by the differential head directly to the monolith in the normal condition. During the maintenance condition, the weight of the hanging gate is transferred to the monolith as a force couple at the top anchorage and the pintle.

The tables and description of the conditions at Markland are only shown to give the reader a flavor of the model and how it works. Each project had the analysis completed and the same load cases as shown in this narrative. Additionally, the random variables and constants are site-specific values but are input into the model the same as shown for Markland.

5.8.3 Random Variables and Constants in the Analysis

The geotechnical shear strength parameters for all sites are based on information obtained from the as-built drawings, design memoranda, foundation reports, periodic inspection reports, and reference material. Each district's geotechnical engineers provided the necessary data to complete the analysis. Cross-sections, boring logs, N-values, and laboratory test results are used to determine the range in strength values. Very limited test results are available for the majority of the sites. As a result, typical strength values are obtained from reference material and original design values. The probabilistic values used in the reliability analyses include the type of probability distribution function, mean, standard deviation, range, coefficient of variance, and correlation coefficient, and are provided in the following table. Unit weights, shear strength parameters, and ultimate bearing capacity values are provided for the soil and rock foundation. Cross-bed shear strengths are also provided for the monoliths embedded in rock.

5.8.4 Lock Wall Reliability Model Computations

The Microsoft Excel™ spreadsheet and the @Risk™ add-on application is comprised of six sheets (*Input Parameters*, *Monolith Geometry*, *Soil Geometry*, *Water Elevation*, *Stability Analysis*, and *Stability Results*) and two visual basic modules (*Update* and *VBProgram*). @Risk™ is an add-on software application for Microsoft Excel™ that provides Monte Carlo simulation for reliability analysis. The material properties and input data are represented by probability distribution functions instead of discrete values. For each Monte Carlo trial, material properties and input data are randomly selected according to their respective probability distributions for the stability analysis. The structure is analyzed for its stability in overturning, sliding, and bearing. Any unsatisfactory performance is tabulated for each trial. A sufficient number of trials, 10,000 for this model, are required to achieve convergence and

a particular level of confidence in the simulation results. The general model spread sheets are set up similar to the model for the miter gate sills.

Variable	Mean	Standard Deviation	Maximum	Minimum	Distribution	Units	Description
Soil:							
Mst Unit Wt	0.115	0.003	0.124	0.106	Normal	kcf	Driving soil, unit weight, moist
Sat. Unit Wt	0.125	0.004	0.137	0.113	Normal	kcf	Driving soil, unit weight, saturated
Phi, internal	33	2	38	30	Normal	deg	Driving soil, internal friction angle
Rock:							
Phi, sliding	38	4	45	35	Normal	deg	Rock, sliding friction angle
C, sliding	20	20	25	0	Normal	psi	Rock, sliding shear strength
Phi crossbed	47	4.5	57	37	Normal	deg	Rock, cross-bed friction angle
c, crossbed	75	25	100	50	Normal	psi	Rock, cross-bed shear strength
Sat Unit Wt	0.1672	0.002	0.1697	0.1660	Normal	kcf	Rock, saturated unit weight
BrgCapacity	2083.3	208.3	2430.6	1736.1	Normal	psi	Rock, ultimate bearing capacity
Lower Pool					CDF [1,2]	NA	Lower Pool elevation
Hawser Pull	57.5	11.5	80.5	34.5	Normal	kip	Hawser pull force, normal to face

[1] Cumulative Density Function established for Lower Pool is used.
[2] For river wall R-48, the maintenance condition, the maximum main chamber is flooded when the lower pool elevation exceeds EL 431.08.
Not applicable.

Table ED 5-6. Geotechnical Random Variable Parameters (Markland Example)

Constant	Value	Units	Description
Conc Unit Wt	0.1475	Kcf	Concrete, unit weight
Water Unit Wt	0.0625	Kcf	Water, unit weight
Saturation Level	455.0	Ft	Water saturation level in backfill
Upper Pool	[1] 455.0	Ft	Upper Pool elevation

[1] When L.P. EL > U.P. EL – 1 ft, U.P. EL = L.P.EL + 1 ft.

Table ED 5-7. Geotechnical Constants for (Markland Example)

For the lock wall monolith reliability model, the probability distribution functions, parameters, and constants are provided in the *Input Parameters* sheet. The geometry, voids, and centroid computation of the monolith are provided in the *Monolith Geometry* sheet. Soil geometry is provided for one or two types of backfill and the sheet calculates the moist and saturated soil layers, weights, and centroids using the visual basic *Update* functions. The lower pool cumulative density function and upper pool discrete value are provided in the *Water Elevation* sheet. Soil and rock elevations for computation of driving and resisting forces are provided in the *Stability Analysis* sheet. The stability calculations and results for overturning, sliding, and bearing are provided in the *Stability Results* sheet. A visual basic module is used to track unsatisfactory performances during the Monte Carlo trials. The respective unsatisfactory performances for each limit state and cumulative unsatisfactory performances are also tabulated on this sheet.

The stability analyses follow the guidance provided in Chapter 4 of EM 1110-2-2502. For the overturning stability analysis, the vertical and horizontal forces and the resultant moments are summed. The resultant moments are categorized as resisting or overturning moments. The effective base in compression and the uplift is solved for simultaneously using a closed-form solution. The closed-form

solution is a function of the overturning and resisting moments, uplift pressures at the toe and heel of the structure, and the resultant vertical load. A negative effective base in compression indicates that the structure performs unsatisfactorily in overturning. Once the effective base and uplift are established, the sliding stability analysis is conducted. The passive resistance of the rock and structural wedge is computed and the resisting forces are summed with the resultant net negative driving forces. If the sum of the resisting and driving forces is negative, the structure performs unsatisfactorily in sliding. The maximum bearing pressure is then calculated and compared to the ultimate bearing capacity for the rock foundation. If the bearing pressure exceeds ultimate bearing strength, the structure performs unsatisfactorily in bearing. Each mode of unsatisfactory performance is tabulated for each trial. However, any trial that results in a calculated unsatisfactory performance in any one or combination of the three performance modes will be counted for reliability purposes as one unsatisfactory performance for the structure.

5.8.5 Results and Conclusions

No unsatisfactory performances were calculated in 10,000 iterations for both the normal and maintenance load cases for any of the non-EDM sites. There were no unsatisfactory performance occurrences because of the original safety criteria used in design of the structures. Additionally, each site is founded on sound rock that resists all three possible failure modes.

These results are reasonable and expected since no significant movement of the walls has been noted at any of the sites since construction. Since there were no unsatisfactory performances, the economists did not need to run their analysis for the lock wall monoliths at the sites that have been completed. Thus, the event tree for lock walls is not included with this appendix.

5.8.6 References

1. Headquarters, Department of the Army. (1989). “Retaining and Flood Walls,” Engineering and Design, EM 1110-2-2502, Washington, DC.
2. Headquarters, Department of the Army. (1997). “Stability Analysis of Concrete Structures,” Engineering and Design, EC 1110-2-291, Washington, DC.
3. ORMSS Meetings – Discussions with Operations and Design Sections.
4. Headquarters, Department of the Army. (1993). “Reliability Assessment of Navigational Structures, Stability of Existing Gravity Structures,” Engineering and Design, ETL 1110-2-321, Washington, DC.
5. Ebeling, R. M., M. E. Pace, WES, and E. E. Morrison, Jr., N.A.S. Fallon. (1997). “Evaluating the Stability of Existing Massive Concrete Gravity Structures Founded on Rock,” Technical Report REMR-CS-54, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

5.9 LOCK CHAMBER MAJOR REHABILITATION EVALUATIONS

One of the key analyses being evaluated within ORMSS is the need and timing of major rehabilitations for individual lock chambers. This was analyzed for each lock where the number of components justified for replacement would exceed the current monetary threshold for major rehabilitations and last over at least two construction seasons, as required by current USACE guidance. The current threshold for major rehabilitation is approximately $10.8 million spread over multiple years. For the purposes of this study, the rehab “package” was considered to be all components that were individually justified for component replacement within the study period. The cost of individual

component replacements, which requires separate closures and repair costs, was compared against a major rehab option where the components are "bundled" into a single project with multiple closures over 2 to 3 construction seasons. In most cases, the rehab option was selected by ORNIM as the least cost alternative since more closures are eliminated and future reliability is reset to a value of 1.0 for each component replaced, thus, eliminating future failures within the analysis. The lock chamber selected for illustrating the major rehabilitation analysis for ORMSS is the Cannelton main lock chamber. The analysis is shown for the Clear Skies forecast.

The following individual components are economically justified for replacement ahead of failure for the Cannelton main lock chamber: miter gates, miter gate machinery, hydraulic system, culvert valves, and electrical system. The cost and closure time required for individual component replacements is evaluated versus the closure time and cost associated with a major rehabilitation of the lock chamber. As noted earlier, the major rehabilitation was only evaluated if it met the current requirements of the major rehab program, primarily cost and construction time. A comparison of the projected individual component replacements of the Cannelton main lock chamber versus a projected major rehab cost and closure requirements is shown in Table ED 5-8.

Component	Year 1 Repair Cost / Closure	Year 2 Repair Cost / Closure	Year 3 Repair Cost / Closure
Miter Gates	$6.5 M / 0 days closed	$8.8 M / 30 days closed	$3.8 M / 30 days closed
Culvert Valves	$0.9 M / 0 days ½ speed	$2.2 M / 60 days ½ speed	$1.3 M / 60 days ½ speed
Miter Gate Machinery	$1.9 M / 30 days closed	Not Required	Not Required
Hydraulic System	$2.5 M / 30 days closed	Not Required	Not Required
Electrical System	$3.5 M / 60 days closed	Not Required	Not Required
Major Rehabilitation	$6.7 M / 0 days closed	$13.1 M / 45 days closed	$8.6 M / 45 days closed

Table ED 5-8. Individual Component Replacement Information versus Major Rehabilitation

Comparing the information provided for Cannelton in Table ED 5-8, it is clear that considerably less chamber closure time is required when comparing a major rehabilitation to individual component replacements. This makes sense given the fact that the major rehab is combining several different repairs into the same closures. In addition, the total cost is conservatively assumed to be approximately 10% less than the individual components since much less mobilization and demobilization is required when compared to replacing components individually. ORNIM was run for a major rehabilitation of the Cannelton main chamber and the results are shown in Figure ED 5-66. A summary of the results for the Cannelton main chamber are as follows:

Fix-As-Fails Average Annual Cost = $5.84 million
Individual Component Replacement Cost = $1.75 million
Optimized Major Rehab Date = $0.16 million

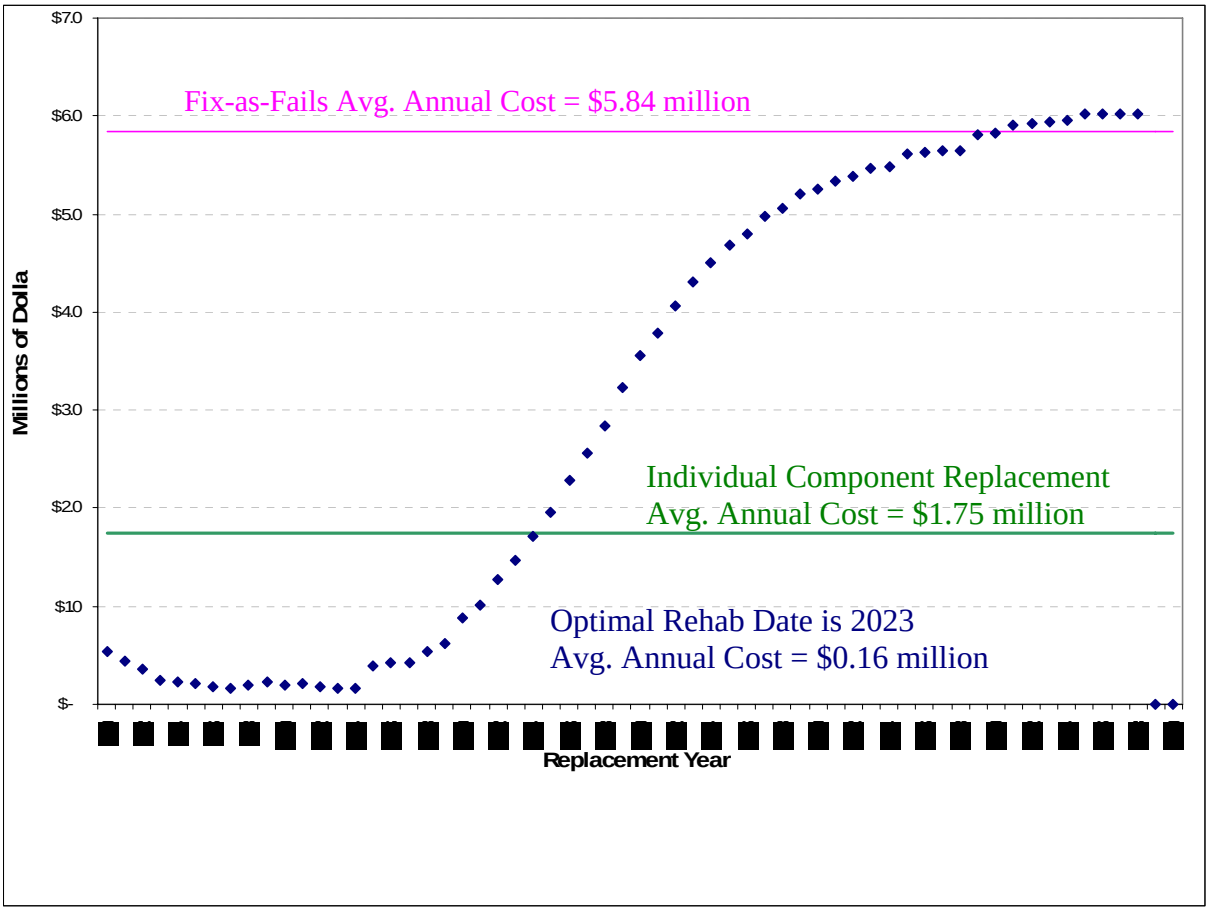


Figure ED 5-66. ORNIM Output for Cannelton Main Chamber Major Rehabilitation for the Clear Skies Traffic Forecast

The fix-as-fails represents the average annual total cost (repair and navigation impacts) of doing maintenance in a reactive mode, thus, replacing components after they fail. The individual component replacement average annual cost represents the total cost (repair and navigation impacts) of replacing the miter gates, culvert valves, miter gate machinery, hydraulic system, and electrical system all on their individual component optimized date, which is shown in the ORMSS overall summary table at the end of this section of the report. The date of 2023 represents the optimal replacement date for the major rehabilitation of the Cannelton main chamber for the lowest traffic scenario, which is the Clear Skies. The optimized dates for the major rehab of the main chamber at Cannelton for the other traffic forecasts are 2020 (Modified Clear Skies), 2017 (NAAQS), 2017 (Utility Based), and 2017 (Utility High). Although it is evident from Figure ED 5-66 that any year between 2017 and 20023 yields roughly the same average annual cost. ORNIM selects the absolute lowest cost option, but the randomness of the economic and engineering analysis is probably better indicated through the use of a curve fit or trend line. If that were done in this case, the optimal date for the major rehab would be roughly 2021 for all traffic projections. It is something to keep in mind when reviewing the results of the model and the intended accuracy of the analysis.

The optimization of major rehabilitations for other lock chambers is handled in the same manner. For a complete list of economically justified, optimally timed major rehabs refer to Section ED 5.10 which provides tables showing the economical results for individual component replacement and major rehabs for all projects as a part of ORMSS.

5.10 SUMMARY OF ECONOMIC ANALYSIS RESULTS

ORNIM was used to determine the economic justification of individual component replacement and major rehabs of all lock chambers on the Ohio River. Major rehabs were only analyzed when the components requiring replacement within the study period met the cost and construction criteria associated with current USACE major rehab guidance. There are five future traffic scenarios being evaluated within ORMSS: Clear Skies, Modified Clear Skies, NAAQS, Utility Based, and Utility High. For a more detailed description of each of these traffic scenarios, please refer to the Economics Appendix. The Engineering Team provided hazard rates to the Economics Team for the low, high, and middle traffic scenario for each component, as well as consequence event trees. ORNIM was then used to interpolate hazard rates between these values for the traffic scenarios where hazard rates were not provided. It is important to note that the high and middle scenarios vary at different projects due to characteristics associated with the traffic projections. The low scenario at each project was the Clear Skies scenario. The results for each project are shown in the individual tables within the Economics Appendix. If a component does not show up in the list, this means that a reliability analysis was completed for the project but no failures were encountered in the analysis and was not analyzed as an individual component in the economic analysis.

Section 6

LOCK CHAMBER COSTS AND CLOSURES NOT ASSOCIATED WITH RELIABILITY ISSUES

6.1 Background

This section describes the cost and closure schedules used in the formulation process for both the Without Project and With Project conditions. The cost and closure schedules are a series of spreadsheet matrices that detail lock chamber specific costs, closures, and other project costs for the time frame 2005 through 2065 for all 20 navigation projects on the Ohio River, although the economic analysis reports from 2010 and beyond. The schedules were essential in order to perform a complete economic analysis since maintenance levels vary between individual projects, as well as for different scenarios. The schedules consist of different types of closures, some of which are probabilistic-based and others that are fixed in the schedule. The various types of closures are detailed in the chapter of the Engineering Appendix. Matrices were developed according to each district's current maintenance program, as well as for multiple large-scale investment strategies. Maintenance programs vary considerably, as do available data between LRD districts due to different manpower availability, number of projects, differences in Operations accounting/record keeping methods, and project variability. In fact, maintenance for projects within the same district will vary due to the age and level of deterioration. This is covered in more detail within this section.

6.2 Cost and Closure Categories for Schedules

For the purposes of this report, this narrative will focus on the general categories of costs and closures associated with the matrices. There will be a detailed layout of how all the information was developed for a single lock to clearly describe the process of developing the information embedded within the cost and closure matrices. The same general process was used to develop the closure schedules for each lock.

Closure of either an auxiliary or main chamber at a site can occur for a variety of reasons. Some closures are related to level of maintenance previously performed on the lock chamber, while others are not affected by maintenance history. In addition, some closures require repair costs, while others are not associated with repairs but are a function of weather, debris, or other non-repair related phenomena. This is more clearly explained within each category of closure. The categories and information used in the cost and closure matrices was based upon an extensive database search of historical records over roughly the last 20 years. The information was developed by reviewing historical records associated with the Corps of Engineers' Lock Performance Monitoring System (LPMS) data, Operations repair reports and field notes, Corps of Engineers Financial Management System (CEFMS) data, historical notices to navigation, and

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finally, daily log books at the site. In general, the Operations repair reports coupled with historical navigation notices, as well as the on-site log books generally provided the most reliable set of historical data to draw from when developing the cost and closure information. In addition, the time frame for which this data was available has been around longer than the other sources of information, namely LPMS and CEFMS data. The LPMS and CEFMS data were also useful but variability among how project personnel from each site input the data required a more careful screening of the information. Each of these historical repairs was logged on a site-specific spreadsheet by lock chamber and then cross-referenced with the other databases. As noted earlier, the quality and availability of data varied considerably among the three districts, but overall, the ORMSS Engineering Team had a good amount of historic data to develop repair costs, categories of closures, and trends associated with the locks.

For clarity purposes, only one site will be detailed within this narrative in order to give the reader a detailed explanation of how the data was collected, categorized, and used in the analysis. The Cannelton Locks and Dam Project in the Louisville District was selected as a good example project to detail the development of the cost and closure information. The historical database collected and categorized for both the auxiliary and main lock chamber at Cannelton is shown in Table ED 6-1.

There is a lot of detailed information in Table ED 6-1. The detailed explanation of the categories is provided within this portion of the Engineering Appendix. The information in Table ED 6-1 reflects individual lock chamber closures in excess of 24 hours from 1988 through 2003 (16 years of data inclusive) at Cannelton. Any lock chamber closures less than 24 hours in duration were modeled within the economic transit delay curves. The top half of Table ED 6-1, shown in blue, reflects the historical closures for the Cannelton auxiliary chamber, while the bottom half of the table reflects historical main chamber closures. The historical main chamber closures are shown in red text. The right side of the table shows the various sources where the information was obtained. In some instances, multiple sources referenced the same historical closure. In these cases, check marks are shown for multiple sources. In general, navigation notices are only sent out for planned, lengthy duration closures. These closures typically had a detailed Operations report completed for them as well. Historical maintenance work related to main chamber culvert valves are highlighted in yellow. In these cases, the Louisville District repair fleet was set up in the existing auxiliary chamber while doing repairs to main chamber culvert valves. Thus, the auxiliary chamber was closed and main chamber was operating at ½ filling/emptying speed while repairs were being made.

As noted earlier, Nav Notices and Ops Records were only available for planned, lengthy duration closures. Therefore, Random Minor closures did not have this type of information. These Random Minor closures had to be separated into ones that required repair and those that were weather related. If the LPMS database indicated that the closures was for “debris in lock”, “flood”, “ice”, or other weather-related, then it was classified as a *Random Minor No Repair* closure. If LPMS coding showed “Test/Maint” or “Other” then it was categorized as *Random Minor Repair Required*, unless it was known to fall into the major maintenance category where typically Operations repair records and navigation notices also referenced the closure. A detailed explanation of each of the lock chamber closure categories is provided following Table ED 6-1.

Table ED 6-1. Cannelton Historical Cost and Closure Information

DATE	Begin Time	End Date	End Time	LOCK	CHAMBER	LPMS SYMBOL	LPMS CLOSURE CLASSIFICATION	DURATION (DAYS)	ORMSS CATEGORY	INDEXED REPAIR COST (Oct-04 $$$)	DESCRIPTION OF REPAIR WORK	SOURCE OF CLOSURE INFORMATION			
												Log Books	LPMS	Ops Records	Nav Notice
7/5/1988	700	7/7/1988	2000	Cannelton	Auxiliary	Q	Debris in Lock	2.54	RM - No Cost	n/a	debris-related closure	√			
3/28/1989	1915	3/30/1989	730	Cannelton	Auxiliary	T	Test / Maint	1.51	RM - Repairs		could not find cost		√		
4/20/1989	2130	5/3/1989	1000	Cannelton	Auxiliary	Culvert Valves	Main. - 1/2 sp. Aux - close	12.53	Maintenance Closure		main chamber culvert valve repairs - auxiliary chamber closed	√	√	√	
7/5/1989	2230	7/28/1989	1035	Cannelton	Auxiliary	Culvert Valves	Main. - 1/2 sp. Aux - close	22.50	Maintenance Closure		main chamber culvert valve repairs - auxiliary chamber closed	√	√	√	
9/12/1989	700	9/15/1989	350	Cannelton	Auxiliary	T	Test / Maint	2.85	RM - Repairs		could not find cost	√			
1/4/1990	1430	1/11/1990	1535	Cannelton	Auxiliary	Q	Debris in Lock	7.04	RM - No Cost	n/a	debris-related closure	√			
1/22/1990	700	1/26/1990	425	Cannelton	Auxiliary	Q	Debris in Lock	3.89	RM - No Cost	n/a	debris-related closure	√			
5/17/1990	1200	5/23/1990	1315	Cannelton	Auxiliary	Z	Other	6.05	RM - Repairs	$174,546	miter gate repairs	√		√	
5/29/1990	1125	6/1/1990	245	Cannelton	Auxiliary	T	Test / Maint	2.63	RM - Repairs		could not find cost	√			
6/6/1990	0	6/21/1990	0	Cannelton	Auxiliary	Culvert Valves	Main. - 1/2 sp. Aux - close	15.00	Maintenance Closure		main chamber culvert valve repairs - auxiliary chamber closed			√	
1/26/1991	1230	2/26/1991	820	Cannelton	Auxiliary	Z	Other	30.83	Maintenance Closure		could not find cost	√			
5/5/1991	300	6/3/1991	700	Cannelton	Auxiliary	Culvert Valves	Main. - 1/2 sp. Aux - close	29.17	Maintenance Closure		main chamber culvert valve repairs - auxiliary chamber closed	√	√	√	
8/6/1991	1300	8/9/1991	200	Cannelton	Auxiliary	T	Test / Maint	2.54	RM - Repairs		could not find cost		√		
12/6/1991	700	12/11/1991	1045	Cannelton	Auxiliary	Q	Debris in Lock	5.14	RM - No Cost	n/a	debris-related closure	√			
5/27/1992	210	7/3/1992	2150	Cannelton	Auxiliary	T	Test / Maint	37.81	Maintenance and Painting Closure	$911,515	culvert valve repairs and painting	√	√	√	92-02
4/19/1993	0	4/27/1993	0	Cannelton	Auxiliary	T	Test / Maint	8.00	RM - Main Repair	n/a	staging and clean-up area for main repairs			√	93-05
5/6/1993	600	6/28/1993	1100	Cannelton	Auxiliary	T	Test / Maint	53.21				√			
1/20/1994	800	1/26/1994	2100	Cannelton	Auxiliary	H	Ice	6.54	RM - No Cost	n/a	ice-related closure	√			
5/9/1994	0	5/17/1994	0	Cannelton	Auxiliary	T	Test / Maint	8.00	RM - Main Repair	n/a	staging and clean-up area for main repairs			√	94-08
5/26/1994	0	6/26/1994	615	Cannelton	Auxiliary	T	Test / Maint	31.26	Major Repair/Dewater	$1,127,800	dewater, inspect, and make miter gate repairs	√		√	94-13
7/11/1994	0	7/13/1994	2300	Cannelton	Auxiliary	R	Lock Hardware Malfunction	2.96	RM - Repairs		could not find cost	√			
5/1/1995	0	5/3/1995	1205	Cannelton	Auxiliary	T	Test / Maint	6.50	RM - Repairs		culvert valve machinery repairs		√		95-09
1/18/1996	1850	2/1/1996	2300	Cannelton	Auxiliary	Q	Debris in Lock	14.19	RM - No Cost	n/a	debris-related closure		√		
10/21/1996	700	11/25/1996	2300	Cannelton	Auxiliary	T	Test / Maint	35.67					√		
3/4/1997	700	3/13/1997	2030	Cannelton	Auxiliary	J	Flood	13.55	RM - No Cost	n/a	flood-related closure	√	√		
5/27/1997	0	5/29/1997	2300	Cannelton	Auxiliary	T	Test / Maint	2.96	RM - Repairs		could not find cost	√			
7/6/1999	2130	7/29/1999	1130	Cannelton	Auxiliary	T	Test / Maint	22.58	Maintenance Closure	$668,523	mechanical and electrical repairs to emergency dewater gate		√	√	99-15
11/1/1999	0	11/12/1999	2130	Cannelton	Auxiliary	T	Test / Maint	11.89	Maintenance Closure	$713,731	emergency repairs to structural members		√	√	99-27
11/11/1999	0	11/20/1999	0	Cannelton	Auxiliary	Culvert Valves	Main. - 1/2 sp. Aux - close	9.00	Maintenance Closure		main chamber culvert valve repairs - auxiliary chamber closed		√	√	
5/30/2000	0	6/30/2000	0	Cannelton	Auxiliary	T	Test / Maint	11 days Maint. & 20 days MGOO	Maintenance Closure and MG Lift Mods	$862,297	intake screen repalcement and upper 600-ft miter gate lift mods			√	
9/1/2000	1330	9/5/2000	1300	Cannelton	Auxiliary	Z	Other	3.99	MG Lift Mods	$531,157	600-ft chamber lower miter gate lift modifications		√	√	
7/15/2001	0	8/12/2001	0	Cannelton	Auxiliary	T	Test / Maint	28.00	Maintenance Closure	$484,968	install auxiliary intake screens, repair hydraulic piping, moorings			√	01-13
5/12/2002	0	5/18/2002	2300	Cannelton	Auxiliary	T	Test / Maint	6.96	RM - Repairs		no repairs noted	√			
7/8/2002	0	7/30/2002	2300	Cannelton	Auxiliary	T	Test / Maint	10 days Dvl. & 13 days MGOO	Inspection Dewatering and MG Lift Mods	$1,323,466	dewater and inspect miter gates with minor repairs plus miter gate anchorage switchout for MGOO system	√	√	√	02-07
6/29/1987	1400	7/8/1987	1130	Cannelton	Main	T	Test / Maint	8.89	Inspection Dewatering and Minor Repairs	$453,629	dewater, inspection, and minor repairs to miter gates	√		√	87-01
7/21/1988	1230	8/21/1988	1440	Cannelton	Main	T	Test / Maint	31.09	Major Repair/Dewater		could not find repair cost		√		
4/20/1989	2130	5/3/1989	1000	Cannelton	Main	Culvert Valves	Main. - 1/2 sp. Aux - close	12.53	Main @ 1/2 Speed and Auxiliary Closed	$273,908	main chamber culvert valve repairs - auxiliary chamber closed			√	
7/5/1989	2230	7/28/1989	1035	Cannelton	Main	Culvert Valves	Main. - 1/2 sp. Aux - close	22.50	Main @ 1/2 Speed and Auxiliary Closed	$491,932	main chamber culvert valve repairs - auxiliary chamber closed			√	
6/6/1990	0	6/21/1990	0	Cannelton	Main	Culvert Valves	Main. - 1/2 sp. Aux - close	15.00	Main @ 1/2 Speed and Auxiliary Closed	$441,646	main chamber culvert valve repairs - auxiliary chamber closed			√	
5/5/1991	300	6/3/1991	700	Cannelton	Main	Culvert Valves	Main. - 1/2 sp. Aux - close	29.17	Main @ 1/2 Speed and Auxiliary Closed	$574,906	main chamber culvert valve repairs - auxiliary chamber closed			√	
4/28/1992	1100	4/30/1992	1400	Cannelton	Main	T	Test / Maint	2.13	RM - Repair		could not find repair cost	√			
4/28/1993	0	5/5/1993	0	Cannelton	Main	T	Test / Maint	7.00	Maintenance Closure	$630,545	structural repairs to miter gates			√	93-05
5/17/1994	730	5/26/1994	1010	Cannelton	Main	T	Test / Maint	9.12	Inspection Dewatering and Minor Repairs	$709,357	dewater, inspect and make minor repairs to lock structure	√	√	√	94-08
3/5/1997	930	3/11/1997	1600	Cannelton	Main	J	Flood	6.28	RM - No Cost	n/a	flood-related closure	√	√		
11/16/1998	20	11/17/1998	1245	Cannelton	Main	Z	Other	1.51	RM - Repair		could not find repair cost		√		
7/29/1999	1200	8/3/1999	1230	Cannelton	Main	T	Test / Maint	9.01	Inspection Dewatering and Minor Repairs	$921,446	dewater, inspect miter gates and minor repairs & mechanical / electrical repairs to 1200' emergency dewatering gate	√	√	√	99-15
11/11/1999	0	11/20/1999	0	Cannelton	Main	Culvert Valves	Main. - 1/2 sp. Aux - close	9.00	Main @ 1/2 Speed and Auxiliary Closed	$504,830	main chamber culvert valve repairs - auxiliary chamber closed	√		√	
9/1/2001	0	9/4/2001	2300	Cannelton	Main	T	Test / Maint	3.96	RM - Repair		could not find repair cost	√			
12/10/2001	52	12/11/2001	1300	Cannelton	Main	Z	Other	1.52	RM - Repair		could not find repair cost		√		
1/22/2004	0	1/23/2004	2300	Cannelton	Main	Q	Debris in Lock	1.96	RM - No Cost	n/a	debris-related closure	√			

For the purposes of this study, chamber closures were broken down into three major categories with several sub-categories within each major category. The three major categories of closures are **Random Minor, Maintenance**, and **½ Speed Filling and Emptying Events**. The various sub-categories within each major category are described along with how these closures were scheduled in the matrices. The indexed cost feature of the table was to get all costs to current dollar levels for a consistent approach with other aspects of the study. The costs were indexed using the USACE indexed costs system for civil works structures.

Major Category - Random Minor. Random minor closures are closures that are essentially independent of historical maintenance or replacement/rehabilitation work. These involve down time due to items that are considered unavoidable. Lock chambers are sometimes closed for unforeseen occurrences regardless of historical level of maintenance. Examples of this type of closure would be shutting down the auxiliary chamber to flush ice or debris through the project or weather-related closures (fog, snowstorm, etc…). Some of these can be rather lengthy, but by definition the Engineering Team capped Random Minor closure durations at 15 days since most data supported these closures did not exceed this limit. The Economics Team captures all closures that are less than 24 hours in duration when they develop their chamber-specific transit delay curves for the economic analysis. Anything over 24 hours in duration is captured by the Engineering Team and used in the development of the cost/closure schedules. Some random minor closures require physical repairs and others, such as weather-related closures, require no repairs at all. The Economics Team develops transit delay curves for closure durations of various lengths, so all the closures under this category were rounded off to the nearest transit delay curve duration evaluated by the Economics Team. There are 10 Random Minor closure types as listed below and all closures projected in these categories through the study period (2010 through 2070) were based upon historical trends.

15-day without repair costs
10-day without repair costs
5-day without repair costs
3-day without repair costs
1-day without repair costs

15-day with daily repair cost rate
10-day with daily repair cost rate
5-day with daily repair cost rate
3-day with daily repair cost rate
1-day with daily repair cost rate

The daily repair cost rate was determined based upon all the known Random Minor closures throughout a district where good cost data was available, averaged across the district, and then used for all Random Minor closures with costs throughout that district. For example, the 20-year database for Louisville District locks indicated that the daily repair costs averaged roughly $21,000 per day when indexed to current dollar levels. The Random Minor repair rates for Huntington and Pittsburgh Districts were

$33,000 per day and $35,000 per day, respectively, for these types of closures. Differences in rates between districts are normal since each district does maintenance differently, has a different number of projects, and different manpower/equipment. The Ohio River Navigation Investment Model (ORNIM) handles the Random Minor projected closures and costs by assigning a probability of occurrence that is kept the same in each year of the study period. Thus, each of the Random Minor categories listed above was determined how often to occur over the last 20 years and then a percentage chance of occurrence was applied to each event. The district-specific daily repair fleet cost was the same for both the main and auxiliary chambers for Random Minor closures.

Major Category - Maintenance. There are multiple categories of maintenance closures and many are a function of age and use. The categories were developed after conducting the research on the historical databases across each district. As can be expected, the older and high use projects are closed more often for maintenance. In addition, each district had many differences compared to other districts. In fact, maintenance closure schedules and costs vary at projects within the same district according to site-specific problems. This is particularly true at the older projects on the Ohio River that have not been rehabilitated (Markland, Greenup, and Meldahl). Many of the features of a lock and dam deteriorate with time and use. These features require more frequent maintenance in order to keep them operational. Some of these features (miter gates, operating machinery, etc…) require the lock chamber to be closed in order to perform maintenance.

There are seven sub-categories of Maintenance repairs. Not all of the sub-categories require a chamber closure as some work involves culvert valves which have maintenance done on them while a chamber is open to traffic. A brief description of each category is provided in this narrative.

The costs and durations of many of these repairs are dependent upon whether or not they are occurring in the main or auxiliary chamber. It was noted during the research of historic data that for some districts the daily repair fleet costs for maintenance closures varies according to which chamber is down for repairs. For example, major maintenance main chamber repairs for Louisville District locks averaged roughly $67,000 per day when indexed to current dollar levels. The auxiliary chamber closures only averaged $31,000 per day for major repairs. The primary difference for this is the need to get main chambers open to navigation traffic as soon as possible. Additional staff is provided and repairs requiring main chamber closures are prepared far in advance with a lot of labor done prior to the closure. Table ED 6-3 shows the maintenance events within the Louisville District upon how these daily fleet rates were established.

All this means that the cost is high, but the closure duration is kept as short as possible, thus, increasing the daily repair cost since all the prepatory work is also charged to the same repair project. The auxiliary chamber daily operating costs are lower because the repair fleet can afford to sit in the auxiliary chamber for longer and make multiple repairs over the entire project. For example, intake screens for both main and auxiliary chambers recently required replacement at the Louisville District projects and the repair fleet was stationed in the auxiliary chamber during these repairs. While the cost did not necessarily go up, the number of days was increased, thus, a lower daily rate for auxiliary chamber maintenance repairs.

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SUMMARY OF LOUISVILLE DISTRICT LOCK CHAMBER MAINTENANCE FLEET COSTS

	1200-FT CHAMBER INFORMATION				600-FT AUX. CHAMBER INFORMATION	
LRL Project	# of 1200-ft Closure Events	Avg. Fleet Cost for 1200-ft Closures	# of 1/2 Speed Fill/Empty Events	Avg. Fleet Cost for 1/2 Speed	# of Auxiliary Closure Events	Average Fleet Cost for Auxiliary Closures
Markland	7	$50,634	1	$23,404	6	$22,728
McAlpine	5	$58,392	3	$12,302	auxiliary chamber being replaced	
Cannelton	4	$75,146	5	$25,933	7	$30,308
Newburgh	4	$54,576	none noted	n/a	3	$34,697
John T. Myers	5	$78,012	3	$27,903	3	$42,827
Smithland	6	$85,667	1	$13,465	both chambers are 1200-ft	
	31		13		19	
WEIGHTED AVERAGES		$66,753		$22,088		$30,584
		per day 1200-ft chamber closure		per day 1/2 speed F/E operations		per day of auxiliary chamber closure
		USE $67,000		USE $22,000		USE $31,000

Table ED 6-3. Computations of LRL Daily Fleet Rates from Historical Data

Maintenance Subcategory - Inspection and Minor Repairs. These are relatively short-duration closures (between 10 and 15 days) that are effective at helping districts asses the general condition of their structures, as well as identify potential major problems before they lead to significant failures. These closures vary by district according to their maintenance policy, but they require the repair fleet to travel to the site, dewater the lock chamber, inspect significant structures, make quick repairs as necessary, and then put the chamber back in service. The daily fleet repair rate for each district applies to these closures. They are "hard-wired" into the analysis according to each district's maintenance policy and their frequency. A more aggressive inspection and minor repair frequency is required at aging sites where problems need more attention. The daily rates for main chamber and auxiliary chamber repairs under this category were $67,000/day and $31,000/day, respectively, for Louisville District locks.

Maintenance Subcategory - Major Gate Repairs. These closures are lengthy maintenance closures for repairs to miter gates. Historically, miter gate repairs cause some of the lengthiest closures in terms of chamber down time. These closures are for major repairs to miter gates and typically include replacing pintles, repairing cracks in the gates, quoin and miter block repairs, etc. The duration of these closures typically exceed 30 days. The chamber-specific daily repair fleet rate for the district is applied to these closures. The frequency of these closures is dependent upon the historic age and use of the project. The frequency and duration of major gate repair closures will change to less closures, less frequently following a major rehab and/or lock extension. The daily rates for main chamber and auxiliary chamber repairs under this category were $67,000/day and $31,000/day, respectively, for Louisville District locks.

Major Subcategory - Miter Gate Changeout Modifications. This category is to retrofit miter gates for the a miter gate changeout system. This category is only applicable to the Louisville and Huntington District locks. Miter gate modification requirements include retrofitting the gates to make them liftable for switchout by the gatelifter crane. These modifications to make them liftable are generally short in nature and most have already been completed for the Louisville District sites with the exception of Smithland where there already are twin 1200-ft lock chambers. The other modification requires changes to the anchorage system. These changes will also make the switchout of the gates much easier once they have been completed. The anchorage

changes require two lengthy (30 to 45-day events) in order to modify both sets of miter gate anchorages for the switchout system. These are one-time repairs and once completed are not required again. The chamber-specific daily repair fleet rate for the district is applied to these closures. The daily rates for main chamber and auxiliary chamber repairs under this category were $67,000/day and $31,000/day, respectively, for Louisville District locks.

Major Subcategory - General Maintenance Repair. This repair is for lock chamber maintenance requiring closure, but not related to miter gate repairs. In researching the historical database, these repairs occur once or twice in a 20-year cycle for the main chamber and much more frequently for the auxiliary chamber. The primary reason that the auxiliary chambers see more of these types of closures is that the district repair fleet will safely "park" in the auxiliary chamber while making repairs to other structures on the facility. For example, the intake screens for the filling and emptying system require the repair fleet to make repairs at select times around traffic. This is a lengthy project but doesn't necessarily shut the main chamber down for any extended period during repairs. However, the fleet will park in the auxiliary chamber during this time, thus, completely shutting it off from traffic. The auxiliary chamber provides a safe location for setting the fleet away from navigation and the outside of the approach walls where it is exposed to currents associated with the dam. The chamber-specific daily repair fleet rate is applied to these closures. The daily rates for main chamber and auxiliary chamber repairs under this category were $67,000/day and $31,000/day, respectively, for Louisville District locks.

Maintenance Subcategory – Emergency Repairs. This subcategory is becoming ever more common for the infrastructure on the Ohio River. Aging locks coupled with increased traffic load with tight O/M budgets means that more frequent maintenance closures are required to keep the system operational. These closures are not necessarily "unscheduled" in the truest sense of the word, but they are reflective of the required level of maintenance beyond what is considered normal for locks that are in good, reliable condition. They are a good indicator that the components are reaching the end of their economic service life and are in need of rehabilitation or replacement. For example, the Markland main chamber miter gates are in such poor condition that the Louisville District repair fleet is required to dewater the lock every 1 to 2 years in order to reduce the chance of catastrophic failure of these gates. Typically, dewaterings for inspections and repairs are done every 5 years, thus, many of these closures fall into the Emergency Repairs subcategory because they are way beyond normal O/M requirements. In this example, the repairs on the 5-year interval fall into other categories (Inspection & Minor Repairs and Major Gate Repairs) because that is typical practice for Louisville District locks on the Ohio River that are in good condition.

Major Category – ½ Speed Filling and Emptying Events. Culvert valve repairs were also separated into an individual category to determine how often and for how long the main chamber operates at ½ filling and emptying speed. Decreased filling and emptying times only occur due to valve repairs only occur for 1200-ft chambers on the Ohio River because the shorter, auxiliary chambers only have a single filling valve and single emptying valve. Thus, any repairs to valves on the auxiliary chambers requires them to be closed. The ORMSS Economics Team captures this reduce processing time through the facility by computing specific transit delay curves for ½ speed operating

periods of various durations. All historical data was evaluated to determine which ½ speed transit delay curve durations the Economics Team had to develop. All projected ½ speed operations are rounded to the closest duration evaluated by the Economics Team.

Most times the repair fleet is stationed in the auxiliary chamber while these main chamber valve repairs are made since this does not cause a main chamber closure only a slower filling and emptying time. As shown in Table ED 6-3, it was determined the costs of these repairs average $22,000 per day. This is due to having a smaller repair crew completing valve repairs as compared to major miter gate repairs. There are two types of ½ speed filling and emptying events that need to be considered when evaluating this in the economic analysis. The first is when the repair fleet is stationed in the auxiliary chamber while the main chamber continues to operate at ½ speed as valve repairs are made. The second is when the auxiliary chamber remains open while valves in the main chamber are repaired.

6.3 Other Costs

The various types of maintenance closures and repairs affecting transit time were covered in detail in Section 6.2 of this narrative. In addition, there are other costs to operate the project beyond those associated with maintenance closures. These are detailed below.

Other Project Costs. In order to determine the overall cost to operate the project, non-lock maintenance costs had to be captured in the schedules. Included in these costs are items such as daily operations and minor maintenance costs, recapitalization costs associated with the dam portion of the project, and dredging costs.

The daily operations and minor maintenance costs were developed by tracking them for five consecutive years for each project and updating them to current dollar levels. The daily operations and minor maintenance costs include categories such as USACE on-site labor, overhead, equipment, and minor maintenance (including project contracts such as grass mowing and minor painting). These are assumed to be the same for all scenarios as they are not a function of the maintenance scenarios being evaluated. Each site has different costs since manpower costs vary as does the equipment at each site and the need for varying types of contracts (such as the amount of grass mowing required). Dredging costs directly associated with each project are also included in these annual costs.

Separate large scale dam recapitalization costs are projected for only major work such as replacement of dam gates or complex replacement and repair to the stilling slabs below the gates. These are projected out separately because the investment required to make these repairs is beyond the scope of normal O/M and most likely would require a major rehabilitation funds to be provided. Other more routine dam maintenance costs are captured within the daily operations and minor maintenance category. For this ORMSS report, it was assumed that dam gates would need to be replaced after 75 to 80 years of service as part of a major rehabilitation project unless a particular site warranted earlier replacement. Previous instrumentation and inspection of the dam gates indicate that no gate systems themselves are in such poor condition that this is not an adequate assumption.

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If a major rehabilitation of a dam structure is required before the 75-80 year period, then justification is provided within each schedule. For example, the dam at J.T. Myers will not be 75 years old until approximately 2050, however, a major rehabilitation study for that dam is scheduled for completion in 2006. The primary purpose of the rehabilitation is erosion of the stilling basin below the dam gates that are in need of repairs beyond normal O/M. A secondary reason for the rehabilitation study of the J.T. Myers dam is to install anchors to meet stability requirements. Both of these costs are embedded in the dam portion of the cost/closure schedule at J.T. Myers and spread over the years as detailed in the J.T. Myers Dam Major Rehab report. The current estimate for completing the rehabilitation of the J.T. Myers Dam is approximately $33 million. It is assumed to be spread evenly over three years since stilling basin slab repairs can only be done in low water season.

The stilling basin erosion is a problem at several Ohio River projects, most notably on the middle and lower Ohio River. One of the structures required to make repairs to the stilling basins is a specialized dewatering bulkhead that is included within the J.T. Myers Major Rehab. This bulkhead can be used at other sites with site specific adapters that could be included as part of any rehabilitation project involving stilling basin slab repairs. Projects with known erosion problems will have their repair costs embedded following the J.T. Myers major rehabilitation assumptions and prorated for the number of gate bays. Also, the procurement cost of the dewatering bulkhead will be stripped out of the estimate since it will already be procured as a part of the J.T. Myers Dam Rehab. These repairs and their costs are incorporated at each site as indicated in the cost/closure schedules. It is important to note that the rehab options are the same for all scenarios being evaluated and are incorporated to capture a more accurate reflection of the expected long-term costs to operate the system.

6.4 Projecting Future Costs and Closures

There are two basic scenarios that the Engineering Team had to project future cost/closure schedules for as a part of ORMSS. The first scenario can be considered as a baseline option where the historical maintenance pattern is projected into the future and then increased maintenance is required as the structure continues to age. This pattern is based upon the historical data supporting increased maintenance needs for the older projects on the Ohio River that have not been rehabilitated (Markland, McAlpine, Greenup, Meldahl, New Cumberland, and Pike Island). The second scenario will be the improved maintenance schedule following either a major rehabilitation or large-scale improvement (auxiliary lock extension and/or new lock chamber for EDM). Once a major rehab or large-scale capacity improvement is made it is assumed that the chamber returns to a much improved maintenance scenario since all the unreliable features have been replaced as necessary.

Baseline Maintenance Schedule. One of the primary purposes and outputs of the ORMSS is the long-term investments in infrastructure required of the system in order to keep it a safe and reliable transportation link. The more age and operating cycles that the infrastructure sees, the more cumulative damage occurs to the structure. This is evident from the historical database search of the last 20 years of maintenance costs and

closures. Focusing in on the Louisville District as an example, it is evident that their older facilities (Markland and McAlpine) require more frequent maintenance closures than the newer facilities (Smithland). Most of these additional closures show up under the "Emergency Closures" and "Main @ ½ Speed with Auxiliary Closed" subcategories. This is clearly shown in Table ED 6-3 for all of the Louisville District locks for the years 1987-2004 (inclusive). The maintenance for 2005 and 2006 are projected based upon best estimates of the Louisville District Operations Division in order to get a 20-year cycle to work from (see footnote to table).

Based upon the historical information provided in Table ED 6-3, general patterns regarding maintenance needs can be developed as a guide for projecting future maintenance needs at other high traffic locks. The future maintenance schedule for the Louisville District projects is shown in Figure ED 6-1.

Historical Data from 1987- 2004 from LPMS, CEFMS, Log Books, Operations Records, and Navigation Notices

		1200-FT CHAMBER CLOSURE TYPES AND FREQUENCY					
PROJECT	OPERATIONAL	Inspection & Minor Repairs	Maintenance Repairs	Emergency Closures	Major Gate Repairs	Main @ 1/2 Speed with Aux. Closed	Main @ 1/2 Speed with Aux. Open
Markland	1958	10,10		10,15,10, 15*, 15*	30,45	45,90	
McAlpine	1964	15,15	30	15,10	45	45,45,90	
Cannelton	1972	10,10,10		10	30, 30*	30,30,30,30,30	30*
Newburgh	1975	10,10	10		45, 30*		45*, 30*
John T. Myers	1975	15,10,15	10		45	30,45	45
Smithland Land	1979	10,10,15	10		30	not applicable	30
Smithland River	1979	10,10	10		30	not applicable	

		600-FT AUXILIARY CHAMBER CLOSURE TYPES AND FREQUENCY					
PROJECT	OPERATIONAL	Inspection & Minor Repairs	Maintenance Repairs	Emergency Closures	Major Gate Repairs	Auxiliary Closed & Main @ 1/2 Speed	Maintenance & Painting
Markland	1958	15, 15*	15,15,10,30,10,30	45,60	45,30	45,90	90
Cannelton	1972	10	30,60,45,30,10,30	10	30	30,30,30,30,30	45
Newburgh	1975	10	30*		60		60
John T. Myers	1975	15	30		30,45	30,45	

* Note: In order to get a 20-year cycle, maintenance for the years 2005 and 2006 are needed. The Louisville District plans its major repairs with detailed schedule 2 years in advance, thus, the closures planned for 2005 and 2006 are fairly well defined from a planning standpoint. Therefore, these planned clos will be included in the analysis to get a more accurate reflection of a 20-year cycle.

Table ED 6-3. Historical Maintenance Closure Types for LRL Lock Chambers

The schedule shown in Figure ED 6-1 represents expected closure patterns based upon ages of the locks. Since all of the Louisville District projects are high traffic locks and none have been rehabilitated in the past, this schedule is applicable for all LRL projects. The starting point for particular maintenance types is set based upon the 2005/2006 LRL maintenance schedule or the most recent event prior to this date. The schedule of projected closures for a lock chamber varies according to the age of the project.

As shown in Figure ED 6-1, the schedule was developed around a 20-year operating cycle. This cycle was developed by taking all the sound data from various sources up through 2004. In general this provided about 18 years or so of good information to draw from in terms of establishing applicable patterns. Projected maintenance for the years 2005 and 2006 were used to complete the 20-year patters since most of these closures require long lead times and are pretty much set unless other issues arise. Every type of maintenance closure is rolled into the 20-year cycle with the exception of the "Emergency Closure" subcategory. This subcategory is based upon the operating age of the structure and not the 20-year cycle.

20-YEAR CYCLE CLOSURE INFORMATION BY CATEGORY FOR LOUISVILLE DISTRICT	
INSPECTION & MINOR REPAIRS CATEGORY	
Main Chamber	3 events (10, 15, and 10-day THEN alternate to 15, 10, and 15-day). All at $67,000 per day of closure.
Aux. Chamber	1 event in 20-year cycle (alternate between 10 and 15 days for each cycle) @ $31,000 per day of closure
MAINTENANCE REPAIR CATEGORY	
Main Chamber	1 event (varies between 10 and 30 days) @ $67,000 per day of closure
Aux. Chamber	Stage 1 will be for until an auxiliary lock reaches 25 years, a single 30-day closure @ $31,000 per day
	Stage 2 will be after a project reaches 25 years, 6 closures varying between 10 and 60 days @ $31,000 per day
EMERGENCY REPAIR CATEGORY	
Main Chamber	Stage 1 will be until the lock reaches 30 years in age, no events in 20-year cycle
	Stage 2 will be for lock between 31 and 50 years in age, assume 3 events (10, 15, and 15-day) @$67,000 per day
	Stage 3 will be for lock between 51 and 70 years in age, assume 5 events (15, 30, 15, 30, and 15-day) @$67,000 per day
	Stage 4 will be for lock over 70 years, every other year on a 15, 30, and 45-day pattern @$67,000 per day
Aux. Chamber	Stage 1 will be until the lock reaches 30 years in age, no events in 20-year cycle
	Stage 2 will be for lock between 31 and 50 years in age, assume 2 events (10 and 30-day) @$31,000 per day
	Stage 3 will be for lock between 51 and 70 years in age, assume 4 events (15, 30, 45, and 60-day) @$31,000 per day
	Stage 4 will be for lock over 70 years, every other year on a 30 and 45-day pattern @$31,000 per day
MAJOR GATE REPAIR CATEGORY	
Main Chamber	Assume 1 to 2 every 20 years depending upon beginning date. Duration will alternate between 30 and 45 days.
Aux. Chamber	Assume 1 to 2 every 20 years depending upon beginning date. Duration will alternate between 30 and 60 days.
MAIN CHAMBER @ 1/2 SPEED WITH AUXILIARY CHAMBER CLOSED CATEGORY	
Main Chamber	3 events varying between 30, 45, and 90 days at $22,000 per day of Main Chamber @ 1/2 speed operation
Aux. Chamber	Same events as shown in Main Chamber except the Auxiliary Chamber is closed
MAIN CHAMBER @ 1/2 SPEED WITH AUXILIARY CHAMBER OPEN CATEGORY	
Main Chamber	1 event varying between 30 and 45 days @ $22,000 per day of Main Chamber @ 1/2 speed operation
Aux. Chamber	This category does not affect auxiliary chamber
MAINTENANCE & PAINTING CATEGORY	
Main Chamber	This category does not affect main chamber based upon historic data
Aux. Chamber	1 event that varies between 45 and 90 days

Figure ED 6-1. Projected Maintenance Schedule for Louisville District Locks

Improved Maintenance Scenario. An improved maintenance scenario under ORMSS means that either a major rehabilitation or large-scale capacity improvement (lock extension/new lock) has taken place and the deteriorated lock that was rehabbed or replaced no longer needs additional closures beyond what history has shown to be "typical" frequencies and durations for reliable locks. The improved maintenance scenario contains much less maintenance closures than those associated with an aged and deteriorated project. This is because it is assumed all unreliable features would be replaced or substantially improved such that the lock can be returned to a maintenance schedule that is more reflective of a "reliable" lock. Therefore, there are no emergency closures in the cost/closure schedule following a major rehabilitation or large-scale capacity improvement. In addition, there would be no increased "general maintenance repairs" for auxiliary chambers that are required for older auxiliary lock chambers. The improved maintenance scenario means that the lock that is rehabilitated or extended moves back to a Stage 1 condition (see Figure ED 6-1) following the rehab/extension. The other categories of maintenance closures (with the exception of miter gate changeout modifications) are included in the improved maintenance scenario following a major rehabilitation or lock extension/new lock. The improved maintenance scenario is input into the ORNIM analysis after a major rehab is analyzed in the model. ORNIM tests different rehabilitation dates in the analysis and "slides" maintenance closures around to determine the optimum mix of maintenance with reliability. All maintenance up to the date of the major rehab uses the baseline maintenance scenario within the analysis.

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Section 7

WITH PROJECT CONCEPTUAL DESIGNS AND COSTS FOR LARGE-SCALE IMPROVEMENTS

7.1 INTRODUCTION

One of the primary engineering inputs to the overall economic analysis is conceptual cost estimates for increasing capacity at select projects where lengthy delays to the navigation industry can occur during main chamber closures. These lock chamber closures can occur due to a variety of reasons and are better described in Section 6 of this appendix. The primary point is that the engineering team was required to develop conceptual capacity improvement designs and cost estimates at select projects that indicated a capacity issue during the study period. This was done to support the overall economic and environmental analysis being done as part of the ORMSS SIP. The large-scale capacity improvements designs primarily involved either new lock chambers or extensions of existing auxiliary lock chambers to a nominal length of 1200 feet. For most cases, multiple levels of large scale improvements were considered as part of this analysis. For example, the lock extension option has multiple subcomponents that were varied including approach wall lengths and supplemental filling/emptying systems.

The level of detail in terms of designs and cost estimates is only conceptual because the ORMSS SIP is not authorizing any project improvements. The end result of the ORMSS SIP will be a master investment plan that will provide a template for future studies and project needs to maximize the multiple uses of the Ohio River including navigation infrastructure investments. However, many of the same design features and corresponding unit prices being used are currently being implemented as part of recent Ohio River lock projects either under construction (Olmsted, McAlpine) or in detailed design (Greenup, J.T. Myers). Therefore, they will be utilized as part of the ORMSS SIP conceptual capacity improvement designs and cost estimates. This information will be utilized to the greatest extent possible. General site-specific information will be used to modify the J.T. Myers and Greenup designs where warranted such that major site-specific differences, such as rough estimates for quantities, will be included as part of the ORMSS SIP analysis for the With Project comparisons.

In general, there are two types of projects on the Ohio River where the main chamber is 1200-ft and the auxiliary chamber is 600-ft. The first is representative of many of the projects on the lower river (Newburgh) where there are 6 laterals for filling and emptying the existing auxiliary lock chamber. For these types of projects, the conceptual designs and costs for Newburgh will be detailed in this narrative. The other type is similar to the Meldahl project where higher pool differentials required 11 laterals to fill and empty the lock chamber. These types of projects will be considered representative by Meldahl with respect to this narrative.

The other sites under consideration for the With Project are the upper three locks on the Ohio River (Emsworth, Dashields, and Montgomery, commonly referred to as EDM). As described in Section 4 of this appendix, the EDM projects are unique because their main chamber is only 110’ wide x 600’ long and the auxiliary chamber is extremely

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small, measuring 56' wide by 360' long. Therefore, extensions of the auxiliary chamber at EDM are not practical. The conceptual With Project design and estimates at EDM include new 110' x 600' lock chambers, as well as new 110' x 1200' lock chambers. Individual conceptual designs and costs estimates were developed for each of these projects in order to account for unique site specific conditions.

The details of the engineering plans and how they are implemented in the overall analysis is covered in the Economics Appendix, please refer to it for further clarification as necessary.

7.2 NEWBURGH LOCKS AND DAM LARGE SCALE CAPACITY IMPROVEMENTS

7.2.1 Background on Existing Project - Newburgh

Newburgh Locks and Dam are located at Ohio River mile 776.1 approximately 16 miles upstream of Evansville, Indiana. The project is on the lower Ohio River between the Cannelton and John T. Myers projects. Refer to Figure ED 4-1 for a plan and profile view of the Ohio River. Construction on the Newburgh project occurred between 1966 and 1975. It is a high lift project with twin lock chambers and a gated dam with a short fixed weir. Newburgh has a lift of 16 feet at normal pool levels, which makes it the lowest lift of all the modern Ohio River lock and dam projects. There is a riverside 1200' x 110' main chamber and a landside 600' x 110' auxiliary chamber, typical for most Ohio River projects. A recent aerial photograph of the project is shown in Figure ED 4-43. Newburgh is one of the higher traffic sites on the Ohio River system with approximately 65 million tons transiting through the project annually. In addition, approximately 1,800 recreational craft transit through the facility annually. This makes it the third busiest project on the Ohio River with a 600' auxiliary chamber in terms of annual tonnage (behind Greenup and J.T. Myers). It also makes it the busiest Ohio River project where a capacity improvement is not currently authorized for improvements. For a more detailed description of the existing project features, please refer to Section 4.18 of this Engineering Appendix.

7.2.2 Assessment of Problems and Needs - Newburgh

Currently, the main problem at Newburgh centers on the size of the existing auxiliary chamber relative to the traffic levels at the project. Tow traffic is typically configured to transit through the existing 1200' main chamber in order to maximize shipping efficiency. However, main chamber closures occur for periodic maintenance, inspections, testing, and accidents. When the main chamber is closed, the tows are required to lock through the shorter 600' auxiliary chamber. Since most tows are configured to be longer than 600 feet in length, the barges must be "broken apart" at the project and moved through the shorter auxiliary chamber. This typically requires the use of a helper boat to assist in this process. This is referred to "double-cutting" of tows. Double-cutting drastically increases transit time through the facility. During lengthy closures (over 10 days), a queue of tows builds at the site as processing through the auxiliary chamber slows the entire transit process down. In many instances, tows have to wait several days to lock through the project when the main chamber is closed for major

maintenance work. In contrast, it usually takes about an hour or so to process through the facility (including approach times) when both chambers are open. This problem will only worsen as the project continues to age and experiences more operating cycles on its major components. Therefore, it is evident that capacity improvements at the site are what should be investigated as part of the ORMSS With Project assessments.

7.2.3 Large Scale Improvement Alternatives Considered - Newburgh

Newburgh is almost an exact replica of the next project downstream, John T. Myers. They have the same basic elevations, clearances, and stationing relative to one another. They were both constructed in the same general time frame and are both high-traffic projects, although Newburgh slightly less than J.T. Myers. Therefore, the conceptual large scale improvements evaluated for the Newburgh project relied heavily upon alternatives that were investigated as part of the ORMSS Interim Report, which authorized the auxiliary lock chamber extension at John T. Myers. The J.T. Myers Locks Improvements Project was authorized as part of the Water Resources Development Act (WRDA) of 2000. Thus, the capacity improvement designs and cost estimates for the J.T. Myers project were developed to feasibility level for that project authorization. Since Newburgh is very similar to the J.T. Myers project, conceptual designs and estimates were pulled from the ORMSS Interim Report and site adapted for Newburgh for the purposes of the ORMSS SIP. In addition, recent hydraulic modeling done for the J.T. Myers Locks Improvements Project at ERDC-WES has indicated more cost effective ways to achieve the desired capacity improvements, while potentially lowering the cost of the overall project. These changes were based upon test results from three recently constructed physical hydraulic models: a 1:25 scale filling and emptying (F/E) model, 1:25 outlet diffuser model, and 1:100 navigation model.

The first model constructed was the 1:25 F/E system model that was originally started under the ORMSS project. This model was based upon the J.T. Myers project features. The purpose of the 1:25 F/E model was to investigate more cost effective ways to provide supplemental water for filling and emptying an extended lock chamber as compared to the wrap around culvert system. The design that provided the best balance of potential savings and good performance was a through-the-sill filling system utilizing new slender culverts on the lock floor of the existing auxiliary chamber and tying into the new culvert in the lower land wall. This is combined with a new downstream lateral field and a landside outlet diffuser that empties the lower half of the lock chamber. By utilizing the existing lock chamber floor, the through-the-sill system provides significant savings when compared to the wrap around culvert system. This system does not require removal and replacement of the existing boat mooring facility or the excavation and dewatering required for wrap around culvert. In addition, a deep excavation for an intake structure and an independent culvert valve monolith in the esplanade area are not required with the through-the-sill system. It is estimated that the through-the-sill F/E system will save in the range of 15 million dollars in construction costs when compared to the wrap around culvert system. The performance of the through-the-sill F/E system is also good in terms of filling and emptying times with acceptable hawser forces in the lock chamber. Based upon 1:25 model testing, the filling time is anticipated to be approximately 11-12 minutes for maximum pool differential, while emptying matches that of the existing 1200’ chamber at 8-9 minutes. The F/E model was fully tested with the exception of the outlet diffuser which is currently undergoing design refinements.

The second model constructed and tested was the 1:100 navigation model. This model was constructed to evaluate alternative approach wall configurations, as well as test access into and out of both chambers for each alternative. This model has been used to determine the preferred approach wall lengths for the project. This effort has been closely coordinated with the navigation industry and environmental resource agencies, as have the coordination on other models for the J.T. Myers Locks Improvements Project. In addition, the 1:100 model has provided valuable feedback that has led to proposed bank line changes close to the lock to improve tow access into and out of the extended lock chamber. The testing from the 1:100 model has allowed the Louisville District to reduce the overall length of approach walls by 800 feet saving approximately 7 million dollars versus the original authorized plan for J.T. Myers. These same type of savings are anticipated for the Newburgh site as well and thus, have been included as part of the base plan for Newburgh.

The final physical hydraulic model constructed and tested for J.T. Myers was the 1:25 outlet diffuser model. Due to previous arrangements, the original flume used for the ORMSS and J.T. Myers F/E model was turned over by the Louisville District to the Huntington District for their use in modeling the Greenup Lock Extension Project. The only thing that was not completely tested in the J.T. Myers 1:25 F/E model was the outlet diffuser configuration. Therefore, a 1:25 scale model of the outlet diffuser and lower approach was constructed and tested to determine the best configuration of these features. This model is still undergoing testing and the latest changes from the model will be incorporated into both the updated design and cost estimate as the ORMSS progresses. Model testing for the 1:25 outlet diffuser model should be completed prior to the Draft ORMSS Report due near the end of FY04.

All of the changes for the J.T. Myers Locks Improvements Project from recent model tests have been incorporated into the Newburgh base plan for the ORMSS SIP. Any changes that may be made as a result of on-going testing after the submission of this Preliminary Draft ORMSS Report will be incorporated into the Draft ORMSS Report the following year. Since various capacity improvement alternatives would be evaluated in follow-on studies, a broader range of plans are also being evaluated for Newburgh as part of the ORMSS SIP. This includes both a lower cost option and higher cost option when compared to the base plan. The differences between these plans and the base plans are also provided within this narrative. A summary of the full range of plans considered for the ORMSS SIP is provided below.

Base Plan - Same Basic Features as J.T. Myers Locks Improvements Project. This plan for capacity enhancements at Newburgh has all the same basic features that are currently included as part of the J.T. Myers Locks Improvements Project. This basically includes an extension of the existing auxiliary chamber to a nominal 1200' length, new lower land and lower middle approach walls, extensions of the upper river and middle approach walls, supplemental filling and emptying system to provide water to the new lower area of the extended lock chamber, new miter gates and storage pier, as well as aquatic mitigation features. Because Newburgh is so similar to J.T. Myers, this base plan for Newburgh also incorporates the most recent design changes to the J.T. Myers Locks Improvements Project as a result of physical hydraulic modeling at ERDC-WES. A plan view of the base plan capacity enhancement features for Newburgh is provided in Figure ED 7-1. The separate features of the base plan are broken down below into four main categories with new features shaded red in Figure ED 7-1.

1. Extension of the Auxiliary Chamber
    - New lower float-in land wall to form lock chamber extension
    - New lower float-in miter gate bay monolith
    - New miter gates for lower end of extended lock chamber
2. Supplemental Filling and Emptying System
    - New intake upstream of existing upper miter gate sill
    - New twin, triple box culverts on existing aux. chamber floor
    - New downstream lateral field for flow distribution
    - New filling and emptying culvert valves
    - New landward outlet diffuser
3. Approaches
    - New floating extension of existing upper riverward approach wall
    - New floating extension of existing upper middle approach wall
    - New lower middle approach wall
    - New lower landward approach wall
    - Modified upstream bank line for improved access for land chamber
4. Other
    - Aquatic mitigation features
    - Resident engineer office / operations support facility
    - Removal and rehabilitation of existing miter gates (spare set)
    - New on-site miter gate storage pier

The estimated cost for the base plan is approximately $140 million in October 2003 price levels compared to the J.T. Myers authorized cost of approximately $185 million. The principal savings in the Newburgh Base Plan are associated with shortened approach wall lengths, a new through-the-sill supplemental F/E system, and elimination of the construction of a new dry dock facility. A summary of major cost items and quantities is provided in Table ED 7-1. The same unit costs that were used for the authorization of the J.T. Myers Locks Improvements Project were used in the estimate for the Newburgh capacity improvement plans. However, the unit cost estimates were updated to reflect current pricing levels.

Lower Cost Capacity Improvements - Limited Version of Base Plan. The lower cost option for capacity improvement at Newburgh is intended to represent a reasonable lower bound with respect to improvement options and costs. It uses the base plan as a starting point and strips out select features and modifies others in order to still provide twin 1200-ft lock chambers but with fewer features than the base plan. The same type of construction procedures used for the base plan are also assumed for the lower cost option with the exception of the land wall extension which will use a lower cost method. The lower cost plan includes an extension of the existing auxiliary chamber to a nominal 1200' length, new lower land approach wall, extensions of the upper river and middle approach walls, and aquatic mitigation features.

The stripped out features from the base plan include no supplemental filling/emptying system, no miter gate storage pier, use of the existing lower auxiliary chamber miter gates for the newly extended lock chamber as opposed to new miter gates. No diffuser is necessary since there is no supplemental filling/emptying system. Also, since the lower middle approach wall is not required for navigation conditions at J.T.

Myers based upon hydraulic modeling and is used strictly for protection of the miter gates, it is also eliminated as part of the lower cost option at Newburgh. Finally, minimal lengths of approach wall extension on the upper end are assumed. The minimal length assumed is based upon a navigation rule-of-thumb of 600 feet clear between the end of the upper land guide wall and end of the upper middle wall extension. This same relationship is assumed between the upper middle wall approach wall extension and upper river guard wall extension. The lower land wall will be shortened by 100 feet since that was adequate from a modeling standpoint for J.T. Myers. The additional lengths were added for J.T. Myers due to specific outdraft issues at that project. Bank line improvements are assumed not to be required as part of the lower cost option since this was site specific to J.T. Myers and have also been eliminated from the design and cost estimate for the lower cost option at Newburgh. Costs are further reduced for design and construction management since many features will utilize the same as those designed for J.T. Myers. Construction management costs are lowered because there is less construction required with the low cost option.

Newburgh Auxiliary Lock Extension
Base Plan Cost Estimate

Applicable Changes from J.T. Myers Estimate

Major Feature	J.T. Myers Lock Extension Authorized Feature Cost	Newburgh Lock Extension Updated Feature Cost	Change	Reason for Change
Lands and Damages	$50,000	$50,000	$0	No change from authorized project
Mobilization and Demobilization	$3,655,000	$3,655,000	$0	No change from authorized project
Care and Diversion of Water	$537,000	$537,000	$0	No change from authorized project
Permanent Access Roads & Parking	$975,000	$36,000	$939,000	Changes to new F/E system do not require esplanade changes or revised parking areas
Buildings, Project Operations	$174,000	$1,000,000	-$826,000	New RE Office & truck maintenance building added to project
Earthwork and Foundations for Structures	$10,647,000	$10,647,000	$0	No change from authorized project
Lock Gates and Machinery	$4,922,000	$6,922,000	-$2,000,000	Miter gate storage pier added to project
Approach Walls Including Piers	$38,964,000	$31,689,000	$7,275,000	Walls shortened based upon 1:100 physical hydraulic modeling @ ERDC-WES
Lock Structure	$33,173,000	$30,802,000	$2,371,000	Existing monolith anchoring not required at Newburgh Project
Supplemental F/E System	$28,113,000	$12,500,000	$15,613,000	New through-the-sill supplemental F/E system eliminates need for costly wrap around and dewatering system
Piping System	$687,000	$687,000	$0	No change from authorized project
Power and Lighting System	$2,231,000	$2,231,000	$0	No change from authorized project
Dry Dock for Off Site Construction	$4,602,000	$500,000	$4,102,000	Assumes government owned dry dock facility available by time Newburgh. Minimal costs to facility site as necessary.
Construction Moorage & Service Roads	$2,229,000	$2,229,000	$0	No change from authorized project
Fish and Wildlife Facilities	$4,600,000	$4,600,000	$0	No change from authorized project
Relocate Existing Boat Mooring Area	$3,752,000	$0	$3,752,000	New through-the-sill supplemental F/E system eliminates need to relocate boat mooring facility
Downstream Approach Excavation	$3,677,000	$735,000	$2,942,000	1:100 hydraulic modeling at WES showed very limited need for lower approach excavation
Other Miscellaneous Sitework	$733,000	$733,000	$0	No change from authorized project
PED and Construction Management	$29,453,000	$21,658,628	$7,794,372	Many design, modeling and other savings will be reaped by utilizing same design as J.T. Myers for major project features
EM 1304 Cost Index (Oct 1999 to Oct 2003)	1.0674	1.0674	1.0674	
PROJECT TOTALS	$184,845,928	$140,055,292	$44,790,636	

Table ED 7-1. Newburgh Base Plan Cost Table vs. Authorized Plan

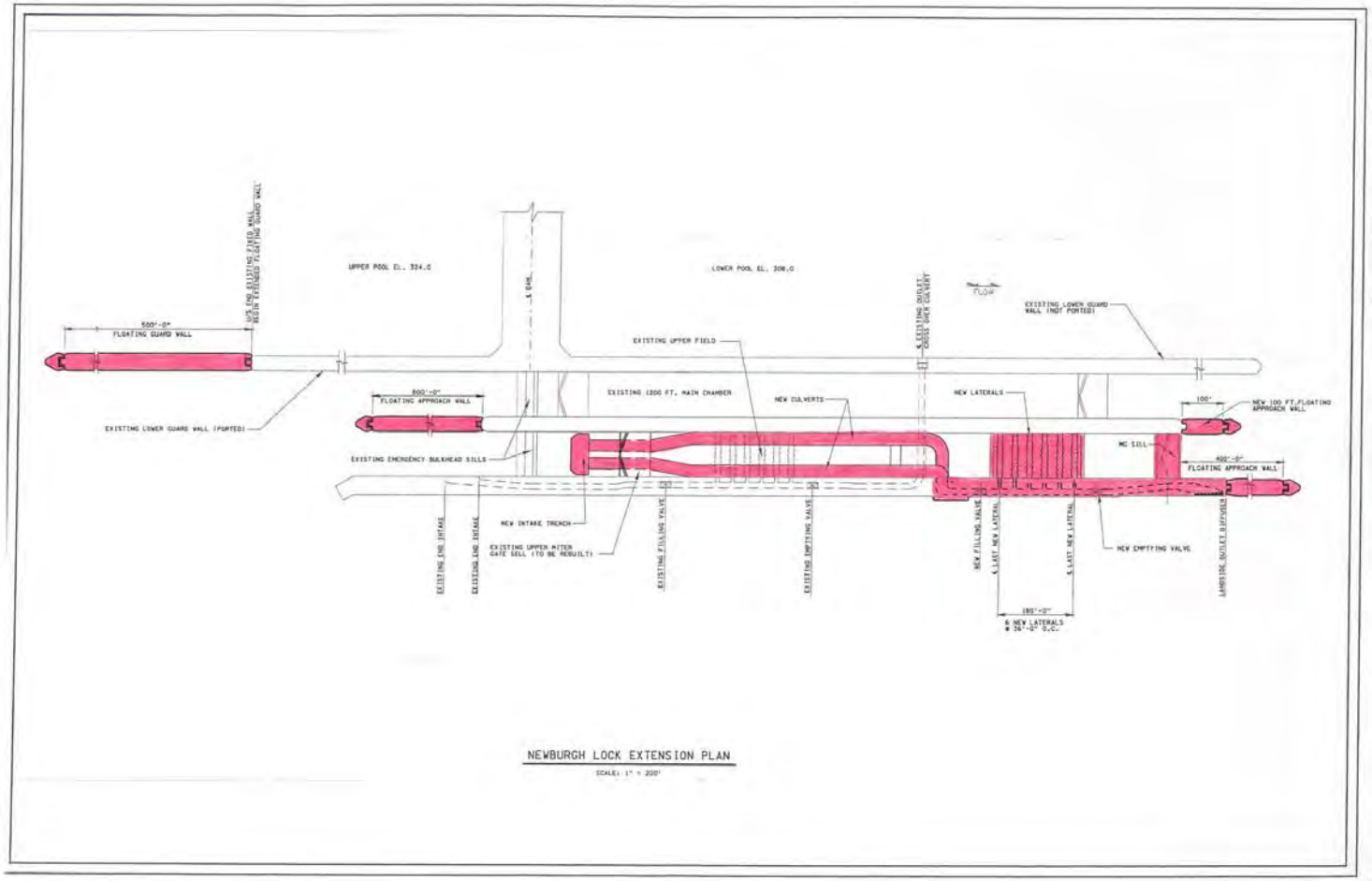

Figure ED 7-1. Newburgh Lock Extension Plan View – Base Plan

The service level associated with the lower cost option will be somewhat reduced from that provided in the base plan. For example, filling time for the lower cost extended lock chamber will be approximately 20-25 minutes compared to 11-12 minutes in the base plan with the supplemental filling/emptying system. Emptying time will also be approximately 20 minutes compared to 8 minutes with the supplemental system. This information is based upon testing of the extended chamber at J.T. Myers with only the existing 600-ft chamber features. In addition, there is another drawback associated with using only the existing 600-ft lock chamber features to fill and empty the extended chamber besides just a slower fill and empty times. The maintenance or failure of the existing valves will require a complete chamber shutdown, whereas, the base plan includes four sets of valves that can be isolated for repairs such that slower chamber operation can continue in the event of valve maintenance or failure.

The conceptual cost estimate for the lower cost alternative is approximately $105 million with basic details shown in Table ED 7-2, which compares it to the low cost alternative. The majority of the savings compared to the base plan come from the elimination of the supplemental filling system, utilization of the existing miter gates on the lower end of the extended chamber, eliminating the on-site miter gate storage pier, and reducing the approach wall lengths.

Newburgh Auxiliary Lock Extension
Low Cost Option

Applicable Changes from Newburgh Base Plan

	BASE PLAN	*LOW COST PLAN*		
Major Feature	**Newburgh Lock Extension Updated Feature Cost**	**Newburgh Lock Extension Updated Feature Cost**	**Change**	**Reason for Change from BASE Plan**
Lands and Damages	$50,000	$50,000	$0	No change from BASE plan
Mobilization and Demobilization	$3,655,000	$3,655,000	$0	No change from BASE plan
Care and Diversion of Water	$537,000	$537,000	$0	No change from BASE plan
Permanent Access Roads & Parking	$36,000	$36,000	$0	No change from BASE plan
Buildings, Project Operations	$1,000,000	$1,000,000	$0	No change from BASE plan
Earthwork and Foundations for Structures	$10,647,000	$10,647,000	$0	No change from BASE plan
Lock Gates and Machinery	$6,922,000	$1,417,000	$5,505,000	Use existing lower auxiliary gates, no pier
Approach Walls Including Piers	$31,689,000	$22,235,000	$9,454,000	Wall lengths reduced by additional 600 feet. Eliminate another pier and pylon for LMW.
Lock Structure	$30,802,000	$30,802,000	$0	No change from BASE plan
Supplemental F/E System	$12,500,000	$0	$12,500,000	No supplemental F/E system provided for low cost option. Slower fill and empty time.
Piping System	$687,000	$687,000	$0	No change from BASE plan
Power and Lighting System	$2,231,000	$2,231,000	$0	No change from BASE plan
Dry Dock for Off Site Construction	$500,000	$500,000	$0	No change from BASE plan
Construction Moorage & Service Roads	$2,229,000	$2,229,000	$0	No change from BASE plan
Fish and Wildlife Facilities	$4,600,000	$4,600,000	$0	No change from BASE plan
Relocate Existing Boat Mooring Area	$0	$0	$0	No change from BASE plan
Downstream Approach Excavation	$735,000	$735,000	$0	No change from BASE plan
Other Miscellaneous Sitework	$733,000	$733,000	$0	No change from BASE plan
PED and Construction Management	$21,658,628	$16,229,984	$5,428,644	Less features to design than BASE plan, thus, less costly engineering and construction management costs anticipated
EM 1304 Cost Indext (Oct 1999 to Oct 2003)	1.0674	1.0674	1.0674	
PROJECT TOTALS	**$140,055,292**	**$104,951,020**	**$35,104,272**	

Table ED 7-2. Newburgh Low Cost Alternative Estimate vs. Base Plan

Higher Cost Option for Capacity Improvements - Based Upon Authorized Project Features at J.T. Myers. For the purposes of the ORMSS SIP, the authorized cost of approximately $184 million (October 2003 price levels) will be used as the high cost alternative. An overall description of the major project features is provided in Section 4.19.4 of this Engineering Appendix. A plan view of the project features associated with the authorized project is shown in Figure ED 4-47.

7.3 MELDAHL LOCKS AND DAM LARGE SCALE CAPACITY IMPROVEMENTS

7.3.1 Background on Existing Project - Meldahl

Meldahl Locks and Dam are located at Ohio River mile 436.2 approximately 1.7 miles downstream of Chilo, Ohio. The navigation locks are located on the North bank, or the Ohio side. The pool extends from the dam upstream for a distance of 95.2 miles to Greenup Dam, located at river mile 341.0. Refer to Figure ED 4-1 for a plan and profile view of the Ohio River. Construction on the Meldahl project occurred between 1959 and 1965. It is a high lift project with twin lock chambers and a gated dam with a short fixed weir. Meldahl has a lift of 30 feet at normal pool levels. There is a riverside 1200' x 110' main chamber and a landside 600' x 110' auxiliary chamber, typical for most Ohio River projects. A recent aerial photograph of the project is shown in Figure ED 4-32. Meldahl is one of the higher traffic sites on the Ohio River system. For a more detailed description of the existing project features, please refer to Section 4.14 of this appendix.

7.3.2 Assessment of Problems and Needs - Meldahl

Currently, the main problem at Meldahl centers on the size of the existing auxiliary chamber relative to the traffic levels at the project coupled with the future reliability of major lock components associated with the main lock chamber. Tow traffic is typically configured to transit through the existing 1200' main chamber in order to maximize shipping efficiency. However, main chamber closures occur for periodic maintenance, inspections, testing, and accidents. This situation is similar to the issue as described in Section 7.1, which covers that same issue for problems and needs at Newburgh. Please refer to that section for a complete description.

7.3.3 Large Scale Improvement Alternatives Considered - Meldahl

Meldahl is similar to several auxiliary lock chamber extension projects being evaluated along the Ohio River as part of this ORMSS SIP study. These nominal 600-foot extension projects all have the same basic features that include extending the land wall on the lower end, providing additional approach wall lengths, and evaluating supplemental F/E systems for the auxiliary lock being extended. Therefore, the conceptual large scale improvements evaluated for the Meldahl project relied heavily upon alternatives that were investigated as part of the ORMSS Interim Report, which authorized the auxiliary lock chamber extensions at John T. Myers and Greenup. As noted earlier, the J.T. Myers and Greenup Locks Improvements Projects were authorized as part of the WRDA of 2000. Thus, the capacity improvement designs and cost estimates for the J.T. Myers and the Greenup projects were developed to feasibility level for these project authorizations. Since Meldahl is very similar to the J.T. Myers and the Greenup projects, conceptual designs and estimates were pulled from the ORMSS Interim Report and site adapted for Meldahl for the purposes of the ORMSS SIP. In addition, recent hydraulic modeling done for the J.T. Myers and Greenup Locks Improvements Project at ERDC-WES has indicated more cost effective ways to provide many of these same features at a lower cost. Many of these features are also applicable for lock extension option at Meldahl and have been included where feasible.

The first models constructed were the two 1:25 F/E system models that were originally started under the ORMSS project. These models were based upon the features of the J.T. Myers and Greenup projects. The purpose of the 1:25 F/E models was to investigate more cost effective ways to provide supplemental water for filling and emptying an extended lock chamber as compared to the wrap around culvert system. As noted earlier in the Newburgh narrative, the design that provided the best balance of potential savings and good performance was a through-the-sill filling system utilizing new slender culverts on the lock floor of the existing auxiliary chamber and tying into the new culvert in the lower land wall. This is combined with a new downstream lateral field and a landside outlet diffuser that empties the lower half of the lock chamber. By utilizing the existing lock chamber floor, the through-the-sill system provides significant savings when compared to the wrap around culvert system. However, due to unique project conditions at the Greenup and Meldahl locks and dam, the through-the-sill filling and emptying system was determined to be not feasible due to clearance issues. For this reason, Meldahl currently intends use a wrap around culvert system for the supplemental F/E system. The testing of the wrap around culvert model for Greenup is started and scheduled to be completed in FY 04. Although this is more expensive, it is still an acceptable method for filling and emptying. The performance of the wrap around culvert F/E system is good in terms of filling and emptying times with acceptable hawser forces in the lock chamber. Based upon numerical modeling, the filling time is anticipated to be approximately 9 minutes for maximum pool differential, while emptying matches that of the existing 1200' chamber at 9 minutes. The F/E model was fully tested with the exception of the outlet diffuser which will use information gathered from the 1:25 J.T. Myers models for design considerations.

The second type of model constructed and tested were the 1:100 navigation models. One was built for the J.T. Myers Project and one was built for the Greenup Project. These models were constructed to evaluate alternative approach wall configurations, as well as to test access into and out of both chambers for each alternative. The models have been used to determine the preferred approach wall lengths for the project. This effort has been closely coordinated with the navigation industry and environmental resource agencies, as have the coordination on other models for the 600 foot lock extension improvement projects. In addition, the 1:100 models have provided valuable feedback that has led to proposed bank line changes close to the lock to improve tow access into and out of the extended lock chamber.

The final physical hydraulic model was constructed and tested for J.T. Myers. This was the 1:25 outlet diffuser model. Due to previous arrangements, the original flume used for the ORMSS and J.T. Myers F/E model was turned over by the Louisville District to the Huntington District for their use in modeling the Greenup Lock Extension Project. The only thing that was not completely tested in the J.T. Myers 1:25 F/E model was the outlet diffuser configuration. Therefore, a 1:25 scale model of the outlet diffuser and lower approach was constructed and tested to determine the best configuration of these features. This model is still undergoing testing and the latest changes from the model will be incorporated into both the updated design and cost estimate.

Some of these changes for the 600 foot lock extension improvement projects from recent model tests have been incorporated into the Meldahl base plan for the ORMSS SIP. Since various capacity improvement alternatives would be evaluated in follow-on studies, a broader range of plans are also being evaluated for Meldahl as part of the ORMSS SIP. This includes both a lower cost option and higher cost option when

compared to the base plan. The differences between these plans and the base plans are also provided within this narrative. A summary of the full range of plans considered for the ORMSS SIP is provided below.

Base Plan - Same Basic Features as Greenup Locks Improvements Project. This plan for capacity enhancements at Meldahl has all the same basic features that are currently included as part of the authorized Greenup Lock Extension Project. This basically includes an extension of the existing auxiliary chamber to a nominal 1200' length, new lower land walls, extensions of the upper river and middle approach walls, supplemental filling and emptying system to provide water to the new lower area of the extended lock chamber, new miter gates and storage pier, as well as aquatic mitigation features. Because Meldahl is so similar to J.T. Myers and Greenup, this base plan for Meldahl also incorporates applicable recent design changes to the 600 foot lock extension improvement projects as a result of physical hydraulic modeling at ERDC-WES. The separate features of the base plan are broken down below into four main categories.

1. Extension of the Auxiliary Chamber
   - New lower lift-in land wall to form lock chamber extension
   - New lower float-in miter gate bay monolith
   - New miter gates for lower end of extended lock chamber
2. Supplemental Filling and Emptying System
   - Wrap around filling system
   - New downstream lateral field for flow distribution
   - New filling and emptying culvert valves
   - New outlet diffuser
3. Approaches
   - New floating extension of existing upper riverward approach wall
   - New floating extension of existing upper middle approach wall
   - New lower landward approach wall
4. Other
   - Aquatic mitigation features
   - Resident engineer office / operations support facility
   - New on-site miter gate storage pier

The estimated cost for the base plan is approximately $162 million dollars compared to the authorized cost of approximately $187 million. The major portion of the $25 million dollar savings associated with the Base Plan at Meldahl is for the shortening of approach wall length extensions to match those determined to be adequate out of the 1:100 J.T. Myers hydraulic model. A summary of major cost items and quantities is provided in Table ED 7-3. The same unit costs that were used for the authorization of the Greenup Improvements Project were used in the estimate for the Meldahl capacity improvement plans. Quantities were updated where applicable. The overall cost was inflated to match current pricing levels by using USACE Engineering Manual 1110-2-1304, which accounts for inflation factors for civil works construction within USACE.

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Meldahl Auxiliary Lock Extension
Base Plan Cost Estimate

Applicable Changes from Greenup Locks Improvements Project

Major Feature	Greenup Lock Extension Project Authorized Feature Cost	Meldahl Lock Extension Updated Feature Cost	Change	Reason for Change
Relocations	$600,000	$600,000	$0	No change from authorized project
Mobilization and Demobilization	$1,032,000	$1,032,000	$0	No change from authorized project
Drainage and Care/Diversion of Water	$767,400	$767,400	$0	No change from authorized project
Permanent/Temporary Roads and Access	$222,800	$222,800	$0	No change from authorized project
Resident Engineer's Office	$463,100	$463,100	$0	No change from authorized project
Utilities, Lines, and Services	$950,600	$950,600	$0	No change from authorized project
Earthwork and Foundations for Structures	$284,700	$284,700	$0	No change from authorized project
Lock Gates, Assembly Pier, and Machinery	$6,956,600	$6,956,600	$0	No change from authorized project
Approach Walls Including Piers	$50,568,700	$34,871,700	$15,697,000	Pontoon walls shortened to lengths from 1:100 navigation model at J.T. Myers
Lock Structure	$30,418,600	$30,418,600	$0	No change from authorized project
Supplemental F/E System	$22,393,700	$22,393,700	$0	No change from authorized project
Lock Wall Demolition	$3,498,200	$3,498,200	$0	No change from authorized project
Piping System	$402,100	$402,100	$0	No change from authorized project
Power and Lighting System	$3,860,000	$3,860,000	$0	No change from authorized project
Associated General Items (Dry Dock Facility, Lock Equipment, Vehicles, Demo Projects, Etc…)	$16,911,400	$12,744,300	$4,167,100	Assume existing casting facility available with minimal (500k) retrofit needed. Also, eliminate one demonstration project on construction methods.
Fish and Wildlife Facilities	$5,634,900	$5,634,900	$0	No change from authorized project
Water Lines	$20,000	$20,000	$0	No change from authorized project
Fencing	$83,500	$83,500	$0	No change from authorized project
Parking Lots	$545,000	$545,000	$0	No change from authorized project
Picnic Shelter and Day Use Area	$133,000	$133,000	$0	No change from authorized project
PED and Construction Management	$29,843,550	$25,753,436	$4,090,114	Many design, modeling and other savings will be reaped by utilizing same design as Greenup and J.T. Myers for major project features
EM 1304 Cost Index (Oct 1999 to Oct 2003)	1.0674	1.0674	1.0674	
PROJECT TOTALS	$187,424,606	$161,855,878	$25,568,728	

Table ED 7-3. Meldahl Base Plan Cost Estimate vs. Authorized Greenup Estimate

Lower Cost Capacity Improvements - Limited Version of Base Plan. The lower cost option for capacity improvement at Meldahl is intended to represent a reasonable lower bound with respect to improvement options and costs. It uses the base plan as a starting point and strips out select features in order to still provide twin 1200-ft lock chambers but with fewer features than the base plan. The same type of construction procedures used for the Base Plan are also used in the lower cost option. The lower cost option includes an extension of the existing auxiliary chamber to a nominal 1200' length, new lower land approach wall, extensions of the upper river and middle approach walls, plus aquatic mitigation features.

The primary stripped out feature in the Low Cost Plan from the Base Plan is the removal of the supplemental F/E system. The condition of the existing main chamber miter gates warrants new miter gates and the inclusion of a storage/construction pier. In addition, minimal lengths of approach wall extension on the upper end are assumed.

The service level associated with the lower cost option will be somewhat reduced from that provided in the base plan. For example, filling time for the lower cost extended lock chamber will be approximately 20 minutes compared to 9 minutes in the base plan. This information is based upon computer modeling for Meldahl with only the existing 600-ft chamber features. Emptying time should also be near 20 minutes compared to 9 minutes for an existing 1200-ft main chamber. Additionally, maintenance or failure of the existing valves will require a complete chamber shutdown, whereas, the base plan includes four sets of valves such that slower chamber operation can continue in the event of valve maintenance or failure.

The lower cost option is estimated to be approximately $133 million. This cost is essentially determined by taking the supplemental F/E system out of the Base Plan cost estimate.

Higher Cost Option for Capacity Improvements - Based Upon Authorized Project Features at Greenup. For the purposes of the ORMSS SIP, the authorized cost of approximately $187 million (October 2003 price levels) will be used as the high cost alternative. An overall description of the major project features has been noted previously throughout this appendix.

7.4 EMSWORTH LOCKS AND DAM LARGE SCALE CAPACITY IMPROVEMENTS

7.4.1 Background on Existing Project - Emsworth

Emsworth Locks and Dam are located at Ohio River mile 6.2 approximately six miles downstream of Pittsburgh, Pennsylvania. The project is the first Lock and Dam on the Ohio River. Refer to Figure ED 4-1 for a plan and profile view of the Ohio River. Construction on the original Emsworth project occurred between 1919 and 1922, followed by a reconstruction of the fixed-crest dams on the main channel and back channels of the Ohio River, to transform them into gated structures in 1937. It is a low lift project with twin lock chambers and gated dams on both the main channel and back channel, with a short fixed weir on the main channel. Emsworth has a lift of 18 feet at normal pool levels. There is a riverside 600' x 110' main chamber and a landside 360' x 56' auxiliary chamber, quite atypical for most Ohio River projects, which have a 1200' x 110' main chamber with a 600' x 110' auxiliary chamber. A recent aerial photograph of the project is shown in Figure ED 4-3. Emsworth Locks and Dams project is the oldest facility on the entire Ohio River, although many parts were upgraded as part of a major rehabilitation program on the upper three Ohio River projects (Emsworth, Dashields, and Montgomery) during the mid-to-late 1980's. Significant problems remain with existing features (mass concrete, etc…) that were unable to be upgraded during the major rehabilitation. In addition, closures of the main chamber forces traffic to divert to the small 56' x 300' auxiliary, which result in significant delay cost to the navigation industry. For a more detailed description of the existing project features, please refer to Section 4.3 of this appendix.

7.4.2 Assessment of Problems and Needs - Emsworth

The Emsworth project plays a major role in the economy of the Pittsburgh region, since the Emsworth dams create and control the pool which flows adjacent to the city of Pittsburgh and its adjoining communities. One major issue associated with the project is the structural deficiencies of the dam associated with both the machinery and vertical lift gates that limits its capacity to control pool elevations under extreme flow conditions. The project is situated in a highly industrialized area with many of the industrial plants relying heavily on water transportation for the receiving of raw materials and the shipping of finished products. Should the lift gates of the dam and/or lifting machinery fail, the resulting loss of pool would be catastrophic with the above mentioned industrial complex's dependence on water transportation. In addition, power plants and industrial and municipal water intakes which rely on water transportation and relatively stable pools would be adversely affected. Two of the 14 dam gates have become inoperable due to reported deficiencies. One of these gates and machinery (gate bay No. 6) was replaced in

2002. A major rehabilitation report for the dam at Emsworth was approved at HQUSACE in 2002, however, funds have not yet been procured to upgrade the dam at Emsworth.

The other primary issue associated with the condition of the Emsworth project is the condition of the mass concrete at the locks. The concrete is already in a poor condition. The main cause of concrete deterioration for the locks and dams is from weathering due to freeze-thaw activity. Due to the fact that the locks and dams were constructed prior to the advent of air-entrained concrete, the mass structure has been particularly susceptible to weathering and freeze-thaw damage. Prior to the major rehabilitation effort in the mid-1980s, horizontal and vertical surfaces of the lock walls were in advanced stages of deterioration. At Emsworth, the vertical and horizontal extent of concrete deterioration measured from the top and chamber face of the lock walls was up to 4.5 and 1.5 feet, respectively. The major rehabilitation projects detailed varying levels of horizontal and vertical wall repairs. As stated previously, these repairs were performed in order to extend the useful life of the projects for another 25 years. These horizontal concrete overlays and vertical refacing of the lock chamber walls are considered cosmetic in nature and do not address the underlying problems associated with the deteriorated state of the existing mass concrete. A more detailed description of the concerns and needs associated with the Emsworth project, including a broad overview of the major rehabilitation that was done during the 1980s, is provided in Section 4.3 of this appendix.

7.4.3 Large Scale Improvement Alternatives Considered - Emsworth

There are four basic With Project plans that are being evaluated as part of project improvements at Emsworth Locks and Dam. All of these With Project plans at Emsworth call for a minimum of one new lock chamber to replace the existing, small auxiliary lock chamber. An auxiliary chamber lock extension at Emsworth, such as those evaluated at Newburgh and Meldahl, is not a practical alternative due to the fact that the existing auxiliary lock chamber is only 56-ft wide. In addition, the mass concrete of the auxiliary lock chamber is in a deteriorated condition and its long-term reliability will be poor without proactive measures. Therefore, an array of new riverward locks are being evaluated to determine their economic merit when compared to the optimized Without Project Condition. Lengths of this proposed new riverward chamber vary. Both 1200-ft long and 600-ft long riverward chambers are being evaluated to determine their economic merit.

For each of these With Project plans, it is anticipated that innovative in-the-wet construction techniques will be utilized in order to reduce construction costs and limit navigation traffic disruptions. Similar construction techniques as utilized in the J.T. Myers Locks Improvements Project are envisioned for constructing the new larger river chamber. The construction methodology will be considered in detail during any follow-on studies. Conceptual design work done during ORMSS indicates that float-in technology is appealing in terms of reduced construction costs and limited navigation interference. Initial stage lock construction would likely entail the off-site fabrication/casting of base rafts for major concrete construction. The prefabricated monoliths would then be transported to the site, likely by floating the monolith base rafts to the vicinity for continued work on them prior to set down. Once operational, the new riverward chamber would handle the majority of all commercial traffic. Depending upon

the plan being evaluated, the existing main chamber would either be delegated as the auxiliary chamber (Base Plan and Low Cost Plan) or replaced with a new lock chamber (High Cost Plans). In addition, follow-on studies could recommend some type of rehabilitation of the existing main chamber if that remains as the auxiliary chamber.

The proposed new river wall for the new main chamber would be constructed immediately adjacent to Pier No. 2. This riverward movement of the new main chamber is necessary since the proposed twin locks would now be two 110' chambers, whereas the existing locks measure only 110' and 56'. Removal of the short fixed crest weir, adjacent to the river wall provided insufficient lateral space for new chamber construction. Hence, removal of Gate Bay No. 1 becomes necessary. The proposed new middle wall, for the new riverward chamber, would be positioned within the existing 56' auxiliary chamber. This alignment is dictated by geometric requirements (new 110' chamber replacing a 56' chamber, and proposed widths of new river and middle walls. The Emsworth main channel dam will be affected, adversely, by this lock construction. One gate bay (No. 1) is slated for removal to provide lateral space requirements (an active railroad exists along the landward side of the esplanade). Few options exist to gain sufficient space for the new lock widths. Relocation of the railroad, landward, is difficult and costly, due to the hilly terrain and real estate concerns. Riverward movement of the twin locks would be constructible; however, the dam would now be constrained to pass the flows, with only seven gate bays in lieu of eight. Investigations have revealed that options exist for replenishing lost hydraulic capacity of the dam gates. The dam sills could be lowered; however, a significant lowering of several feet would be required. A new gate bay could be constructed on the Neville Island end of the dam. This would have been a viable option prior to commercial development on Neville Island. Now, a modern RPS (commercial freight shipping company) has been constructed immediately landward of the bulkhead storage pit, at the far end of the dam. Another option, prior to RPS construction, was to reroute a portion of the river flow, around the far end of the dam, essentially building a large tunnel, capable of passing flow commensurate with a gate bay. Construction of a floodway was also investigated. The floodway could be installed on the proposed new chamber, to pass the higher (flood) flows, when the miter gates would be inoperable anyway, and locked in place in the recesses. Based on preliminary, concept level cost estimates, construction of the lock chamber floodway appears to be the least cost and has been incorporated into all With Project alternatives. All With Project plans at Emsworth essentially call for the same features and utilized the same construction techniques. The basic difference is the configuration of the new lock(s) in terms of how many and their length. A basic description of each plan is provided below and summarized in Table ED 7-4.

The Base Plan calls for a new riverward 110' x 1200' lock chamber to replace the existing 56-ft wide auxiliary lock chamber. The existing 110' x 600' main chamber would be delegated as the future auxiliary chamber under this plan. The approximate cost of the plan is $290 million.

The Low Cost Plan has a new 110' x 600' lock chamber to replace the existing 56-ft wide auxiliary chamber, while the existing 110' x 600' main chamber would be utilized as the future auxiliary chamber. The approximate cost of this plan is $250 million.

High Cost Plan 1 has twin 110' x 600' lock chambers. Like all other plans, these would be sequenced such that navigation traffic is allowed to pass during the majority of all construction activities. The added benefit of this plan is that the long-term viability of

a reliable auxiliary chamber is not in question since the deteriorated existing main chamber is replaced. The conceptual cost of this alternative is estimated at $370 million.

High Cost Plan 2 has a new 110' x 1200' riverward main chamber and the existing, deteriorated main chamber is replaced with a new 110' x 600 auxiliary lock chamber. Again with this option, the long-term reliability of the "auxiliary" chamber is not a concern with two new lock chambers. This plans is estimated at $400 million.

Alternative	Emsworth With Project Alternatives		Total Cost
Number	**River Chamber**	**Land Chamber**	**Rounded**
Low Cost	**New Lock 600' x 110'**	**Existing Land Chamber Becomes Future Auxiliary Chamber**	**$250,000,000**
Base Plan	**New Lock 1200' x 110'**	**Existing Land Chamber Becomes Future Auxiliary Chamber**	**$290,000,000**
High Cost 1	**New Lock 600' x 110'**	**New Lock 600' x 110'**	**$370,000,000**
High Cost 2	**New Lock 1200' x 110'**	**New Lock 600' x 110'**	**$400,000,000**

Table ED 7-5. Emsworth Locks and Dam
(Preliminary Costs of "3 for 3" With Project Plan Alternatives)

7.5 DASHIELDS LOCKS AND DAM LARGE SCALE CAPACITY IMPROVEMENTS

7.5.1 Background on Existing Project - Dashields

Dashields Locks and Dam are located approximately 13.3 miles downstream of Pittsburgh, Pennsylvania, and 7.1 miles downstream of Emsworth Locks and Dams. The project is the second lock and dam on the Ohio River. Refer to Figure ED 4-1 for a plan and profile view of the Ohio River. Construction on the original Dashields project occurred between 1927 and 1929. It is a low lift project with twin lock chambers and a fixed-crest dam. Dashields is the only lock and dam project on the entire 981 miles of the Ohio River constructed and operating with a fixed crest dam across the entire width of river (no gates). Dashields has a lift of 10 feet at normal pool levels. There is a riverside 600' x 110' main chamber and a landside 360' x 56' auxiliary chamber, similar to the lock configuration found at Emsworth. A recent aerial photograph of the project is shown in Figure ED 4-6. The Dashields Locks and Dams project is one of the oldest facilities on the Ohio River. As such, Dashields has numerous condition-related problems that need to be addressed. For a more detailed description of the existing project features, please refer to Section 4.4 of this appendix.

7.5.2 Assessment of Problems and Needs - Dashields

Unstable guide walls coupled with heavily cracked lockwall concrete contribute to serious condition concerns at Dashields. Analysis of upper and lower guide wall stability has confirmed that the walls are unstable. Survey monitoring has revealed movement in both walls. Failure of the guide wall monoliths has the potential to block the approaches to the land chamber and disrupt river traffic. An unscheduled outage of the main chamber would force all traffic, including doubles, to lock thru the auxiliary

chamber, resulting in significant delays, even with the use of helper boats. Concrete cracking is extremely prevalent throughout the monoliths on the land, middle and river walls, and can be easily seen throughout the pipe galleries. Evidence of cracking in the approach walls is shown in Figures ED 4-8 through 4-11 for photographs of concrete deterioration at Dashields.

The main causes of concrete deterioration for the locks and dam at Dashields are the same as those found at Emsworth, which is weathering and freeze-thaw action on non air entrained concrete. Prior to the major rehabilitation projects on the upper three Ohio River projects in the mid-1980s, the concrete at Dashields was by far in the worse condition both from a deterioration standpoint when compared to Emsworth and Montgomery. Dashields utilizes integral filling and emptying culverts and pipe galleries in all three lock walls. These features result in thin-walled sections with numerous reentrant corners, susceptible to stress concentration areas and increased concrete deterioration. These details coupled with the lack of concrete reinforcing, which would be provided in modern structures, encourage conditions susceptible to cracking. Progressive riverward movement of the upper and lower guide walls continue to be monitored. A recent stability report recommended anchoring to retard the riverward movement.

The lock structure continues to be plagued by interior cracking, located at numerous random positions along the monoliths, but prevalent throughout the filling and emptying valve recesses, bulkhead recesses and miter gate machinery recesses. Several structural repairs were performed during the major rehabilitation project. Recently a structural crack has been identified at the downstream land wall culvert valve recess propagating through to the valve bulkhead recess. Due to the age of the underlying original concrete, typical for all three locks and dams, freeze-thaw cycles have caused cracking and deterioration along weather-susceptible surfaces, such as recesses which are covered with aluminum grating. For a more detailed description of the problems and needs at Dashields, please refer to Section 4.4.3 of this appendix.

7.5.3 Large Scale Improvement Alternatives Considered - Dashields

Referring to the With Project alternatives narrative for Emsworth, Section 7.4.3 of the appendix, the same basic alternatives are being evaluated at Dashields. These plans are summarized in Table ED 7-5 for Dashields. Conceptual costs are also provided for these plans within the table, where it is noticed that the project plans at Dashields are lower than those for Emsworth. Much of this difference can be attributed to the differences between the dam configurations between the two projects and associated changes to manage water flow. In addition, there are variations between projects in terms of material quantities, real estate costs, etc. However, the basic configuration of the lock sizes remains unchanged when compared to the alternatives at Emsworth.

Alternative	Dashields With Project Alternatives		Total Cost
Number	**River Chamber**	**Land Chamber**	**Rounded**
Low Cost	**New Lock 600' x 110'**	**Existing Land Chamber Becomes New Auxiliary Chamber**	**$210,000,000**
Base Plan	**New Lock 1200' x 110'**	**Existing Land Chamber Becomes New Auxiliary Chamber**	**$275,000,000**

High Cost 1	**New Lock 600' x 110'**	**New Lock 600' x 110'**	**$295,000,000**
High Cost 2	**New Lock 1200' x 110'**	**New Lock 600' x 110'**	**$355,000,000**

Table ED 7-5. Dashields Locks and Dam
Preliminary Costs of "3 for 3" Plan Alternatives

7.6 MONTGOMERY LOCKS AND DAM LARGE SCALE CAPACITY IMPROVEMENTS

7.6.1 Background on Existing Project - Montgomery

Montgomery Locks and Dam are located at Ohio River Mile 31.7 approximately 18.4 miles downstream of Dashields Locks and Dam. The project is the third lock and dam on the Ohio River. Refer to Figure ED 4-1 for a plan and profile view of the Ohio River. Construction on the original Montgomery project occurred between 1932 and 1936. It is a low lift project with twin lock chambers and a gated dam. The dam was constructed with 10 gated sections and a fixed weir adjacent to the river wall as well as adjacent to the abutment. Montgomery has a lift of 17.5 feet at normal pool levels. There is a riverside 600' x 110' main chamber and a landside 360' x 56' auxiliary chamber, quite atypical for most Ohio River projects, which have a 1200' x 110' main chamber with a 600' x 110' auxiliary chamber. A recent aerial photograph of the project is shown in Figure ED 4-12. Like Emsworth and Dashields, the Montgomery Locks and Dams project is one of the oldest facilities on the Ohio River, built in the early 20th century. As such, Montgomery has numerous condition-related problems that need attention particularly with a small auxiliary lock chamber. Closures of the main chamber forces traffic to divert to the small 56' x 300' auxiliary, which result in significant delays and lost time to the navigation industry. For a more detailed description of the existing project features, please refer to Section 4.5 of this appendix.

7.6.2 Assessment of Problems and Needs - Montgomery

Montgomery Locks and Dams is one of the oldest operating structures in the Pittsburgh District and has several concerns regarding its long-term operation. Heavily cracked lock wall concrete and dam gate hoist problems are among the most severe issues associated with the condition of the Montgomery Project. Concrete cracking is extremely prevalent throughout the monoliths on the land, middle and river walls, and is readily visible throughout the pipe galleries and within recesses (gate, valve, bulkhead, and ladder ways). The construction technique and materials used (non air entrained concrete) at Montgomery are similar in nature to those used at Emsworth and Dashields. Thus, it is experiencing many of the same problems that were described for those projects, particularly associated with the condition of the mass concrete structure. A few examples of the concrete deterioration is shown in Figures ED 4-14 and 4-15 of this appendix.

The gate hoists on the dam are a serious concern at Montgomery. The condition of the chains, and gate position indicators and two drive motors, one on each pier, creates

a serious situation. The dam gate hoist chains tend to kink and are showing other signs of wear and lack of internal lubrication. The gate position indicators are driven by the hoist machinery and do not directly read the position of the gate. If a hoist chain were to kink or foul, the position indicator would not yield an accurate reading. Maintaining a level gate position is critical to safe dam operation. If a dam gate were to become jammed, part of the hoist machinery could fail and drop or jam the gate. The use of two drive motors in lifting the gate can create a large force. Also, a more positive and reliable method of determining the gate position should be evaluated. Until the condition of the dam gate hoist machinery can be ascertained all mote operations of the dam gates should be discontinued.

The maintenance of the control systems is very difficult because many of the parts are obsolete. Also, some of the original manufacturers are no longer in business, and the parts are not in inventory. Some of the control units were unique designs that were specified by Corps design. In particular, the programmable units are very difficult – if not impossible – to maintain and repair.

For a more detailed description of the assessment of problems and needs for the current project, please refer to Section 4.5.3 of the appendix.

7.6.3 Large Scale Improvement Alternatives Considered - Montgomery

Referring to the With Project alternatives narrative for Emsworth and Dashields, Sections 7.4.3 and 7.5.3 of this appendix, respectively, the same basic alternatives are being evaluated at Montgomery. These plans are summarized in Table ED 7-6 for Montgomery. Site-specific adaptations were made for appropriate features, thus, the conceptual costs vary at Montgomery when compared to Emsworth and Dashields. However, the basic configuration of the lock sizes remains unchanged when compared to the alternatives at Emsworth and Dashields.

Alternative	Montgomery With Project Alternatives		Total Cost
Number	**River Chamber**	**Land Chamber**	**Rounded**
Low Cost	**New Lock 600' x 110'**	**Existing Land Chamber Becomes New Auxiliary Chamber**	**$240,000,000**
Base Plan	**New Lock 1200' x 110'**	**Existing Land Chamber Becomes New Auxiliary Chamber**	**$325,000,000**
High Cost 1	**New Lock 600' x 110'**	**New Lock 600' x 110'**	**$365,000,000**
High Cost 2	**New Lock 1200' x 110'**	**New Lock 600' x 110'**	**$440,000,000**

Table ED 7-6. Montgomery Locks and Dam Preliminary Costs of "3 for 3" Plan Alternatives

DEPARTMENT OF THE ARMY
U.S. ARMY ENGINEER DISTRICT, LOUISVILLE
CORPS OF ENGINEERS
P.O. BOX 59
LOUISVILLE, KENTUCKY 40201-0059

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Economics Appendix

July 2011

ORMSS SIP Economics Appendix
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List of Acronyms

ATC	Average Towing Cost
BEA	Bureau of Economic Analysis
BTU	British Thermal Unit
CAAA	Clean Air Act Amendments
COE	Corps of Engineers
CR	Component Replacement
DOE	Department of Energy
EDM	Emsworth, Dashields and Montgomery
EIA	Energy Information Administration
EQ	Equilibrium Model
ER	Engineering Regulation
HQ	Headquarters (Corps)
IWR	Institute for Water Resources
L/D	Lock(s) and Dam
LPMS	Lock Performance Monitoring System
LRD	Great Lakes and Ohio River Division
LRM	Lock Risk Module
MRS	Marginal Rate Savings
MTC	Marginal Towing Cost
NAAQS	National Ambient Air Quality Standards
NAVPAT	Navigation Predictive Analysis Technique
NED	National Economic Development
NER	National Ecosystem Restoration
ODC	Origin-Destination-Commodity
O&M	Operation and Maintenance
OM	Optimization Module
ORB	Ohio River Basin
ORMSS	Ohio River Mainstem Systems Study
ORNIM	Ohio River Navigation Investment Model
ORNL	Oak Ridge National Laboratory
ORS	Ohio River System
P&G	Principles and Guidelines
PMP	Project Management Plan
PRB	Powder River Basin
RM	Reactive Maintenance
SIP	System Investment Plan
TCM	Tow Cost Model
TVA	Tennessee Valley Authority
USACE	US Army Corps of Engineers
WAM	Waterway Analysis Model
WCSC	Waterborne Commerce Statistical Center
WOPC	Without-Project Condition
WPC	With-Project Condition
WSDM	Waterway Supply Demand Module

SECTION 1
INTRODUCTION

1.1 PURPOSE

This document supports the draft Main Report to the Ohio River Mainstem Systems Study (ORMSS) System Investment Plan (SIP). The study will develop the models and databases necessary to evaluate long-range operations, maintenance, and capacity needs; forecast future use and adequacy; and identify long-term maintenance, major rehabilitation and new construction needs for the Ohio River mainstem. It is a feasibility level study that will produce a System Investment Plan (SIP), which will include an array of operational, repair, rehabilitation, and replacement opportunities through 2070 given different traffic demand forecast scenarios.

This Economics Appendix supplements earlier investigations of navigation problems on the Ohio River that indicated a need for larger auxiliary locks at the Myers and Greenup projects. The findings of the Myers/Greenup Interim Report (2001) were to extend the existing auxiliary chambers while conserving fish and wildlife resources.

The purpose of this appendix is to explain the economic foundations and analytic procedures used to estimate the system impacts and the National Economic Development (NED) benefits of an array of navigation improvement investment opportunities identified in the SIP. This study will not recommend a course of action nor will it recommend projects for Congressional authorization. It is intended to recommend more detailed (project level) feasibility studies that could lead to specific authorizations.

The primary benefit for Federal investment in commercially navigable waterways is the collective transportation cost savings for water shipment over the least-costly alternative routing. Other objectives of navigation improvements include assisting in the development, safety and security of waterborne commerce; enhancing fish and wildlife; enhancing environmental quality; and enhancing social well-being. The importance to the nation of the inland waterways within the overall transportation network justifies continuing Federal responsibility for navigation improvements.

The study of future transportation challenges confronting the Ohio River provides an opportunity for public discourse on questions about where and when to increase system capacity, how to increase system reliability, and what roles existing operation strategies should play in the efficient and environmentally sustainable operation and maintenance of the Ohio River.

1.2 NEED FOR SYSTEMS ANALYSIS

Interdependence of traffic flows among the many individual elements of the system is a major problem in the economic evaluation of a lock-and-dam project. A change in the performance capabilities of one lock or channel segment can affect the efficiency of other components of the system. For example, the additional traffic accommodated because of improvements at J.T. Myers or Greenup locks and dams may increase delays at other projects in the system and thereby reduce the benefits for improvement. Similarly, other system projects can restrict traffic flows on the mainstem Ohio and prevent the materialization of the expected benefits of proposed navigation improvements. For this reason the evaluation methodology employed in this study measures the performance of the total navigation system. By evaluating the economic performance of the system for each plan of improvement, the impacts of specific improvements on the rest of the system are estimated and the marginal system benefits attributable to each plan can be measured. The plans that yield net system benefits can then be identified and compared.

The complex interrelationships and voluminous data dictate the use of computer modeling techniques. The Corps of Engineers, with the aid of various private economic and systems analysis consultants, has developed a set of transportation and economic models that incorporate statistical techniques to meet the needs of the analysis of a complex regional transportation system. The set consists of two distinct models: the Waterway Analysis Model (WAM) and the Ohio River Navigation Investment Model (ORNIM[1]). In general these models have been designed to help Corps planners achieve two goals: i) to operate and maintain the inland waterway network as efficiently as possible, and when necessary, ii) to select the best size, location, and timing of inland navigation waterway improvements.

The series of economic models employed in determining system benefits requires four main classes of data as inputs: i) data describing the navigation system, ii) data describing the equipment used on that system (towboats and barges for example), iii) data describing the origins and destinations, and tonnages of commodities shipped, and iv) data describing the costs of moving these commodities by barge and by overland modes of transportation.

Among of the more important components of the navigation system description are the (WAM) tonnage-transit curves for each lock being modeled. These curves describe the relationship between traffic levels and the time it takes a tow to transit a given lock. The tonnage-transit curves are used in ORNIM to estimate movement specific transit time and cost, the most variable component of total waterway transportation costs. Tracking the change in transit costs at different traffic levels and under different system assumptions (lock dimensions, number of locks, lock operating policies, and vessel fleets) allows the analyst to measure changes in waterway system benefits over time. **Attachment 1, Ohio**

[1] ORNIM was built by Oak Ridge National Laboratory (ORNL) in collaboration with the Navigation Planning Center of the Great Lakes and Ohio River Division (LRD). It is based on a long history of model development within the Corps beginning in the 1970s with the Tow Cost Model (TCM) and the Equilibrium Model (EQ).

River Navigation Investment Model (ORNIM) and **Attachment 2, Capacity Analysis**, provide full discussion of the ORNIM and WAM model, respectively.

1.3 FRAMEWORK OF ECONOMIC CONCEPTS

1.3.1 Background

At locks too small to efficiently handle higher traffic volumes or changing fleet configurations, congestion leads to degradation in service (reflected in higher transit times), which erodes rate-savings for all movements transiting the lock. Traffic-related service degradation has been the primary focus of lock improvement studies over the years, but reduced performance can be traced to causes other than increasing traffic volumes.

Aging projects and heavy usage can cause serious reliability concerns. In the Ohio River Navigation System (ORS), closures of the large main chambers lasting more than a couple of days are especially serious as this causes traffic to be processed in the smaller, less-efficient auxiliary chamber. During main chamber closures, the typically-sized Ohio River tow capable of transiting a main chamber in one 60-minute operation must move through the smaller auxiliary lock chamber in two operations lasting about 150-minutes. In this situation where the smaller auxiliary chamber carries the whole of the project's traffic, project performance is severely degraded. Service disruptions of this type result in longer transit times and higher transportation costs for those shippers relying on the affected lock.

Investments, including more aggressive maintenance, should be analyzed to determine the best course of action. From an economic viewpoint, investment that maximizes national economic development (NED) benefits is the best investment. The NED benefits are increases in the net value of the national output of goods and services and the NED evaluation is an incremental analysis between two future scenarios, or conditions. The future condition in the system without investment(s) is referred to as the without-project condition (WOPC), and the future condition with investment(s) is referred to as the with-project condition (WPC). In other words, the purpose of the analysis "… *is to estimate changes in national economic development that occur as a result of differences in project outputs with a plan, as opposed to national economic development without a plan.*"[2]

The established framework for answering these questions is described in the Principles and Guidelines. Identifying future scenarios or conditions is central to this framework. An economic analysis of these competing future conditions, over a 60-year planning horizon, seeks to estimate the stream of benefits and costs associated with each respective future. Estimating the contributions to National Economic Development (NED) benefits is accomplished by comparing with- and without-project futures to determine the incremental benefits or disbenefits of the WPC.

[2] Planning Manual, IWR Report 96-R-21, November 1996, page 56.

NED benefits for a navigation project investment are composed primarily of the reductions in transportation costs attributable to the availability of the improved waterway system. These reductions in transportation costs are achieved by increasing the efficiency of existing waterway movements, by providing for shifts of waterway and overland traffic to more efficient modes and routes, and by providing for shifts to more efficient origin-destination combinations. Further benefits accrue from traffic that is transported only because of the lower transportation cost from an improved project, and from creating or enhancing the potential for other productive uses of the waterway, such as the generation of hydropower. National defense benefits are also realized from regional and national growth, and from the diversity in transportation modes. But, the conceptual basis for the "*… basic economic benefit of a navigation project is the reduction in the value of resources required to transport commodities.*"[3] These reductions in transportation costs can be classified as:

- Cost Reduction Benefits – transportation cost savings accrued to movements that move on the waterway under both with and without-project conditions, generated by a reduction in the economic cost of using the waterway. This can occur from reduced trip delays (expanded lock capacity and/or policies that reduce congestion) and / or increased shipping efficiencies (larger tow-size and/or heavier barge loadings).

- Shift-of-Mode Benefit – transportation cost savings accrued to movements that only move on the waterway under the with-project condition. These movements were transported on a different transportation mode at a higher cost under the without-project condition; the benefit is the difference between the costs of using the alternative mode without the project and the costs of using the waterway with the alternative under consideration.

- Shift of Origin-Destination Benefit – If the project would result in a shift in the origin of a commodity, the benefit is the difference in total costs of getting the commodity to its place of use with and without the project. If a project would result in a shift in the destination of a commodity, the benefit is the difference in net revenue to the producer with and without the project. The shift of origin-destination benefit cannot exceed the reduction in the transportation charges achieved by the project.

- Induced Movements Benefit – This benefit applies if a commodity or additional quantities of a commodity would be transported only because of lowered transportation charge with the project. The quantities are limited to increases in production and consumption resulting from lower transportation costs. An increase in waterway shipments resulting from a shift in origin or destination is not included. The new movement benefit is defined as the increase in producer and consumer surplus; practically, it can be measured as the delivered price of the commodity less all associated economic costs, including all of the costs of barge transportation other than those of the navigation project. This benefit cannot exceed the reduction in the transportation charges achieved by the project.

[3] ER 1105-2-100, 28 December 1990, page 6-55.

Economic analysis of waterway infrastructure service degradation focuses on the evaluation and comparison of the existing waterway system with alternative measures: 1) increasing capacity (decreasing transit times and thereby reducing delay costs); or 2) increasing reliability (replacing or rehabilitating aging structures, thereby reducing the probability of structural failure and its consequences). This analysis can be described within a supply and demand framework.

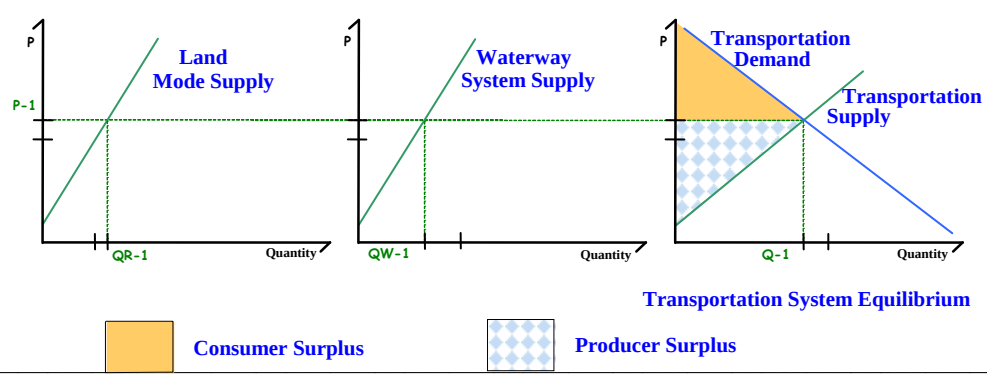
Again, the primary benefit for Federal investment in the inland waterways is the collective transportation cost savings for barge shipment over the least-costly alternative routing. The benefit, generally referred to as transportation rate-savings, also accounts for any differences in transportation costs arising from loading, unloading, trans-loading, demurrage, and other activities involved in the point-to-point transportation of goods. Estimating waterway investment benefits requires an analysis of: 1) waterway transportation demands; 2) transportation costs for the waterway routing; and 3) transportation costs for the least-costly all-overland alternative routing.

1.3.2 Theoretical Framework

This section provides the economic foundation for the development and application of ORNIM as discussed in the next section (1.3.3). The Corps, and therefore ORNIM, must be consistent with established Principles and Guidelines when estimating the benefits of river system improvements. The Principles and Guidelines (P&G), which were published in March 1983, provide general guidance for doing benefit assessments. P&G leaves open for the analyst to improve their tools and assessments as new data become available and computational capabilities improve. ORNIM is a reflection of the Corps' recognition that a new state-of-the-art is possible.

Assume there is some upward sloping supply curve for land and water transportation as shown in **Figure 1-1**. The supply can be added horizontally to derive the supply curve for transportation. Since the land and water modes are assumed perfect substitutes, the demand curve for transportation can be found by horizontally summing individual movement demands. The intersection of system supply and demand gives the without-project condition market equilibrium at P-1 with an equilibrium system traffic level of Q-1 (QR-1 moving via land and QW-1 moving via waterway). The total benefit of the transportation system is the consumer surplus above P-1 and under the demand curve and the producer surplus below P-1 and above the system supply curve.

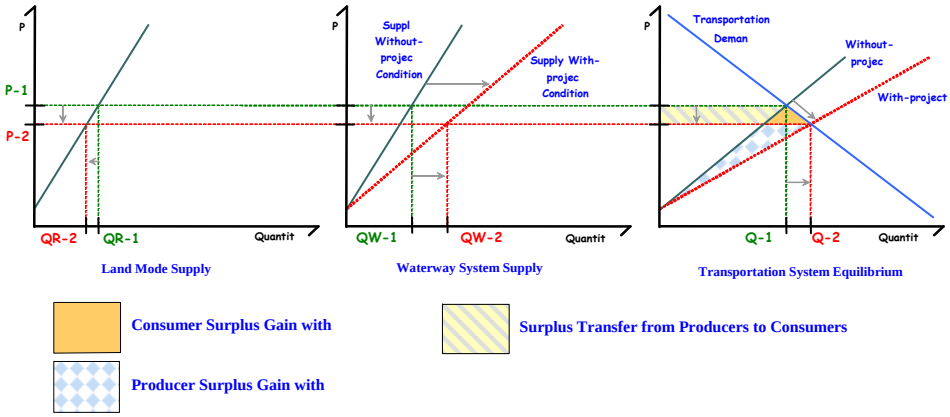
FIGURE 1-1
Transportation System Equilibrium - WOPC Benefits



A distinction should be made between the demand for commodities (coal, grain, etc.) and the resulting derived demand for transportation of these commodities. The demand for transportation is a derived demand driven by the demand of the commodities seeking transportation, which are in turn driven by the demand for the end products produced by these commodities. The demand for the end products is driven by such things as population, technology, relative prices of competing and complementary goods, income and individual tastes and preferences. The demand for barge transportation and the demand for land transportation are interdependent and are affected by the market clearing price in the transportation sector.

With an improvement to the waterway navigation system, the waterway supply curve will shift to the right (assuming the navigation investment result in lower transportation costs for all levels of quantity supplied). This shift results in a shift of the total transportation supply and results in a new system equilibrium at a lower price P-2 and a higher system equilibrium traffic level of Q-2 (land traffic is reduced while total traffic and water traffic increase). Subsequently, the incremental benefit of the with-project condition comes from consumer and producer surplus gains, with a shift of surplus from producers to consumers as shown in **Figure 1-2**.

FIGURE 1-2
Transportation System - Incremental WPC Benefits

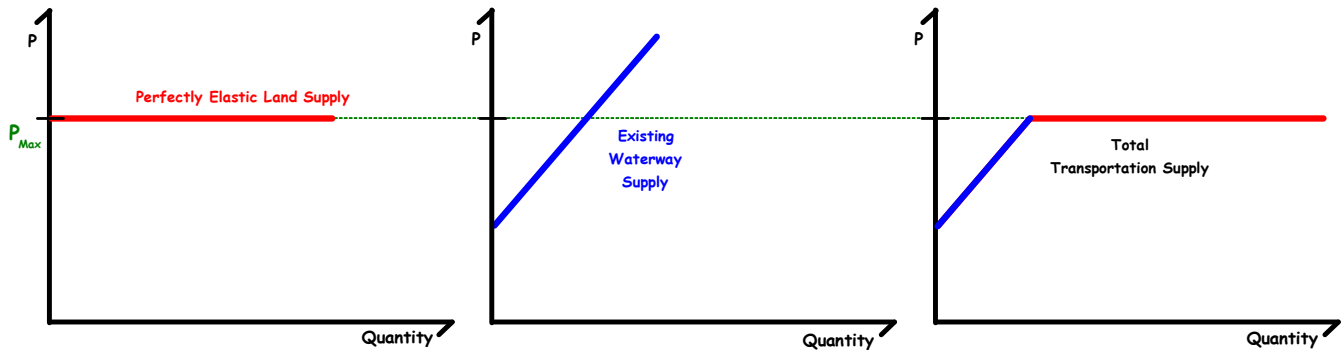


In addition, the with-project increase in quantity of transportation demanded shown in Figure 1-2 above, results from an increase in water transportation demand (QW-1 to QW-2) relative to land transportation demand (QR-1 to QR-2) as water transportation becomes more competitive. Transportation system equilibrium traffic increases from Q-1 to Q-2 and costs reduce from P-1 to P-2

The Corps guidelines for estimating waterway benefits were established in the 1950s through a "*mutual understanding*" between the water resource agencies. The first such understanding was recorded in the Federal Inter-Agency River Basin Committee's *Proposed Practices for Economic Analysis of River Basin Projects* in May 1950 (U.S. Senate), and later revised in May 1958. In that report, referred to as the Green Book (because of the color of its cover), navigation benefits were identified as the difference

between the total "…*cost of transportation by an alternative means and the non-project or associated cost of transportation by waterway*." In other words, guidance allows the conservative assumption of a totally elastic supply of land transportation. This caps the equilibrium price of transportation at the land price and limits the willingness-to-pay for water transportation. As shown in **Figure 1-3**, assuming land and water are perfect substitutes, the maximum transportation price is P_{max}.

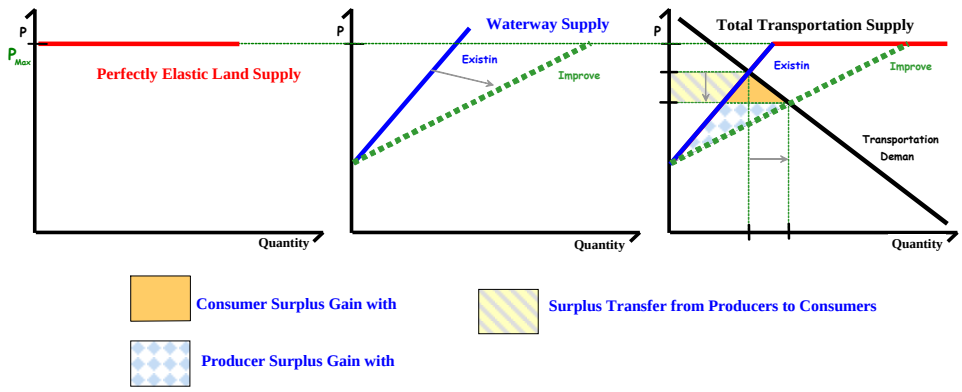
FIGURE 1-3
Conceptual Supply Curves



The effect of perfectly elastic land supply on equilibrium is a function of the relationship between the land supply price, the water supply curve and transportation demand. Four situations can occur: i) land supply price is greater than all quantities of water supply and all demand is met by water mode; ii) land supply price is less than any quantity of water supply and all demand is met by land mode; iii) land supply price is less than any quantity of existing water supply, but not for all quantities of the improved water supply; or iv) demand is met with a combination of land and water supply.

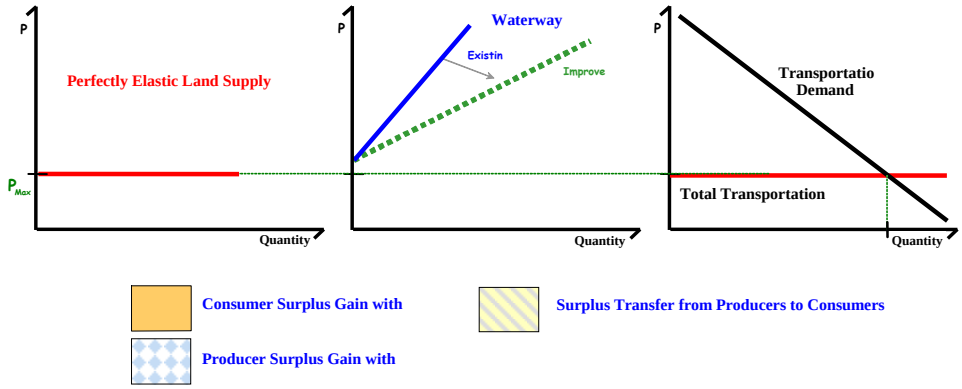
In the first case, where the land supply price is greater than all quantities of water supply and all demand is met by water mode (**Figure 1-4**), consumer surplus, producer surplus and a surplus transfer from producers to consumers occurs under a water supply increase (improvement) as previously shown in **Figure 1-2**. In this case the land rate is actually immaterial in the determination of benefits (with project incremental transportation savings) and the demand for barge transportation is equivalent to the total transportation demand. Corps regulations define these benefits as "Cost Reduction Benefits."

FIGURE 1-4
System Equilibrium Assuming Elastic Land Supply – CASE 1



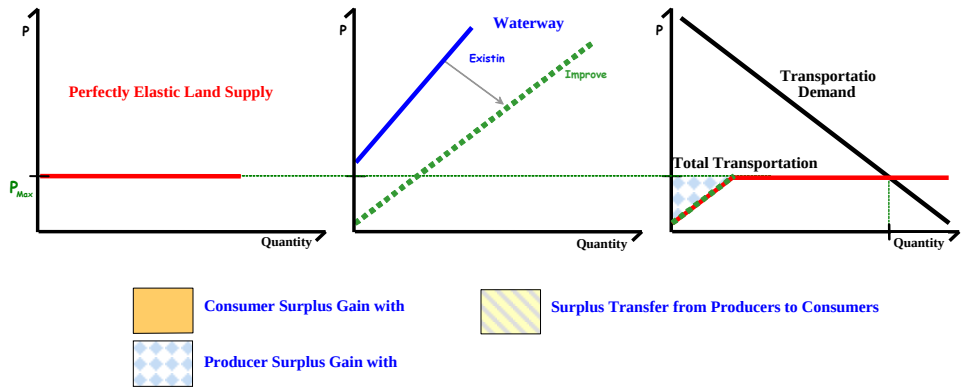
In the second case, where the land supply price is less than all quantities of water supply under the existing water system and under the improved water system, all demand is met by the land modes (**Figure 1-5**). In this case there is no surplus generated by a waterway improvement. Situations where the water improvement can supply transportation less than the land mode price are handled under case 3 below.

FIGURE 1-5
System Equilibrium Assuming Elastic Land Supply – CASE 2



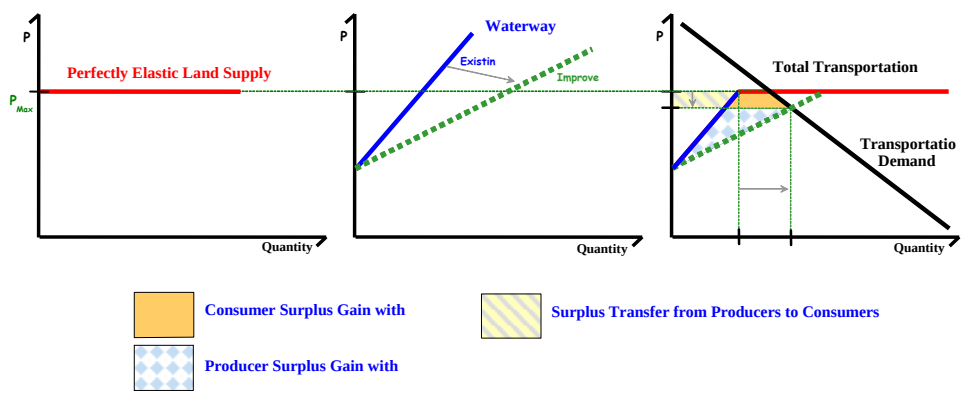
In the third case, water supply is only used under the improved water supply condition (**Figure 1-6**), and only producer surplus is produced under a water supply increase (improvement). The equilibrium quantity of transportation supply remains constant, however, some traffic is shifted from the land mode to the water mode. If the supply of water transportation increases enough, all land mode traffic could shift to water transportation, and even additional demand could be met. Corps regulations define these benefits as "Shift-of-Mode Benefits."

FIGURE 1-6
System Equilibrium Assuming Elastic Land Supply – CASE 3



In the fourth case, there is a combination of land and water supply being used to meet demands (**Figure 1-7**), consumer surplus, producer surplus and a surplus transfer from producers to consumers occurs under a water supply increase (improvement) as previously shown in **Figure 1-2** and **Figure 1-4**. In this case there is a combination of "Cost Reduction" and "shift-of-Mode" benefits.

FIGURE 1-7
System Equilibrium Assuming Elastic Land Supply – CASE 4



This assumption of a perfectly elastic land supply reduces the problem to an analysis of the demand for barge transportation (not total transportation) and the supply of barge transportation (not total transportation); to calculate the incremental transportation savings for a waterway improvement, the quantity of demand supplied by land modes is not needed[4].

[4] The quantity of land mode traffic is needed if externality costs are calculated.

1.3.3 Model Framework

ORNIM can be described as a spatially-detailed, partial-equilibrium model. It is not designed to estimate the total benefits of a river system, nor the benefits the nation would lose if the river system no longer existed. A more general equilibrium model would be needed to assess the total value of a river system. ORNIM is appropriate to estimate the benefits of incremental improvements to a river system. ORNIM has been described as a transportation planning model. A comprehensive transportation planning model conducting general equilibrium freight transportation supply and demand analysis can involve many complicated simultaneous decisions using multiple economic agents, with spatial and time dimensions. A typical four-step transportation planning model treats trip generation, trip distribution, mode choice, and route assignment endogenously. ORNIM, however, focuses on mode choice, or more specifically modal diversion from water transportation, with trip generation and distribution handled exogenously through traffic forecast inputs. Routing can be assigned by ORNIM, but routing is typically not an issue in Ohio River Basin (ORB) waterway studies because multiple water routes do not exist.

ORNIM operates within a supply and demand framework with inputs that model the supply of water transportation and the demand for water transportation. Demand is represented by the willingness-to-pay[5] for waterway services by rank-ordering all waterway commodity movements and their transportation rate-savings. Supply is represented by the cost of the waterway service with lock performance tonnage-transit curves developed from the WAM (see **Attachment 2, Capacity Analysis**).

1.3.3.1 Supply

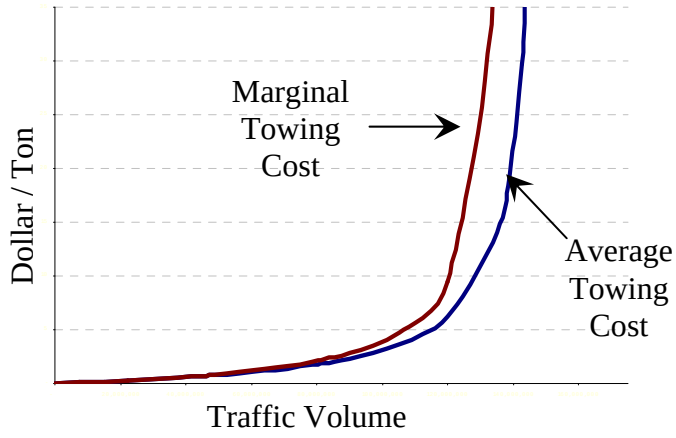
On the supply side, or the performance/cost curve side, the supply curve represents, for every level of traffic, the shipper cost of shipping commodities via the water routing. Two waterway cost curves are depicted in **Figure 1-8** -- the average towing cost (ATC) curve and the marginal towing cost (MTC) curve. The ATC curve represents the <u>average</u> cost of shipping at different traffic levels. It rises because the average delay, and therefore the average cost, is higher at higher levels of traffic. The MTC curve represents the <u>additional</u> cost to the shipping industry of transporting an additional ton of cargo on the waterway. It increases at a faster rate than the ATC because the higher delays associated with higher levels of traffic are sustained by all shippers, not only the shipper who causes the delay. The costs shown include only those costs borne by the shippers (e.g., equipment, labor, fuel, and supplies), and not those borne by the Federal Government in the operation and maintenance of the waterway system.

Shippers in the inland waterway operate in their own self-interest. Individual shippers will not restrict output to a social optimum, where the last increment of tonnage added to the system exhibits just enough marginal rate savings to offset the marginal towing costs (including induced delays) (MRS=MTC). Instead, shippers tend to expand waterway volumes to the level at which their marginal rate-savings or demand is just equal to average towing cost (MRS = ATC). This occurs because an individual carrier pays only

[5] A proxy measure of willingness-to-pay is developed from the rate differential between existing water routing and least cost alternative routing.

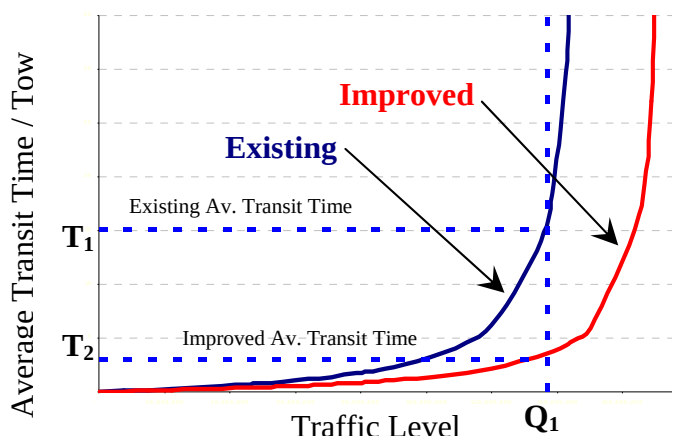
its shipping costs and does not pay the true cost to society (i.e. the increased costs its use of the waterway imposed on other shippers in the form of additional delays). For example, in a congested lock situation, the addition of just a few more tows per day causes lock delays to increase exponentially because of the queuing effect. The additional tows do not pay for the total marginal increase in tow delay. Rather, the increased delay costs are spread among all tows using the congested lock, making each less efficient. For this reason, the ATC is used in the analysis of inland navigation projects.

FIGURE 1-8
Conceptual Waterway Supply Curves



Tonnage-transit curves are developed with lock performance monitoring system (LPMS) timing data in the WAM. The curves are used to represent the transit time relationship with volume of traffic serviced under different alternatives (**Figure 1-9**) and can be used to value the resources required to transit the project under without- and with-project conditions. Since the cost of waterway transportation is a function of transit times in the system, costs under both situations can be estimated. For a given quantity of traffic (Q_1), average transit time under the existing condition is T_1. Under an improved condition the average transit time drops to T_2. In this situation, waterway transportation costs for the shippers are reduced.

FIGURE 1-9
Tonnage-Transit Curves, Existing vs. Improved



1.3.3.2 Demand

System demand is modeled with waterway commodity movements ranked in descending order of transportation rate-savings. The rate-savings serve as a proxy for willingness-to-pay. The least-cost alternate route cost is used to measure willingness-to-pay for movements on the waterway system because we assume that a shippers' marginal willingness-to-pay is the difference in transportation costs between the waterway routing and the least-cost all-overland routing. As a result, the system demand curve represents the marginal system rate-savings (MRS) or marginal benefit curve. The demand (MRS) curve represents, for different levels of traffic, shippers' marginal willingness-to-pay for the use of the waterway. If the alternative mode offers lower transportation costs (negative rate-savings for the waterway routing), then the alternate routing will be used. If the waterway and alternative routing costs are the same (zero rate-savings), then the shipper is indifferent as to the mode/route used. If the alternative routing costs are higher (positive waterway rate-savings), the waterway routing will be used with the incentive (or willingness-to-pay) for using the waterway increasing as the savings for using the waterway increases.

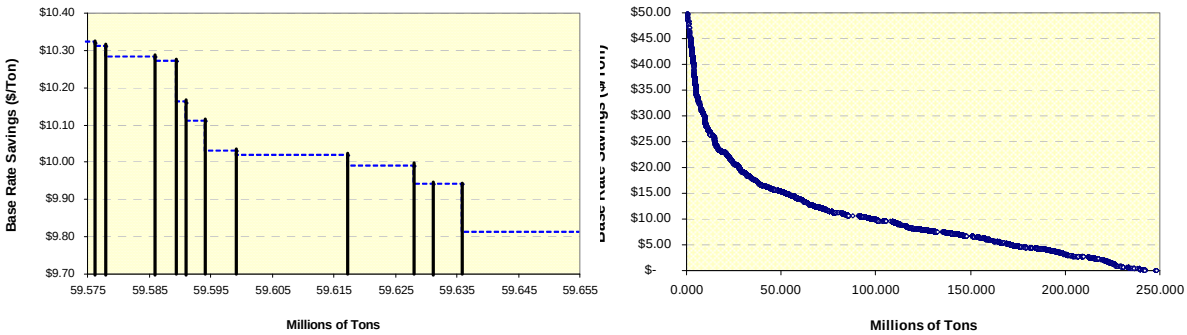
Corps regulations require that NED benefits be based on long-run marginal costs. Shippers make transportation decisions based on the rates they are actually charged. In competitive markets, rates (prices) correspond to marginal cost, and given market stability, prices will settle at long-run marginal costs. Transportation rates are used to estimate the long run marginal cost of waterway transportation.

The rank ordered waterway transportation rate-savings curve (system demand for barge transportation) is developed off port-dock barge level WCSC data. The origin-destination-commodity (ODC) movements for this “base” year are rated and forecast into the future. As a result, this represents a forecast for water transportation demand and not a forecast of total demand for the commodities between the ODC triplicates[6]. For each movement, the water transportation rate for the base year is subtracted from the least-costly all-overland rate for the base year to derive the “base rate-savings” which is assumed to be the willingness-to-pay for barge transportation.

A distinction should be made between movement level demand (individual) and system demand. System demand is simply the horizontal summation of individual movement demands. System demand is elastic while individual movement demand is assumed (and modeled) inelastic as shown in **Figure 1-10**; the market or system demand curve is a sorted aggregation of the inelastic individual movement demands. The aggregate demand curve plots the willingness-to-pay, associated with each movement in the system. The result is a set of discrete points representing numerous individual demands.

[6] Induced demands are handled through separate studies.

FIGURE 1-10
System Demand for Barge Transportation



Source: 1999 ORS WCSC flows with FY00 rates aggregated to unique ORNIM port, 9-group commodity and 12-group barge type.

1.3.3.3 Equilibrium

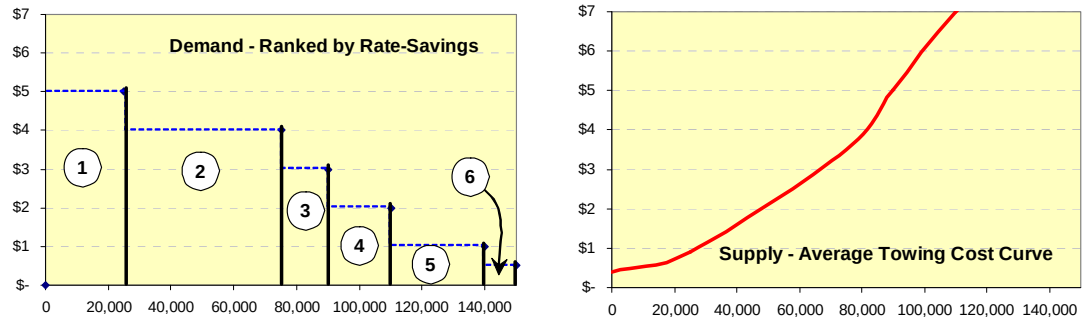
Projecting future system benefits necessarily involves being able to project future equilibrium traffic levels on the waterway system and the resulting transportation rate-savings for each movement. In order to understand the model's determination of system equilibrium traffic levels and its calculation of benefits, an example of six waterway movements is constructed and shown in **Table 1-1**. Other important assumptions in this example are that the system only contains one navigation project and each movement shares similar fleet characteristics (e.g. same tow-sizes, empty returns, etc.).

TABLE 1-1
Example of System Movements

Movement Number	WW Demand Tonnage	Rate ($/ton)		Base Rate-Savings ($/Ton)
		Water	Land	
1	25,000	$ 5.00	$ 10.00	$ 5.00
2	50,000	$ 4.00	$ 8.00	$ 4.00
3	15,000	$ 3.00	$ 6.00	$ 3.00
4	20,000	$ 2.00	$ 4.00	$ 2.00
5	30,000	$ 1.00	$ 2.00	$ 1.00
6	10,000	$ 0.50	$ 1.00	$ 0.50

In this example the system supply cost curve is analogous to the project's tonnage-transit curve (**Figure 1-9**) except that the Y-axis is converted to a dollar-per-ton value by multiplying the average transit time by the average hourly equipment costs and dividing by the tonnage moved. This transforms the tonnage-transit curve into the average cost curve shown in **Figure 1-8**. In other words, supply constraints on the existing waterway rate are assumed to be caused only by traffic congestion and the delay-costs this congestion imposes upon the system. The system demand curve is represented by an ordering of the six commodity movements sorted from highest to lowest rate-savings (**Figure 1-11**).

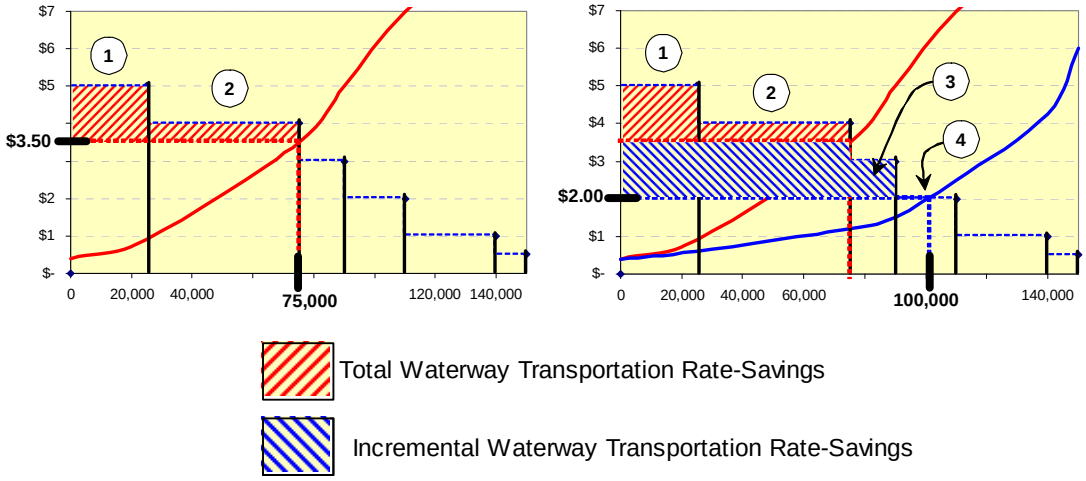
FIGURE 1-11
System Curves



Since the shippers' marginal willingness-to-pay is measured as the difference in transportation costs between the waterway routing and the least-cost alternative routing, if the alternative mode offers lower transportation costs (negative rate-savings for the waterway route), then the alternate route will be used. If the waterway and alternative route costs are equal (zero rate-savings), the shipper is indifferent as to the route (mode) used. If the alternative route costs are higher (positive waterway rate-savings), the waterway route will be used with the incentive for using the waterway increasing as the savings for using the waterway increases.

As shown in **Figure 1-12**, all of movements 1 and 2 move via waterway under the existing system configuration. The system equilibrium tonnage will be 75,000 tons. At equilibrium, the average waterway cost will be an additional $3.50 per ton above the rate base, leaving an "eroded" base-rate savings of $1.50 for movement 1 and $0.50 for movement 2. The resulting system-rate savings is $62,500 ($1.50/ton X 25,000 tons plus $0.50/ton X 50,000 tons). With an improvement at the lock, transit costs are lowered and a new system equilibrium with additional average waterway cost lowered to $2.00 per ton is the result. At this lower cost, system tonnage equilibrium of 100,000 tons is reached. Movements 1 and 2 experience a cost-reduction benefit of $112,500 ($1.50/ton X 75,000 tons) and with the lower waterway transportation costs, all of movement 3 and some of movement 4 move on the waterway. This additional waterway tonnage represents shift-of-mode tonnage. In our example displayed in **Figure 1-12** shift-of-mode benefits would be $15,000 ($1.00/ton X 15,000). Note there are no shift-of-mode benefits generated for the marginal movement (movement 4) unless the entire movement is moved and the cost curve crosses below the base rate-savings. This is because equilibrium-adjusted-base-rate savings for movement 4 equals $0.00.

FIGURE 1-12
System Equilibrium



In reality, ORNIM considers the cost curves for multiple locks with thousands of movements each with unique origins and destinations, and cost characteristics. ORNIM iterates to determine the equilibrium level of traffic where every movement that has a cost advantage on the waterway moves on the waterway. As different mixes of movements are considered in the system, each project is affected differently resulting in different average transit times at each project. The movements transit many different combinations of projects. The increase in transit time is translated into a cost increase for each movement taking into account its specific cost characteristics. For example, liquid commodities that have a shipping plan in 1 tanker barge tows have higher cost increases than dry cargo commodities moving in 15-barge open hopper tows. A detailed step by step discussion of the equilibrium process is given in **Attachment 1, Ohio River Navigation Investment Model (ORNIM)**.

1.4 RISK AND UNCERTAINTY

Corps of Engineers guidelines as presented in the Principles and Guidelines have long recognized that uncertainty is inherent in all phases of the analysis of waterway investments. As such, this analysis provides information regarding the level of uncertainty associated with the values estimated for a number of critical inputs. These include traffic demand projections, lock performance descriptors (capacity and lock availability), and structural reliability. Estimating values for these inputs rests upon a large set of variables, many of which are unique to the input being estimated.

This study focuses its descriptions of uncertainty on the key determinants of economic feasibility--traffic demand projections, lock performance and structural reliability. In the case of traffic demand projections, alternative traffic forecast scenarios based upon competing sets of assumptions are presented and analyzed (**Attachment 4, Traffic Demand Forecasts**). Discrete event simulations based upon statistical analysis of tow operator behavior and actual lock operations are used to estimate traffic-delay or transit relationships at all locks (**Attachment 2, Capacity Analysis**). Lock availability

and performance is further described through the use of hazard values and event trees (**Attachment 3, Project Maintenance Analysis**), which is the key input into the Monte Carlo-type simulation which calculates expected future adverse impacts associated with a lock's structural reliability (**Attachment 1, ORNIM**).

1.5 APPENDIX ORGANIZATION

The remainder of this appendix is organized into the following major topical sections. **Section 2** describes the resources and economy of the six-state study area. **Section 3** highlights the industries dependent upon the waterways. **Section 4** describes the navigation system that was analyzed to determine the extent and magnitude of impacts resulting from any system improvements. **Section 5** analyzes the vessel fleet and the performance characteristics of the Ohio River. **Section 6** discusses the historic and projected traffic demands. **Section 7** describes the system benefit evaluation process, including the system model used, major model inputs, and the results of model calibration. **Section 8** identifies and evaluates the Ohio River mainstem without-project condition. **Section 9** identifies and evaluates alternative investment plans and S**ection 10** presents the economically justified Ohio River mainstem navigation system investment plan (SIP).

Seven attachments complement this appendix. **Attachment 1** provides a thorough discussion on the economic model used in the analysis. **Attachment 2** discusses the tonnage-transit curves used in the economic analysis. **Attachment 3** describes how component reliability is used to develop and evaluate maintenance alternatives. **Attachment 4** documents development of traffic demand forecast scenarios used in the analysis. **Attachment 5** discusses current traffic management schemes deployed on the mainstem Ohio River during lock closures and **Attachments 6 and 7** describe the transportation rates used in the analysis and the results of our efforts to accumulate information on waterway shipper responses to changes in the price of waterway transportation.

Section 2

BASIN RESOURCES AND ECONOMY

2.1 GENERAL

The region served by the Ohio River navigation system (ORS) is a rectangular-shaped area roughly bounded on the east by the Allegheny Mountains, on the west by the Mississippi River, on the north by the Great Lakes, and on the south by the Tennessee River. The Ohio River bisects the study area in a northeast to southwest direction. The eastern portion of the study area is characterized as generally mountainous, giving way to eroded uplands with vast reserves of coal. The western area is characterized as generally rolling terrain, which gives way to the eastern prairie lands of Illinois. **Figure 2.1** illustrates the navigable rivers of the Ohio River Basin (ORB).

The ORB's topography is diverse. This diversity has produced an economic benefit to the region by promoting the development of its industries. The terrain varies from the hilly regions of the Appalachian range and Great Smokies to the rolling plains of Indiana and Illinois. Each of these topographical environments promoted a distinct type of economic specialization, and the exchange of the region's industrial resources and products by barge and other modes of transportation has promoted its industrial development.

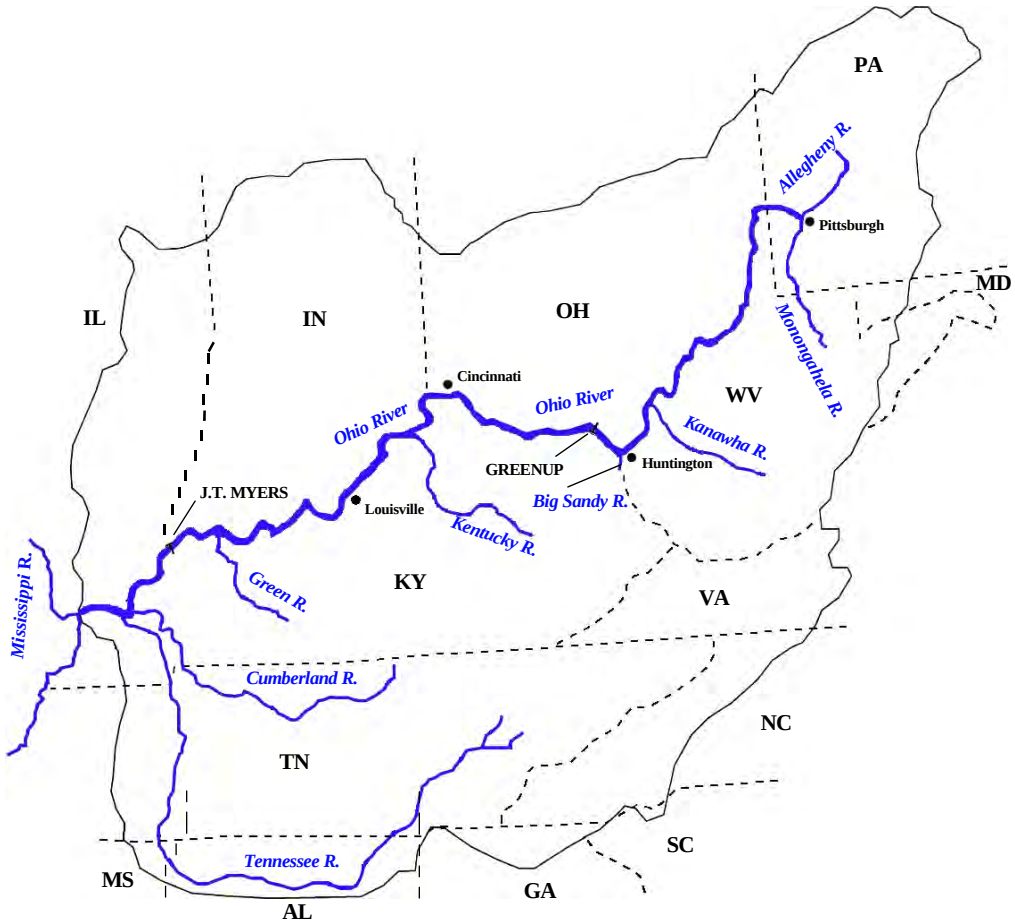
The population of the ORB states and waterside economic areas (BEAs) is 55 million, or 21 percent of the national total. Although the population is distributed throughout the area, there are six major population centers in the region: Indianapolis, Columbus, Nashville, Pittsburgh, Cincinnati and Louisville, the last four of which are located on navigable Ohio River Basin waterways. These and smaller riverside cities, like Charleston and Huntington, WV; Evansville, IN; and Knoxville, TN, are indicative of the population concentration in the basin's river valleys. **Table 2-1** shows trends in population, employment, and earnings for ORB states, for BEA areas in or near the basin, and for the country from 2000 to 2003.

Extensive coal deposits, abundant limestone reserves, fertile soils, abundant water supplies, and extensive woodlands are the area's principal resources. These resources, along with less extensive deposits of crude oil, natural gas, glass sands, clays, and minerals such as salt, zinc and copper, supported initial settlement of the area and the development of its first industries—coal mining, farming, chemical manufacture, meat packing, glass making, pottery, petroleum refining, and steel manufacturing. Some of these are still major industries in the region, most notably the steel, chemical, and coal mining industries.

In the ORB's major cities the economy is robust and diversified, depending upon services and technology, and much less on manufacturing. The smaller cities still rely heavily upon manufacturing (especially steel, automobile and aluminum production), while the hinterlands are still heavily dependant upon extractive industries (especially coal

mining) and farming. The regional sectors of highest importance to waterway traffic are coal mining and their primary customer, electric utilities; stone quarrying and construction; farming; and manufacturing.

FIGURE 2-1
Ohio River Basin



2.2 HISTORICAL PERSPECTIVE

The dominant influences during the early settlement and growth of the region were the rich soils, favorable climate, dense forests, and numerous waterways providing transportation arteries. Mineral resources, particularly coal, salt, limestone, oil, and gas also became important in molding the regional economy.

Agriculture was the foundation of the ORB economy. Farm employment accounted for over sixty percent of total employment in 1850. Agriculture continued to dominate until the early years of the 20th century. At that time, great strides in agricultural productivity released manpower resources from farming, making them available for manufacturing employment. By 1925, employment in manufacturing exceeded employment in agriculture.

TABLE 2-1
Population, Employment and Earnings for Waterside ORB States and BEA Areas Compared to the United States

BEA City Name	Population (thousands) 2000[2/]	Population (thousands) 2003[3/]	Avg. Ann. % Change 2000-03	Employment (thousands) 2000[2/]	Employment (thousands) 2003[3/]	Avg. Ann. % Change 2000-03	Earnings (millions) 2000[2/]	Earnings (millions) 2003[3/]	Avg. Ann. % Change 2000-03
Atlanta-Sandy Springs-Gainesville, GA-AL	6,194	6,594	2.11%	295	386	9.34%	5,547	9,160	18.20%
Knoxville-Sevierville-La Follette, TN	1,085	1,121	1.09%	359	536	14.28%	6,529	12,491	24.14%
Lexington-Fayette-Frankfort-Richmond, KY	1,444	1,468	0.55%	690	894	9.03%	13,441	19,261	12.74%
Charleston, WV	1,207	1,202	-0.14%	516	568	3.27%	11,094	13,128	5.77%
Cincinnati-Middletown-Wilmington, OH-KY-IN	2,215	2,252	0.55%	892	1,259	12.16%	19,053	33,913	21.19%
Columbus-Marion-Chillicothe, OH	2,468	2,534	0.88%	928	1,362	13.65%	18,562	34,541	23.00%
Pittsburgh-New Castle, PA	2,981	2,953	-0.31%	171	158	-2.54%	3,958	3,548	-3.58%
Cleveland-Akron-Elyria, OH	4,693	4,688	-0.04%	2,294	2,652	4.95%	53,206	72,192	10.71%
Evansville, IN-KY	743	749	0.27%	404	481	6.02%	7,973	10,847	10.81%
Louisville-Elizabethtown-Scottsburg, KY-IN	1,461	1,491	0.68%	630	819	9.16%	12,397	20,248	17.77%
Nashville-Davidson-Murfreesboro-Columbia, TN	2,446	2,527	1.09%	894	1,413	16.48%	15,137	34,762	31.93%
Paducah, KY-IL	240	240	0.00%	97	123	8.23%	1,756	2,776	16.49%
Memphis, TN-MS-AR	1,931	1,959	0.48%	783	1,060	10.62%	13,871	26,853	24.63%
Huntsville-Decatur, AL	1,000	1,017	0.56%	373	534	12.71%	6,988	12,946	22.82%
Tupelo, MS	533	534	0.06%	259	315	6.71%	3,772	6,249	18.33%
St. Louis-St. Charles-Farmington, MO-IL	3,258	3,311	0.54%	1,595	2,017	8.13%	33,411	52,515	16.27%
Total	33,899	34,640	0.72%	11,180	14,577	9.25%	226,695	365,429	17.25%
BEAs % of U.S.	12.0%	11.9%		6.7%	8.7%		3.5%	5.1%	
United States	282,192	290,789	1.01%	166,759	167,174	0.08%	6,504,679	7,113,751	3.03%
Eight ORB States									
Alabama	4,452	4,504	0.39%	1,714	2,305	10.38%	76,977	55,165	-10.51%
Illinois	12,440	12,649	0.56%	5,745	7,017	6.89%	313,024	213,535	-11.97%
Indiana	6,092	6,200	0.59%	2,670	3,469	9.12%	125,272	88,071	-11.08%
Kentucky	4,049	4,118	0.56%	1,644	2,170	9.69%	73,872	50,164	-12.10%
Ohio	11,364	11,438	0.22%	5,203	6,525	7.84%	244,121	173,530	-10.75%
Pennsylvania	12,286	12,371	0.23%	5,563	6,610	5.92%	268,169	184,716	-11.69%
Tennessee	5,703	5,845	0.82%	2,227	3,254	13.47%	117,216	90,650	-8.21%
West Virginia	1,807	1,811	0.07%	781	859	3.22%	26,951	19,127	-10.80%
Total	58,193	58,936	0.42%	25,547	32,209	8.03%	1,245,602	874,958	-11.11%
Percent of U.S.	20.6%	20.3%		15.3%	19.3%		19.1%	12.3%	

Source: [1/]http://www.bea.doc.gov/bea/regional/reis (BEA Economic Areas, Table CA1-3-Population)
[2/]http://www.bea.doc.gov/bea/regional/reis/ (SIC industry 1969-2000)
[3/]http://www.bea.doc.gov/bea/regional/reis/ (NAICS industry 2001-2003)

By the 1920s, newly developed technologies and consumer goods – including automobiles, airplanes, telephones, and radios – led to a surge in national demand for manufactured goods. Each of these new industries and products enhanced the economic desirability of upgraded and expanded highway, rail, air, and water networks. The increased demand for coal to stoke industrial boilers, fuel trains, charge blast furnaces, produce steam for the generation of electricity, and to provide heat to homes and factories necessitated the more rapid development of the inland waterway infrastructure.

Since World War II, the trend toward increased manpower resources in manufacturing and mining has abated. Most industries have made great technological strides in productivity. The demand for labor in manufacturing has decreased while the demand for labor in services has increased. The shift in employment from manufacturing to services has coincided with a major demographic shift in the United States. People and markets have tended to shift to the south and southwest as the nation's population has sought more favorable climate and living conditions.

The industrial shift towards services had detrimental consequences on the ORB economy in the 1980s. The resulting economic downturn meant a loss of jobs, earnings and tax base in the basin. The most visible effect of these forces was the massive rationalization of the steel industry.

2.3 RESOURCES

2.3.1 Coal

Coal traffic currently accounts for over 55 percent of all tonnage shipped on the Ohio River with 80 percent going to waterside electric generating plants. Coal reserves are extensive in the basin, and the availability of low-cost coal is largely responsible for the establishment and growth of manufacturing in the area. Coal was key to the development of the steel industry, which dominated the economy of the Pittsburgh area for over a century, and to the electric generating industry, whose low cost made the area attractive for a wide range of industries.

Coal is found in abundance in the basin (see **Figure 2.2**), but with the major seams located in the eastern section. The western reserves within the basin are not only less abundant, but have characteristics that are significantly different, reflecting the different geologic forces that created the coal. Bordering the river down to Huntington, the coal is generally high energy and low to medium in sulfur content. The seams extending southward from Pennsylvania's Allegheny River valley through eastern Ohio, West Virginia, Virginia, eastern Kentucky, and on into Tennessee are referred to as the Appalachian coalfields. The seams in Illinois, Indiana, and western Kentucky are referred to as the Illinois Basin, a subset of the larger Interior coalfields. Both Appalachian and Illinois Basin deposits are bituminous coals of relatively high energy content, especially when compared with the sub-bituminous coals of Wyoming's Powder River Basin (PRB).

The more important characteristics of coals are sulfur content and heat content (BTU). The Appalachian coals are generally lower in sulfur content than the Illinois Basin coals, though higher in sulfur content than the PRB coals. ORB coals have higher BTU content than PRB coals. Sulfur is an undesirable element in a particular grade of coal's makeup. Known coal resources in the ORB with sulfur and BTU content are shown in **Table 2-2**. Since 2000, basin population and earnings have grown less than the national average while employment has grown by more than the national average (see Table 2-1). The eight ORB states comprise about 25 percent of the nation's population, employment and earnings.

Ohio River Basin coal producers account for nearly one-half of national coal production. Coal production levels in the ORB are listed in **Table 2-3**. Production levels vary by decade between the tributary basins, but it has been relatively constant for the ORB as a whole at about 350 million tons a year. Production is highest in the low-sulfur coalfields of central Appalachia (Big Sandy and Kanawha river basins) followed by production in northern Appalachia (Allegheny and Monongahela river basins). Though most of the coal produced in the basin is consumed in the basin, coals from the northern Appalachian fields are especially valuable as metallurgical coals used in the steel-making process throughout the United States and the world. High quality (low sulfur and high-energy content) coals from these same fields are used to generate electricity throughout the Eastern and Midwestern United States and in Canada, Asia, and Europe.

FIGURE 2-2
Ohio River Basin Coal Reserves

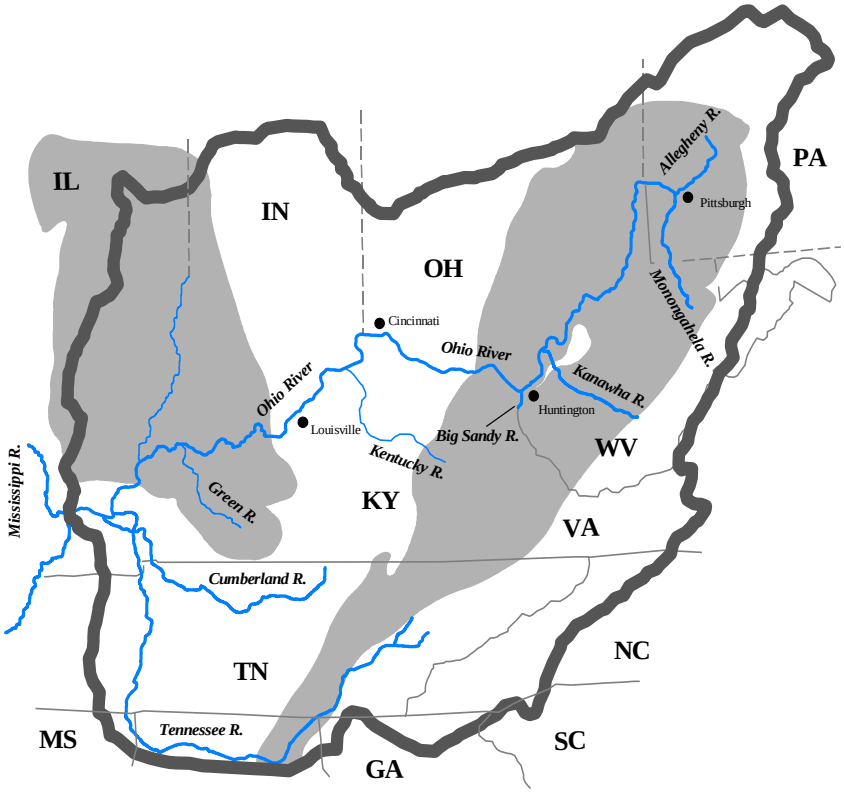


TABLE 2-2
Sulfur and BTU Content of Basin Coal Resources

Tributary Basin	Millions of Tons	Sulfur*	BTU
Allegheny	3,895.3	2.86	13,353
Big Sandy	16,793.4	0.81	15,155
Cumberland	1,588.5	2.32	13,550
Green	7,337.8	3.90	12,810
Kanawha	29,908.1	0.97	14,050
Kentucky	1,646.5	0.90	13,103
Monongahela	16,889.3	2.43	13,402
Ohio	39,605.2	3.37	12,984
Tennessee	264.6	1.77	13,473
Total	148,288.6	2.44	13,406

* Sulfur content is measured in pounds per million BTU

Source: Resource estimates from "National Coal Resource Assessment, 2000 Resource Assessment of Selected Coal Beds and Zones in the Northern and Central Appalachian Basin Coal Regions, USGS
Sulfur and BTU content from EIA, disk cn6530.hb2.reserve.base.data

TABLE 2-3
Coal Production in Ohio River Basin
(Millions of Tons)

River Basin	1970	1980	1990	2000
Allegheny	14.6	14.1	10.5	5.1
Big Sandy	79.7	90.7	120.6	101.6
Cumberland	1.8	5.1	3.8	0.8
Green	48.0	31.9	31.8	18.1
Kanawha	59.0	48.0	71.0	79.3
Kentucky	3.4	7.7	5.2	1.0
Monongahela	62.8	48.0	53.2	66.9
Ohio	75.5	61.9	77.7	66.5
Tennessee	6.4	7.8	4.4	2.7
Ohio River System	351.3	315.3	378.4	342.0
East of Mississippi	567.8	578.7	630.2	509.3
U.S. Total	612.7	829.7	1,029.1	1,075.5

Sources: Minerals Year Book 1970, Bureau of Mines; Coal Production 1980 and 1990, Energy Information Administration; http://www.eia.doe.gov/cneaf/coal; and Annual Energy Review 2000, EIA

Despite over a century of mining, the area still contains large reserves of coal that are sufficient to meet the nation's expected needs for several centuries to come. As shown in **Table 2-4**, over one-quarter of the nation's coal reserves and over 90 percent of its highest energy reserves lie in the Ohio River Basin. At current production rates, the basin's reserves are sufficient to continue producing coal within the basin for the next 350 to 400 years.

2.3.2 Soils

The western basin farms of Illinois, Indiana, and Ohio rest upon the eastern extremity of the nation's most fertile soils equaled in the world only by the pampas of Argentina and the Ukraine's chernozem grasslands. Agriculture in these states, and to a lesser extent in western Kentucky, revolves around the cultivation of corn, soybeans, and wheat, in that order. In 1996, these first three states accounted for 26 percent of the nation's corn production and 32 percent of soybean production. They represent 3.7 percent of the land area of the U.S., 11.1 percent of the cropland, and 16.8 percent of the value of farm products (**Table 2-5**). Barge movements accounted for 9.4 percent of nationwide shipments of farm products and19.9 percent of the movements out of Illinois, Indiana, and Ohio. In 1996, nearly 15 million tons of farm products were barged on the Ohio River system.

TABLE 2-4
Coal Reserves

Description	Major Coal Field	Demonstrated Reserves 1/ (mmtons)	% of Major Coal Field	% of US
Alabama	Appalachian	4,546.6	4.2%	0.9%
Eastern Kentucky	Appalachian	12,086.2	11.2%	2.4%
Ohio	Appalachian	23,663.9	21.9%	4.7%
Pennsylvania	Appalachian	21,426.6	19.8%	4.2%
Tennessee	Appalachian	815.7	0.8%	0.2%
Virginia	Appalachian	2,202.0	2.0%	0.4%
West Virginia	Appalachian	35,397.1	32.7%	7.0%
		100,138.1	**92.6%**	**19.7%**
Illinois	Interior	105,068.9	65.8%	20.7%
Indiana	Interior	9,916.5	6.2%	2.0%
Western Kentucky	Interior	19,954.4	12.5%	3.9%
		134,939.8	**84.5%**	**26.6%**
Appalachia		**108,088.8**		
Interior		**159,611.4**		
West		**240,039.5**		
US		**507,739.6**		

1/ Demonstrated coal reserves include beds of bituminous and anthracite coals 28 inches or more thick and sub-bituminous coal 60 inches or more thick at depths up to 1000 feet. Also included are lignite seams 60 inches or more thick that can be surfaced mined.

TABLE 2-5
Cropland and Value of Production
(Million Acres and Million $)

Area	Land Area	Cropland	Value of Production
IL, IN, OH	84.7	50.9	23,974
Rest of ORB	128.4	28.4	7,843
U.S.	2,263.2	460.0	142,442
IL, IN, OH as % of U.S.	3.7	11.1	16.8

2.3.3 Water Supply

Among the nation's streams, the Ohio River is second only to the lower Mississippi in terms of volume of flow. Streams flowing out of the Appalachian Mountains and the Allegheny plateau; the Monongahela, the Allegheny, the Kanawha, the Cumberland, and the Tennessee rivers contribute the greatest flow to the Ohio. However, its vast watershed is also drained by major streams like the Muskingum, the Scioto, the Little Miami, the Kentucky, the Green and the Wabash rivers. A system of reservoirs on these streams or their tributaries insures reliable flows for navigation and municipal and industrial water supply on the Ohio and its tributaries.

2.3.4 Woodlands

Forty-three percent of the basin is classified as forestland according to the Department of Agriculture. This compares to 29 percent for the nation as a whole (**Table 2-6**). Most of the basin's forested land is confined to the Appalachian Mountains or its western foothills and upland areas, though sizeable tracts of forestland can be found in southeastern Ohio and southern Illinois. While hardwoods, especially oaks, prevail, there are sizeable stands of cultivated southern pine in the Tennessee Valley in particular. Higher-grade hardwoods are harvested for domestic and foreign manufacture of furniture, while the lower grades are used for lumber, railroad timbers, packing material, and more recently, paper manufacture. The pines are used extensively for the manufacture of paper and cardboard, primarily in the Tennessee Valley and along the Gulf Coast.

TABLE 2-6
Land Use
(Million Acres)

Land Use	U.S.	%	Basin	%
Forest Land	648	29%	91	43%
Other	1,615	71%	122	57%
Total	2,263	100%	213	100%

2.4 ECONOMY

The economic environment in the ORB is quite similar to that of the country as a whole. It includes highly diversified manufacturing complexes, urban service and trade centers, rich agricultural areas, and industries centered on the utilization of the region's abundant natural resources.

The ORB is strategically situated to supply raw materials to other regions of the country. To the east, the populous northeastern corridor bounds the ORB. To the north lie the Upper Mississippi Valley and Great Lakes region. To the south, the Ohio and Mississippi rivers tie the region to the economies of the southern Atlantic and Gulf Coast regions.

In addition to its proximity to other economic regions and markets, the ORB is linked to those places by a diverse and well-developed transportation infrastructure. The centerpiece of this infrastructure is the ORS. The Ohio and navigable portions of the Allegheny, Monongahela, Kanawha, Green, Tennessee, Cumberland, and Kentucky rivers form a web of arteries for the inexpensive movement of goods within the ORB; connecting its industries to many other local and domestic markets.

Pittsburgh area steel producers gained some measure of advantage from their ready access to water transportation. This advantage contributed to the emergence o Pittsburgh as the steel-making center of the United States for most of the 20th century. The electric power industry also found ideal conditions for growth along the Ohio and its tributaries. Chemical and metals industries (particularly aluminum) also appeared in the region because of the availability of water transportation.

The economy of the basin is diversified, but more oriented towards coal mining and manufacturing than the whole U.S. economy. Focusing on coal mining, 62,840, or 77 percent of the nationwide total number of coal mining jobs, are located in the basin states (**Table 2-7**).

TABLE 2-7
Employment by Sector - 1998
(Percentages)

Sector	Ohio Basin	U.S.
Farming	2.1	2.6
Manufacturing	18.3	14.5
Mining (Coal)	0.2	0.001
Other	79.4	82.9
Total Number	27,367,400	129,204,000

2.5 CONCLUSIONS

The basin is rich in natural resources and is served by a transportation system that has served as a catalyst for extensive economic development. In summary, the principal resources are fertile soils, extensive forests, abundant water supplies, and large deposits of coal. The area is served by all modes of transportation, but with the unique regional advantage of the Ohio River, which bisects the basin. As a result, the area has a robust and diversified economy.

SECTION 3

WATERWAY DEPENDENT INDUSTRIES

3.1 GENERAL

Waterway dependent industries are those industries that realize some advantage for locating alongside a navigable waterway system. The two major advantages are the availability of a large and reliable supply of water for use in the industrial process, and the availability of an efficient and reliable waterway transportation system for the movement of goods into or out-of the facility. The transportation advantage is the advantage of interest to this study, since locks and dam projects are sized and constructed to facilitate waterway transportation. Other location factors, including taxes, labor force, terrain, and rail and road access are also important, but are beyond the scope of this study.

The degree of reliance on waterway transportation differs among industries. Moreover, in some cases the dependency is direct, while in other cases it is indirect. For example, a new electric furnace steel mill may not use the river at all for transportation, but it may have located in the area because of the availability of low-cost electricity from a nearby generating plant that receives coal by barge. Major industrial users of the waterways are shown in **Table 3-1**.

TABLE 3-1
Major Users of Waterway Transportation and Dependency

1. High Dependence
1) Coal Mining
2) Electric Generating
3) Coke Production
4) Steel Production
5) Petrol-Chemicals
6) Construction
7) Other Lower Profile Industries
2. Low Dependence
1) Agriculture
2) Wood Products

The major users of the waterway are the coal industry and the electric generating industry (see **Table 3-2**). While it is likely that both industries would have developed even without a navigable transportation system, it is unlikely that they would have grown to the extent that they have. The reason is that waterway transportation provides a cost-advantage over other modes, which allows coal produced in the area to be competitively priced in a geographically wider market than it would be otherwise. As far back as a

hundred years ago, coal produced in the Monongahela River Basin was shipped down-river as far as Oklahoma. In contrast, no coal was delivered overland to these markets. The same is true of the electric generating industry; because of the low transportation cost of waterway shipments, and the multiple sources of coal available via waterway transportation, electric generating costs in the basin are among the lowest in the nation.[1] Electricity produced in the basin can be economically exported to high-cost production areas. Again, the size of the market and the amount of electricity generated would be less without the transportation cost savings provided by the waterway system.

TABLE 3-2
ORS Waterway Commodity Traffic, 2001

Commodity		Tons (Millions)
Coal	**Total**	**157.1**
	Steam Coal	130.7
	Metalurgical Coal	10.1
	all else	16.3
Crude Petroleum	**Total**	**0.3**
Petroleum Products	**Total**	**20.2**
Chemicals	**Total**	**10.6**
	Fertilizers	2.8
	all else	7.8
Aggregates	**Total**	**46.7**
	Sand & Gravel	18.4
	Limestone	24.6
	all else	3.7
Grains	**Total**	**18.2**
Ores & Minerals	**Total**	**6.9**
Iron & Steel	**Total**	**11.0**
	Steel Scrap	1.6
	all else	9.4
Others	**Total**	**8.9**
	Wood Products	0.6
	all else	8.3
Grand Total		**279.9**

Low-cost electricity also attracted energy-intensive industries to the region. Foremost among these are the aluminum and the steel industries, particularly the new electric furnace plants that recycle scrap into steel. The principal input of both industries is electricity, and therefore, the availability of low-cost electricity is a major consideration in location decisions.

The traditional steel industry is similar to the electric generating industry in its relation to coal and secondary processors. First, coal is the basic fuel of the industry, although the coal is pre-processed at coke plants where impurities and other undesirable characteristics are removed. The coke is then transported to raw steel producing plants where it is burned to produce the heat to separate iron from other materials. The iron is

[1] According to the U.S. Department of Energy, Energy Information Administration, average revenue per kilowatt-hour is 5.9 cents for the eight Ohio River Basin states and 6.8 cents for the entire United States. Only six states have lower average revenues than the mean average revenue for the basin states.

transformed into steel, which is itself transformed into ingots, slabs, or other shapes for shipment to plants where it is used in the construction of appliances, automobiles, and other final consumer products. The availability of coal and the efficiency of transporting it by barge to Pittsburgh were major determinants in the early development of the steel industry in the Pittsburgh area.

While coal and coal/electricity-dependent industries are the major waterway dependent industries, there are important non-coal related industries as well. The largest of these, from a tonnage standpoint, is the aggregates industry, which produces limestone, sand, and gravel. Sand and gravel move by barge from waterside quarries and dredge sites to riverside yards and ready-mix plants, and in some cases, directly to construction sites. In addition to providing low cost transportation, shipment by barge minimizes the movement of trucks through congested areas. Waterside limestone quarries and mines supply these same construction industry users and the cement, lime, and electric utility industries as well. Two other major industries in the region are the oil and chemical industries. In the case of the chemical industry, raw feedstock materials generally come from petrol-chemical complexes located along the Gulf Coast. Barge-sized allotments are the most economical and safest way to supply Ohio Basin facilities producing specialized chemical products. One barge carries the equivalent of several rail cars and being double hulled, means spills are less likely. The petroleum industry in the basin relies heavily on the ORS for its transportation needs. One reason is that asphalt and fuel oil, two industry commodities, cannot be shipped by pipeline. This makes barge transportation the most sensible, economical, and reliable mode of transportation. Petroleum refiners depend on the waterways to ship final product to major urban areas located on the river.

Agriculture is an enterprise that uses the waterway transportation system extensively to link to domestic and overseas markets and to diversify its marketing options. Grain shippers often prefer barge to alternative modes because barges not only provide transportation, but also can serve as relatively low-cost floating warehouses. The waterway system serves as the primary conduit for Midwestern grains and other agricultural products to reach growing domestic and overseas markets. From a national perspective, access to the export market, especially via the Mississippi River, is the waterway's principal effect on agriculture. In the Ohio Basin, the waterway's role is divided between connecting upper Midwestern farmers with Southeastern grain processors and poultry producers, and connecting lower Ohio Basin farmers with the Mississippi River and the Gulf Coast.

Wood-related activities include timber harvesting for export, lumber, and the processing of wood for pulp and paper mills. While a limited amount of hardwood export occurs, most forest products move in the form of pulpwood or wood chips for eventual paper product manufacture. Paper and paper product manufacturers additionally support the manufacture and delivery of salt, which is used to make chlorine and caustic soda—direct inputs to paper and paper product manufacture. Chlor-alkali plants manufacture the critical chlorine and caustic soda inputs, and rely on waterborne shipments of salt, primarily from salt mines along the Gulf Coast. Chlor-alkali plants are often located close to paper plants, allowing chlorine shipments by pipeline and minimizing any transportation costs or risks.

There are a number of other water-dependent industries along the waterway that depend on the waterway more for water supply but also use the waterway as an optional transportation mode, and for an occasional barge shipment. These types of plants include mineral processing plants such as zinc, nickel, and aluminum plants. Other facilities are highly dependent on the waterway transportation system, but may ship modest quantities on the system. These facilities would include the intermodal ports that provide a wide variety of shipping options to a wide variety of industries and cargoes in order to survive.

3.2 HIGH-LEVEL DEPENDENCE

3.2.1 Coal Mining

The markets for coal are electric generating plants, coke plants, other industrial plants such as cement, and export. As a consumer of coal, the electric generating industry dwarfs the other sectors, consuming 911 million tons a year or 87 percent of the one billion tons of coal produced in the U.S. every year. The Ohio River Basin is an important production region and proximity to waterways provides a cost advantage over production in other regions of the country. A listing of the largest mines located in counties along the Ohio, Monongahela, Green, Kanawha, and Big Sandy rivers is provided in **Table 3-3**, along with production numbers for 2001. Over ten percent of national production came from these large ORB mines in 2001.

Coal production in the Appalachian region of the basin was up in 2001. Most of the increase was accounted for by the two major coal producing states in the region—Eastern Kentucky and West Virginia even though West Virginia coal production was constrained by a lawsuit in Federal court involving mountaintop removal and valley fills. Eastern Kentucky's production rose and Pennsylvania produced about the same as in the previous year. Ohio, the fourth largest coal producing state in the Appalachian region also increased coal production. Alabama and Tennessee had slight increases in their coal production in 2001. The Interior region increased coal production in 2001 as well. Reflecting the opening of three new mines in 2001 in Indiana, as well as the first full year of production by four other coal mines in the state, the greatest increase in tonnage in the Interior region was registered by Indiana. Coal production in Western Kentucky dropped in 2001, while production in Illinois increased marginally. **Table 3-4** shows the number of ORB coal mines, by state, and the overall decrease in their number since 1996.

3.2.2 Electric Generation

The electric generating industry is one of the little noticed, but key industries, in the nation's economy. Its importance is little appreciated until we are without power, and find ourselves groping in the dark for candles and throwing out food from our refrigerators. The electric power industry is currently undergoing radical change. The industry has been dominated by monopolistic and tightly regulated utilities. Technological innovation and consumer demand for choice provides an impetus for the deregulation of electric utilities. Deregulation is slowly introducing competition into the generation and wholesale selling of electricity.

TABLE 3-3
Major ORB Waterside Coal Mines, 2001

State	County	Company	Mine	Kilotons
IL	Gallatin	Coal Miners, Inc.	Eagle Valley Mine	1,316
		State Total		**1,316**
IN	Warrick	Peabody Coal Co.	Lynnville Surf & Prep Plant	999
IN	Warrick	Peabody Coal Co.	Squaw Creek & Prep Plant	407
IN		**State Total**		**1,407**
KY	Union	Peabody Coal Co.	Camp No. 1	1,424
KY	Union	Peabody Coal Co.	Camp No. 11	1,541
KY	Union	Island Creek Coal Co.	Ohio #11 Undrgrd Mine	667
		State Total		3,632
OH	Belmont	Ohio Valley Coal Co.	Powhatan No. 6 & Prep Plant	4,611
OH	Meigs	Southern Ohio Coal Co.	Meigs 31 & Prep Plant (Ms-293)	2,165
OH	Meigs	Southern Ohio Coal Co.	Meigs No. 2 (Ms-294)	2,120
OH	Monroe	Quarto Mining Co.	Powhatan #4 Mine & Prep	448
		State Total		**9,344**
PA	Greene	Consolidation Coal Co.	Bailey No. 1 mine	10,327
PA	Greene	Cyprus Cumberland Resources	Cumberland Mine & Prep Plant	6,655
PA	Greene	Consolidation Coal Co.	Dilworth Mine (NWV Region)	5,034
PA	Greene	Enlow Fork Mining Co.	Enlow Fork Mine	10,326
PA	Greene	Cyprus Emerald Resources Corp.	Emerald No. 1 mine & Prep	6,738
PA	Greene	New Warrick Mining Co.	Warwick #3 Undrgrd & Prep Plant	
PA	Somerset	PBS Coal Mining, Inc.	PBS No. 1 Surface Mine	
PA	Washington	Maple Creek Mining, Inc.	Maple Creek	2,642
PA	Washington	MonView Mining, Inc.	Mathies Mine & Prep Plant	1,280
PA	Washington	Eighty Four Mining Co.	Mine No. 84	3,595
		State Total		**46,597**
WV	Barbour	Phillipi Development, Inc.	Sentinel Mi 1583/2587	
WV	Brooke	Windsor Coal Co.	Windsor Mine & Prep Plant	
WV	Harrison	Consolidation Coal Co.	Robinson Run #95 D-4786 & Prep	4,910
WV	Marion	Consolidation Coal Co.	Loveridge #22 D-402 & Prep	
WV	Marshall	McElroy Coal Co.	McElroy Mi 5443	
WV	Marshall	Consolidation Coal Co.	Shoemaker Mi 4791	4,088
WV	Monongalia	Consolidation Coal Co.	Blacksville No. 2 Mine & Prep	
WV	Monongalia	Eastern Associated Coal Corp.	Federal No. 2 & Prep	4,878
WV	Monongalia	Consolidation Coal Co.	Humphrey No. 7 D-415 & Prep	
WV	Monongalia	Patriot Mining Co., Inc.	Osage & Bethel	
WV	Fayette	Cyprus Kanawha Corp.	Armstrong Creek	
WV	Kanawha	Cannelton Industries, Inc.	Stockton Mine	
WV	Kanawha	Dunn Coal & Dock	No. 1	
WV	Wayne	Pen Coal Corp.	Kiah Creek Surface Mine	
WV	Wayne	Rockspring Development Co.	Camp Creek Mine	
		State Total		**13,876**
		Grand Total		**72,540**

Source: EIA Annual Coal Report, Major U.S. Coal Mines, 2001

TABLE 3-4
Number of ORB Coal Mines, 1996-2001

ORB State	1996	1997	1998	1999	2000	2001	Av. Ann. Pct. Chnge. 1996-01
Alabama	53	51	53	47	42	40	-5.47%
Indiana	37	39	41	34	30	33	-2.26%
Illinois	31	28	24	23	18	20	-8.39%
Kentucky	544	529	482	458	408	467	-3.01%
Ohio	99	81	83	79	60	60	-9.53%
Pennsylvania	402	403	375	339	307	266	-7.93%
Tennessee	26	27	27	24	20	23	-2.42%
West Virginia	386	349	346	306	297	304	-4.66%
U.S. Total	1,903	1,828	1,726	1,591	1,453	1,512	-4.50%

The electric power industry involves the generation, transmission, and distribution of electricity. Fossil fuels are the most widely used fuel for electricity generation. Coal is the most widely used fossil fuel in the United States, and particularly in the ORB. In fact, the ORB is the U.S. region most dependent upon coal for electric power generation. Fossil fuels are transported to generating plants by rail, river barge, truck, conveyor, and pipeline with a modal share of 15 percent, 78 percent, 5 percent and 2 percent resprctively. Electricity is transmitted from generating plants to consumers by wire. The electric power industry is the largest user of the ORS. In 2001, over 130 million tons of coal and 2.3 million tons of lime were barged to electricity generating plants. These movements represent almost fifty percent of total tonnage transported on the ORS.

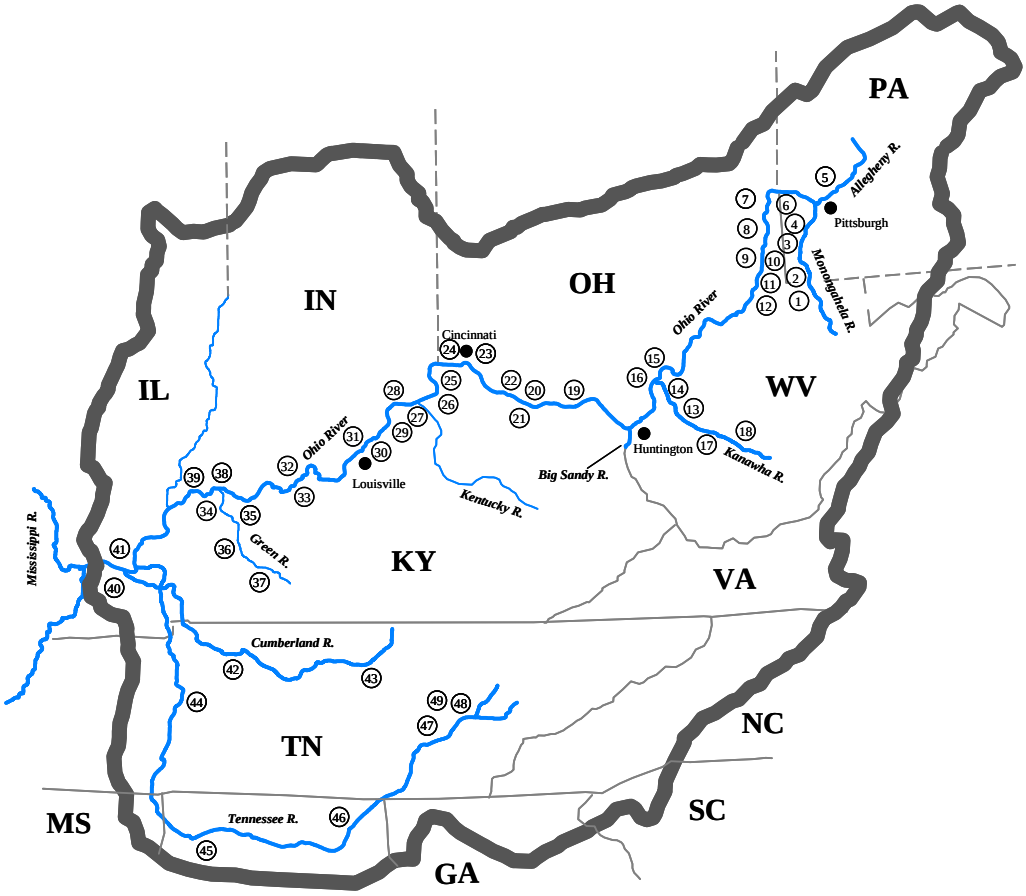
The electricity industry is an important consumer, as well as a key producer, in the economy. The industry consumes about 87 percent of the over 1 billion tons of coal produced in the country (**Table 3-5)**. Of this amount, about 14 percent or nearly 120 million tons moves on the Ohio River system to waterside power plants. The tonnage accounts for about 1 of every 2 tons shipped on the system. **Figure 3-1** shows the location of the coal-fired power plants along the river system and **Table 3-6** shows the capacity and coal-burn of each plant. The waterside power plants shown in Figure 3-1 and listed in Table 3-6 receive over 78 percent of its coal by barge

TABLE 3-5
U.S. Coal Production and Consumption, 1999-2004
(Million Tons)

Item	1999	2000	2001	2002	2003	2004
Production by Region						
Appalachian	425.6	419.4	431.2	396.2	376.0	389.3
Interior	162.5	143.5	146.9	146.6	146.0	145.8
Western	512.3	510.7	547.9	550.4	548.7	575.2
Total	1,100.4	1,073.6	1,126.0	1,093.2	1,070.7	1,110.3
Consumption by Sector						
Electric Power	940.9	985.8	965.1	977.5	1,005.1	1,015.1
Coke Plants	28.1	28.9	26.1	23.7	24.2	23.7
Other Industrial Plants	64.7	65.2	65.3	60.7	61.3	61.2
Combined Heat and Power (CHP)	27.7	28.0	26.4	26.2	24.8	28.0
Non-CHP	37.0	37.2	38.8	34.5	36.4	33.2
Residential	0.6	0.5	0.5	0.5	0.5	0.5
Commercial	4.3	3.7	3.9	4.0	3.8	3.8
Total	1,103.3	1,149.3	1,126.1	1,127.1	1,156.1	1,165.5

Source: U.S. Energy Information Administration, *U.S. Coal Supply and Demand: 2004 Review*, table 1.
http://www.eia.doe.gov/cneaf/coal/page/special/feature04.pdf

FIGURE 3-1
Coal-Fired Power Plants along the ORS



Code	Plant	Code	Plant	Code	Plant
1	Fort Martin	18	Kanawha Rv	35	Wilson
2	Hatfield	19	Killen	36	Green River
3	Mitchell	20	Stuart	37	Paradise
4	Elrama	21	Spurlock	38	Warrick
5	Cheswick	22	Zimmer	39	Brown
6	Mansfield	23	Beckjord	40	Shawnee
7	Sammis	24	Miami Fort	41	Joppa
8	Cardinal	25	Tanners Crk	42	Cumberland
9	Burger	26	East Bend	43	Gallatin
10	Kammer	27	Ghent	44	Johnsonville
11	Mitchell	28	Clifty Crk	45	Colbert
12	Pleasants	29	Trimble	46	Widows Crk
13	Mountaineer	30	Mill Crk	47	Watts Bar
14	Sporn	31	Gallagher	48	Kingston
15	Gavin	32	Rockport	49	Bull Run
16	Kyger Creek	33	Coleman		
17	Amos	34	Reid		

TABLE 3-6
Waterside Electric Generating Plants

Name	Milepoint*	River	State	Electricity Generation (MWh)	Coal Consumption (Ktons)
Amos	39.7	Kanawha	WV	15,332,459	5,891.27
Beckjord	452.9	Ohio	OH	5,996,393	2,581.65
Brown	0.0	Ohio	IN	2,463,116	1,148.86
Bull Run	47.6	Clinch	TN	5,005,472	1,781.99
Burger	102.3	Ohio	OH	2,083,114	852.97
Cardinal	76.2	Ohio	OH	9,318,453	3,751.46
Cheswick	15.4	Allegheny	PA	3,075,764	1,231.58
Clifty Crk	559.6	Ohio	IN	9,731,944	4,909.20
Colbert	245.3	Tennessee	AL	7,700,791	3,224.20
Coleman	728.5	Ohio	KY	3,028,554	1,408.85
Cumberland	103.4	Cumberland	TN	16,172,326	6,867.29
East Bend	511.0	Ohio	KY	3,911,592	1,614.75
Elrama	25.1	Monongahela	PA	2,557,114	1,171.99
Fort Martin	92.0	Monongahela	WV	5,338,113	2,037.71
Gallagher	610.1	Ohio	IN	2,655,158	1,158.53
Gallatin	244.1	Cumberland	TN	6,587,951	2,574.40
Gavin	258.5	Ohio	WV	16,861,183	7,367.77
Ghent	535.8	Ohio	KY	11,916,391	4,995.45
Green River	81.5	Green	KY	708,250	354.78
Hatfield	79.0	Monongahela	PA	9,028,465	3,439.43
Johnsonville	99.6	Tennessee	TN	7,653,279	3,687.73
Joppa	952.3	Ohio	IL	7,873,723	4,833.63
Kammer	111.1	Ohio	WV	4,529,114	1,786.55
Kanawha Rv	78.3	Kanawha	WV	1,920,846	763.62
Killen	390.6	Ohio	OH	4,274,313	1,750.61
Kingston	2.6	Clinch	TN	9,782,767	3,851.90
Kyger Creek	259.6	Ohio	OH	7,739,685	2,924.82
Mansfield	33.1	Ohio	PA	14,556,736	5,944.03
Miami Fort	490.1	Ohio	OH	7,474,143	3,049.96
Mill Crk	626.5	Ohio	KY	8,765,110	3,995.44
Mitchell	112.3	Ohio	WV	8,296,523	3,213.29
Mitchell	29.5	Monongahela	PA	788,777	338.73
Mountaineer	243.4	Ohio	WV	7,363,098	2,756.07
Paradise	99.5	Green	KY	14,335,401	6,117.32
Pleasants	160.5	Ohio	WV	8,232,933	3,454.05
Reid	41.2	Green	KY	85,973	45.20
Rockport	744.7	Ohio	IN	16,790,788	10,100.27
Sammis	52.9	Ohio	OH	13,858,788	5,800.34
Shawnee	946.0	Ohio	KY	7,923,517	3,572.54
Sporn	241.6	Ohio	WV	5,900,556	2,343.48
Spurlock	414.1	Ohio	KY	5,453,418	2,177.98
Stuart	404.5	Ohio	OH	13,860,448	5,770.66
Tanners Crk	494.0	Ohio	IN	4,936,598	1,939.41
Trimble	0.0	Ohio	KY	3,016,348	1,419.80
Warrick	774.0	Ohio	IN	1,149,274	538.57
Watts Bar	529.1	Tennessee	TN	-2,756	0.00
Widows Crk	407.3	Tennessee	AL	8,766,790	3,985.68
Wilson	74.0	Green	KY	3,045,944	1,380.21
Zimmer	0.0	Ohio	OH	10,266,343	4,042.93

* Mile points indicate distance from source for the Ohio River and distance from the mouth for tributaries.

3.2.3 Coke Production

Coal is pre-processed in coke plants to remove impurities and other undesirable characteristics prior to use in a traditional steel plant. The process is accomplished in a series of ovens, which effectively bake out the impurities. By-products of the process include gases, which are often transported to adjacent plants for use as inputs in chemical processing. The coke itself is transported to steel plants where it is used to process iron ore into iron and thence into steel. A listing of the waterside coke plants in the basin is provided in **Table 3-7**. The number of coke plants within the basin and the country as a whole has declined significantly over the past 20 years, such that the remaining plants are generally considered to be internationally competitive. The coke plant at Clairton is the largest in the country; its output goes to USX steel plants throughout the country.

TABLE 3-7
Waterside Coke Plants

Name	Milepoint	River	State
AK Steel	320.0	Ohio	KY
New Boston Coke Corp.	351.0	Ohio	OH
Koppers Industries	38.0	Monongahela	PA
Shenango, Inc.	8.0	Ohio	PA
USX Clairton	20.1	Monongahela	PA
Wheeling-Pittsburgh Steel	69.0	Ohio	WV

3.2.4 Steel Production

Iron and steel are two of the most important materials in an industrial economy. Steel is used in construction, automotive assembly, and appliances. Regionally, steel production has declined precipitously since the early 1980s, when most of the old integrated plants in the Pittsburgh area were closed and demolished. The construction or expansion of electric arc furnaces led to a resurgence of steel production in the 1990s. New mini-mills have sprung up on the Ohio and Tennessee rivers. This growth was accompanied by continuing expansion of the automobile industry in the Ohio River Basin. The industry remains a key generator of barge transportation. A list of the major waterside steel plants in the basin is provided in **Table 3-8**.

TABLE 3-8
Major Waterside Steel Plants

Name	Milepoint	River	State	Type	Capacity (mmtons)
AK Steel	320.0	Ohio	KY	BOF	2
Kentucky Electric	n/a	Ohio	KY	Electric	n/a
Gallatin Steel	536.0	Ohio	KY	Electric	1.0
Newport Steel	2.0	Licking	KY	Electric	0.7
Steel of West Virginia	307.0	Ohio	WV	Electric	0.3
Weirton Steel	63.0	Ohio	WV	BOF	3.0
Wheeling	69.0	Ohio	WV	BOF	2.4
USX	11.0	Monongahela	PA	BOF	2.9

3.2.5 Petrol-Chemicals

The petroleum industry generates large volumes of traffic on the inland waterways in the form of refined petroleum product outputs and, to a much lesser extent, crude oil inputs. The chemical industry is comprised of basic chemical building blocks (low-value bulk) and final products (primarily high-value except fertilizer which is also bulk). This means that only basic chemicals and fertilizer are candidates for barge traffic.

The heaviest concentration of chemical companies is on the Kanawha River and on the Ohio River between Marietta and Portsmouth, Ohio. One medium-sized refinery, located in Ashland, Kentucky, is located on this same stretch of river. Other petrol-chemical facilities (**Table 3-9**) ranging from plants to tank farms are located throughout the basin.

TABLE 3-9
Waterside Petrol-Chemical Facilities

Name	Milepoint	River	State	Type
Amoco Chemicals Corp.	299	Tennessee	AL	Petro
Aristech Chemical Co.	337	Ohio	OH	Chem
Ashland Petroleum Co.	317	Ohio	WV	Petro
Ashland Petroleum Co. Midland	35	Ohio	PA	Petro
B.F. Goodrich Co.	17	Tennessee	KY	Chem
Chevron Chemical Co.	177	Ohio	OH	Chem
Dow Corning	541	Ohio	KY	Chem
Dupont	68	Kanawha	WV	Chem
Koppers Industries, Inc.	70	Ohio	WV	Chem
Monsanto Co.	302	Tennessee	AL	Chem
Nova Chemicals, Inc.	30	Ohio	PA	Chem
PPG Industries, Inc.	120	Ohio	WV	Chem
Quaker State Oil	47	Ohio	WV	Petro
Union Carbide Corp.	55	Kanawha	WV	Chem

3.2.6 Construction

Construction activities are important markets for a wide variety of industries. Waterway transportation is used to move bulk construction materials: crushed stone, gravel, sand, cement, concrete, asphalt, and structural steel. While movements of these materials are directly affected by building construction, heavy construction is responsible for the largest waterway flows. Heavy construction projects are major consumers of stone, with large waterway improvement projects being especially important to waterside aggregate producers.

Construction is the largest consumer of raw materials of any industry in the country. The principal raw materials are stone, sand and gravel, steel, and wood products. Most waterborne construction material is crushed stone, sand and gravel used in making concrete. Typically, barges move the aggregate from quarry or dredge site to ready mix plants or stone yards located in or near urban areas. The waterway leg allows the shipper to bypass populated areas with their large bulk flows, while still getting product where they need it. Trucks are generally used to transport product to the work site, though some large construction projects receive aggregate by barge directly.

3.2.7 Other Lower Profile Industries

The list of industries and facilities dependent on the waterway system is extensive, and only the major ones are listed above. Some of the "lower profile" industries are highly dependent on the waterways, but involve lower volumes due to the nature of the business and/or the value of the product.

3.2.7.1 Steel Recycling

The steel scrap business involves the acquisition of junked autos, appliances, industrial trimmings, and other items and processing these items into prime scrap. Processing involves the removal of non-steel components from the junked items. The prime scrap is then sold to steel plants which either blend the scrap with iron to produce steel, or which make steel entirely from melting scrap in an electric furnace. The scrap is sold to both domestic and foreign companies.

Scrap is the major input to electric arc furnaces. Much of the scrap used is generated by the steel production process (home scrap) and by metal processors and users (purchased scrap). Mini-mills have traditionally located near their markets and a source of scrap (major urban areas). Scrap is generally moved by rail and to a lesser extent by truck. Some mini-mills have located near rivers to receive scrap by barge.

The U.S. steel industry consumed over 63 million tons of scrap in producing over 99 million tons in 2001. Because of the low value and broad and dispersed sources of scrap, many scrap companies choose to locate along the river system. Prime scrap is generally railed to domestic mills and barged to New Orleans for foreign mills. Shipments of scrap on the Ohio River system totaled 1.6 million tons in 2001.

3.2.7.2 Synthetic Fuel Production

Decades of mining have resulted in millions of tons of waste materials that are aesthetically and environmentally detrimental. Efforts are underway to economically cleanup up these piles of wastes. One effort involves the conversion of part of the wastes into useful products, such as synthetic fuels. The synthetic fuels, referred to as briquettes, are reusable by either the utility industry or the steel industry, depending on the grade of the briquettes. Again, the businesses prefer a waterside site since the wastes come from multiple origins, which are often on or near the water.

3.2.7.3 Gypsum Recycling

Synthetic gypsum, which is a byproduct of flue gas desulfurization, a process that removes SO_2 from coal-fired emissions, is used to produce wallboards for construction industry. Again, the businesses prefer a waterside site since the wastes come from multiple origins, which are often on or near the water.

3.2.7.4 Aluminum and Zinc Production

The principal minerals refined at basin plants are aluminum bauxite and zinc oxide. The Ohio River Basin is home to the second largest concentration of aluminum plants in the U.S. Aluminum plants are located in the region because of low-cost electricity afforded by the region's coal and hydroelectric power plants. While most zinc used in the U.S. is imported, zinc ores are processed in the basin because of localized deposits on the Tennessee River. The ore is barged to refiners on the Cumberland, McClellan-Kerr-Arkansas, and Ohio rivers.

3.2.7.5 Cement and Lime Production

Rich, vast deposits of limestone supply more than just crushed stone for heavy construction. These deposits also support cement and lime production, which is centered in the southern and western portion of the basin. Numerous cement kilns in Ohio, Indiana, Kentucky, Illinois, Missouri, Tennessee, and Alabama receive limestone and ship cement by barge. Six lime kilns located in Kentucky, Missouri, and Tennessee rely upon waterborne limestone, and in turn ship lime to the region's steel makers, paper plants, and electric utilities.

3.3 LOWER LEVEL DEPENDENCE

Farming is dependent on waterway transportation to the extent that waterway transportation allows farm products to be competitive in distant markets. This, in turn, affects the farmer's selection of what to grow since the market for high valued products expands with distance. The most distant markets are overseas, while closer markets are generally food-processing plants. A listing of facilities used to load or unload barges of farm products is provided in **Table 3-10**.

TABLE 3-10
Waterside Facilities for Farm Products

Name	Milepoint	River	State
A.E. Staley	592	Tennessee	TN
Aurora Terminal Co., Inc.	496	Ohio	IN
Bunge Corp.	980	Ohio	IL
Cargill, Inc.	793	Ohio	IN
Cargill, Inc.	479	Ohio	OH
Consolidated Grain & Barge	597	Ohio	IN
Consolidated Grain & Barge	475	Ohio	OH
Continental Grain Co.	831	Ohio	IN
Garnac Grain Co.	780	Ohio	IN
Hopkinsville Elevator Co.	123	Cumberland	TN
Indiana Port Commission	831	Ohio	IN
Livingston Point River Terminal	4	Tennessee	KY
Owensboro Grain Co.	756	Ohio	KY
Peavey Co.	805	Ohio	KY
Wabash Elevator Co.	843	Ohio	KY

Paper and wood product production are major activities in the southern part of the basin, particularly along the Tennessee River. Shipments of products to and from these plants are of significant local importance, although minor in terms of overall Ohio River System tonnage.

3.4 CONCLUSION

All industries in the ORB are to some degree dependent on the existence of an efficient and reliable navigation system. This includes industries that may never have shipped via barge and have no plans for doing so. In fact, some of the industries most highly dependent on waterway transportation do not ship on the rivers, but depend on the cost-savings that it provides to their suppliers, making them both more competitive. The waterway transportation system allows for lower transportation costs, and therefore lower delivered costs of basic raw materials, most importantly coal, ores, chemicals and stone, to secondary producers of goods such as electricity, coke, specialty chemicals, and construction materials. In turn, these industries generally spawn tertiary producers of items like steel coils and slabs, aluminum, and paper products, which are then used in factories that produce final consumer goods such as automobiles, appliances, utensils, packaging, and food products.

Section 6 of this appendix, Historic and Projected Traffic, documents the steady growth of waterway traffic over the past 63 years (**Table 3-11**) and provides indisputable evidence of basin shipper's dependence on the ORS. With the exception of export demand for coal and grain, the preponderance of commodities shipped on the waterway are *relatively unaffected* by changes in waterway prices. Both raw material production facilities and the downstream production facilities they supply represent major capital investments. More importantly for this study, these investments represent a long-term commitment to the waterway, a commitment likely unwavering over a 20- to 30-year horizon. There are a number of reasons for this. Alternative development sites are

extremely limited for quarries, power plants, steel mills, coal mines, chemical plants, petroleum refineries, and paper mills. Some of these facilities are legacies of job-rich economic development now considered undesirable in other areas of the country. Also, in many instances, production is geographically circumscribed, as is the case with stone, wood products, and coal. Consuming plants may also require specifications unique to a particular ORB resource. This is particularly true with respect to the requirements of some utility plants for certain grades of coal for their boilers and chemical properties of limestone for their flue-gas de-sulfurization units. Finally, transportation options are often extremely limited. Large machines and steel fabrications, like electricity generators, often can move no other way than by water, and high volume bulk commodity shipments can be moved in a less disruptive fashion past major urban concentrations when they use the waterways. Limited alternatives for locating new plants, substituting product from other areas, and arranging alternative transportation act to make long run demands for waterway service in the ORB relatively stable.

TABLE 3-11
Historic ORS and Mainstem Traffic
(Million Tons)

	Ohio River		Mainstem
Year	**Mainstem**	**System**	**% Total**
1940	29.5	51.2	57.6%
1950	48.6	66.1	73.5%
1960	79.5	105.3	75.5%
1970	129.6	163.9	79.1%
1980	174.9	200.5	87.2%
1990	225.7	257.8	87.5%
2000	236.3	271.7	87.0%
2003	228.8	259.8	88.1%
Avg. Annual			
1940-2003	3.3%	2.6%	
1990-2003	0.1%	0.1%	

Source: WCSC data.

SECTION 4

OHIO RIVER NAVIGATION SYSTEM

4.1 INTRODUCTION

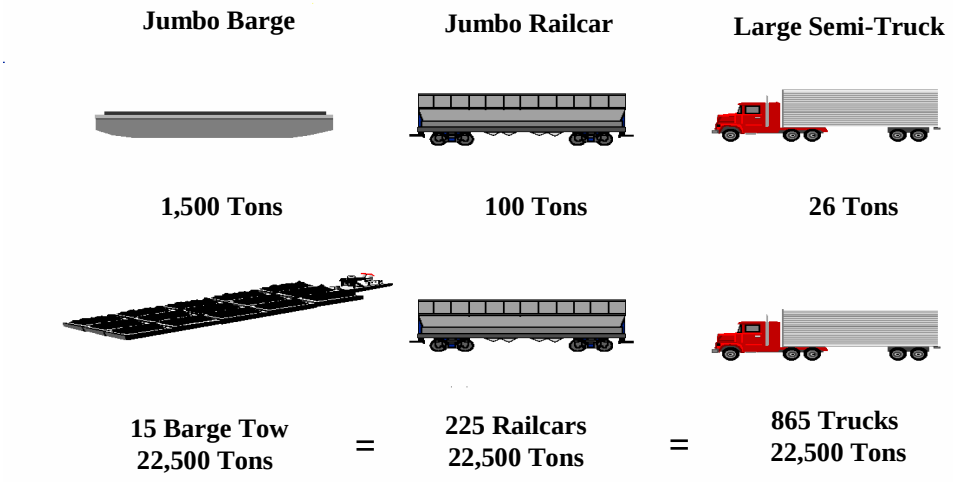
The Ohio River navigation system (ORS) is a major portion of the nation's inland navigation system, providing commercial navigation in the eastern one-third of the country. The ORS consists of more than 2,600 miles of commercially navigable waterways. It includes the Ohio River and the navigable portions of the Allegheny, Monongahela, Kanawha, Big Sandy, Green, Tennessee, Cumberland, and Kentucky rivers. The Ohio River serves as a collector of system traffic for distribution to points within and outside the Ohio basin while the tributary streams serve major mining areas and industrial concentrations within the Basin. Through interconnections with the Mississippi River and its tributaries, ORS traffic has access to Midwestern states and deep-draft ports on the Great Lakes and Gulf Coast. Year–round navigation on the Ohio River is provided by a system of 20 locks and dams and annual maintenance dredging.

Tows moving on the ORS system are configured to operate as efficiently as possible along each waterway segment. Lock size and channel dimensions are critical in limiting the most efficient tow configuration. Currently, the Ohio River fleet consists mostly of jumbo barges. A typical Ohio River tow is a 3,500 horsepower towboat moving 15 barges, while tows for tributaries are smaller, due to channel and lock restrictions.

Barge transportation is an energy efficient mode for carrying large quantities of bulk commodities. A typical barge can carry as much coal or grain as 15 rail cars for about the same energy per ton-mile. On certain river segments, river efficiency is much greater than rail due to the back haul opportunities barging provides. **Figure 4-1** compares the average carrying capacity for jumbo barges, railcars, and large semi-tractor trailers. The figure shows that a typical Ohio River tow carrying 22,500 tons is the equivalent of 225 railcars (2.25 unit trains) and 865 trucks.

The study area includes the mainstem Ohio River, which extends from the junction of the Allegheny and Monongahela rivers at Pittsburgh, Pennsylvania, to near Cairo, Illinois where the Ohio joins the Mississippi River. This area includes 981 miles of commercially navigable channel and a total drainage area of 204,000 square miles. Year-round navigation is provided by a system of 20 locks and dams (see **Figure 4-2)** and annual maintenance dredging. The drainage area encompasses all or portions of fourteen states: Alabama, Georgia, Kentucky, Indiana, Illinois, Maryland, Mississippi, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. The navigable tributary streams to the Ohio River are not part of this draft report.

Figure 4-1
Modal Carrying Capacity



4.2 HISTORY OF DEVELOPMENT

Federal involvement in improving the Ohio River for commercial navigation began in 1824, when Congress directed the Corps to find a method for removing sandbars and snags. In 1906, the Rivers and Harbors Board recommended construction of 54 locks and dams providing a nine-foot channel for the entire length of the Ohio River. This plan, which called for 600-foot long lock chambers, was completed by the Corps between 1910 and 1929.

Once canalization was completed, the waterway spurred economic growth and assisted the rapid nationwide mobilization during World War II. Sustained post-war expansion of the national economy increased the use of all types of commodities carried on the river. This rapid growth in traffic exceeded the government's ability to increase lock capacity and by the 1950s serious delay problems had become obvious. The original 600-foot lock chambers built during the days of steamboats and small wooden barges were obsolete and could not handle modern tows (flotillas of bigger, steel barges pushed by diesel powered boats) in a single lockage.

FIGURE 4-2

Locks and Dams of the Ohio River Navigation System

4.3 RECENT LOCKS AND DAM IMPROVEMENTS

Diesel towboats and the new, larger barges brought increased efficiency to the movement of the energy, construction, and food products demanded by a world newly re-constructed following WW II. These efficiencies, however, could not be fully realized because the ORS remained a system designed to accommodate the transportation technology of the previous century. Lock chambers were small, typically with a main lock chamber 600 by 110 feet and an auxiliary lock chamber 360 by 56 feet, and because wicket dams were low-lift structures, the projects were relatively close together. As a result, plans were formulated in the 1950s to modernize the navigation system. The plans called for the replacement of the many low-lift structures with fewer high-lift structures and larger locks. The modernized structures provide higher-lift dams with longer pool-reaches between projects, and larger lock dimensions. The modernization program envisioned 19 modern high-lift projects and began in 1954 with construction of Greenup Locks and Dam with a 30-foot lift, a 1200-foot by 110-foot main

chamber, and a 600-foot by 110-foot auxiliary chamber. The specifications for the existing 20 mainstem lock and dam projects are listed in **Table 4-1**.

TABLE 4-1
Ohio River Lock Specifications

Lock & Dam	River Mile	Year Operational			Year Rehabilitated			Chamber Sizes	
Project Name	(downstream of Pittsburgh)	Main	Aux.	Dam	Main	Aux.	Dam	Main	Aux.
Emsworth	6.2	1921	1921	1922	1984	1984	1984	600 X 110	360 X 56
Dashields	13.3	1929	1929	1929	1990	1990	1990	600 X 110	360 X 56
Montgomery	31.7	1936	1936	1936	1989	1989	1989	600 X 110	360 X 56
N. Cumberland	54.4	1956	1959	1961				1200 X 110	600 X 110
Pike Island	84.2	1963	1963	1965				1200 X 110	600 X 110
Hannibal	126.4	1972	1972	1975				1200 X 110	600 X 110
Willow Island	162.4	1972	1972	1973				1200 X 110	600 X 110
Belleville	203.9	1968	1968	1969				1200 X 110	600 X 110
Racine	237.5	1967	1967	1970				1200 X 110	600 X 110
R.C. Byrd	279.2	1993	1993	1937			2000+	1200 X 110	600 X 110
Greenup	341.0	1959	1959	1962				1200 X 110	600 X 110
Meldahl	436.2	1962	1962	1964				1200 X 110	600 X 110
Markland	531.5	1959	1959	1964				1200 X 110	600 X 110
McAlpine	606.8	1961	1921	1964		1965		1200 X 110	1200 X 110 a
Cannelton	720.7	1971	1971	1971				1200 X 110	600 X 110
Newburgh	776.1	1975	1975	1975				1200 X 110	600 X 110
J.T. Myers	846.0	1975	1975	1975				1200 X 110	600 X 110
Smithland	918.5	1979	1979	1979				1200 X 110	1200 X 110
L&D No. 52	938.9	1969	1928	1929		1983	1984	1200 X 110	600 X110 b
L&D No. 53	962.6	1980	1929	1929		1982	1984	1200 X 110	600 X 110 b

a. The new McAlpine 1200' x 110' chamber became operational in 2009

b. Olmsted L/D (now under construction near L/D 53), will replace both L/Ds 52 and 53

b. Olmsted L/D will have 2 identical 1200' x 110' chambers

The modernization program continues today with improvement of Robert C. Byrd L/D located upstream of Huntington, West Virginia; Olmsted L/D on the lower Ohio River; and McAlpine L/D located near Louisville, Kentucky. In January 1993, the new Robert C. Byrd locks, measuring 1200 by 110 feet and 600 by 110 feet, became operational -- replacing the small and outdated locks at Gallipolis, Ohio; major rehabilitation of the dam was completed in September 2000. The new Olmsted L/D project at river mile 964.4 is currently under construction. The project, which will provide a modern structure to replace old L/D 52 and L/D 53, consists of twin 1200 by 110-foot locks and a new dam with submersible gates to allow tow passage over the dam during higher flow conditions. Construction was initiated in 1993 and this study assumes Olmsted online. With completion of Olmsted, the Ohio River mainstem will be reduced from 20 to 19 lock and dam structures. The Water Resources Development Act of 1990 authorized improvement of McAlpine L/D at river mile 606.8. The project is currently under construction and will replace the old 600-foot auxiliary lock with a new 1200-foot chamber -- providing this site with twin 1200 by 110-foot locks. This study assumes twin1200-foot chambers at McAlpine.

4.4 CURRENT STATE OF THE WATERWAY

The mainstem Ohio River is currently a large canalized river consisting of 20 pools formed by 20 lock and dam structures. There will be 19 pools and 19 locks and dam structures after completion of Olmsted L/D in 2010, which replaces L/Ds 52 and 53. The current profile of the Ohio River mainstem is described in **Figure 4-3**.

The current geometry of the river, as improved by the higher pool levels of the modernized dam system, generally provides for safe navigation of commercial tows as long as they are no more than 1200 feet long and 108 feet wide. A typical Ohio River jumbo-hopper-barge tow consists of fifteen 195 by 35-foot barges, plus a towboat of varying dimensions, resulting in a tow of about 1170 feet by 105 feet. Occasionally, tows on the lowermost reaches of the Ohio, below Smithland L/D, operate in a double-wide configuration of 30 barges (5 long and 6 wide), typical of the larger tows on the lower Mississippi River. During winter months, these unusually wide tows can navigate over the navigable wickets of Dams 52 and 53 (and after 2010 the wickets at the new Olmsted Dam). Such tows cannot navigate these reaches during the dryer months, when they must use the locks at L/D 52 and 53.

In terms of age and operating characteristics, the lock and dam facilities may be classified into 3 broad groups:

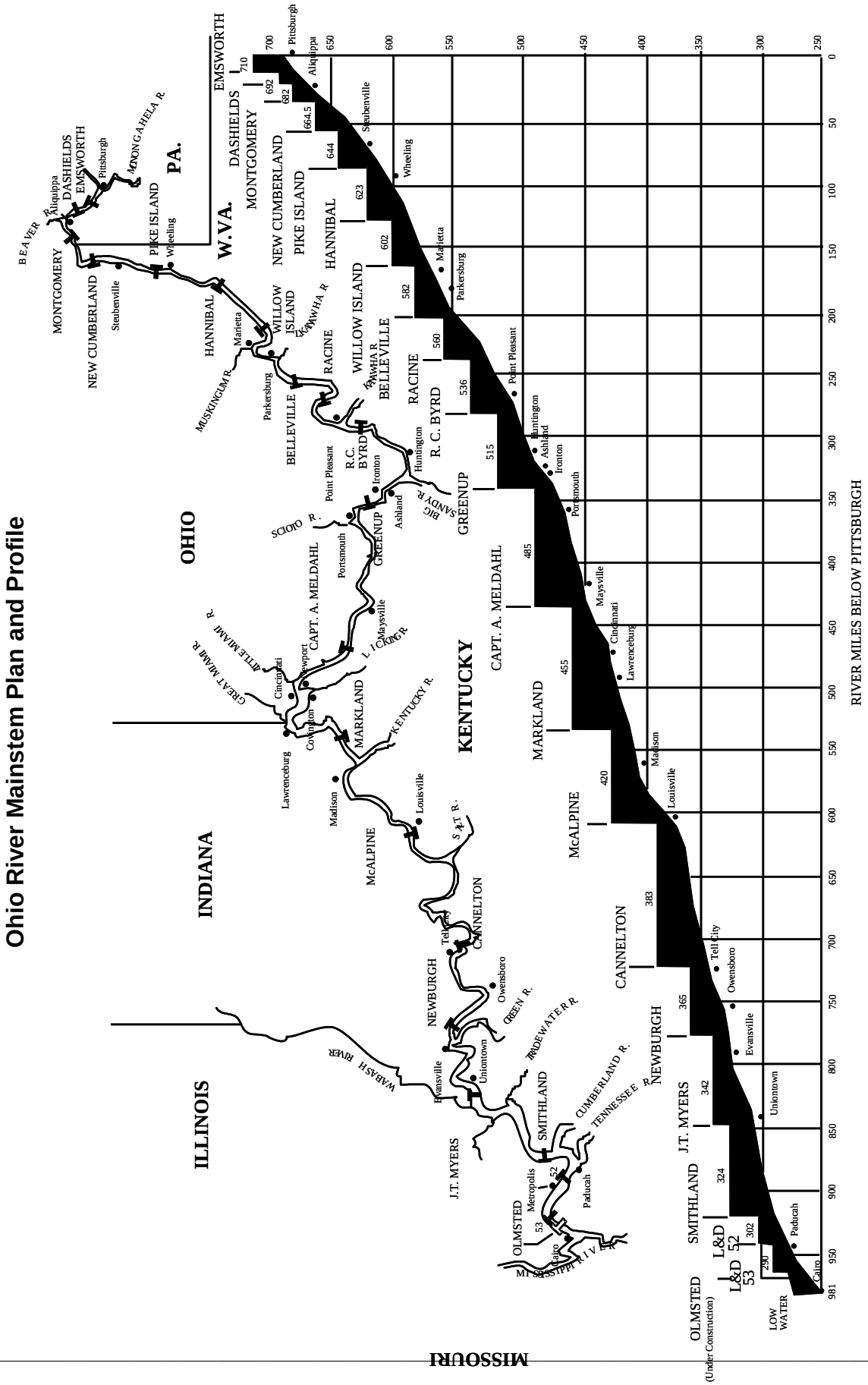
- The 60+ year old three upper most locks and dams are Emsworth, Dashshields, and Montgomery (EDM) just downstream of Pittsburgh PA. These three locks and dams each have one 600 by 110-foot main chamber and a 380 by 56-foot auxiliary chamber. Fifteen-barge tows must double cut to negotiate the main chambers, and must break apart up to 15 times to negotiate the small auxiliary chambers[1]. The condition of these old structures and the inefficiently-small lock sizes, are major concerns.

- The 13 modernized lock and dam structures constructed between 1954 and 1979 plus R.C. Byrd L/D (completed in 1993) include all the contiguous locks from New Cumberland downstream to J.T.Myers, a distance of 791.6 miles. Each of these locks has a 1200 by 110-foot main lock chamber and a 600 by 110-foot auxiliary chamber. The 1200-foot main chamber allows 15-barge tows to lock through in a single operation, while smaller vessels usually use the auxiliary chambers. These locks and dams are spaced about 60 miles apart. They replaced a series of 50 old lower-lift structures built around the turn of the century.

- Locks which have or soon will have dual, side-by-side 1200 by 110-foot chambers include Smithland L/D (placed in operation in 1980), and McAlpine and Olmsted L/Ds.

[1] Tow-size is restricted to 5-barges (5-cut tows) at EDM during main chamber closures.

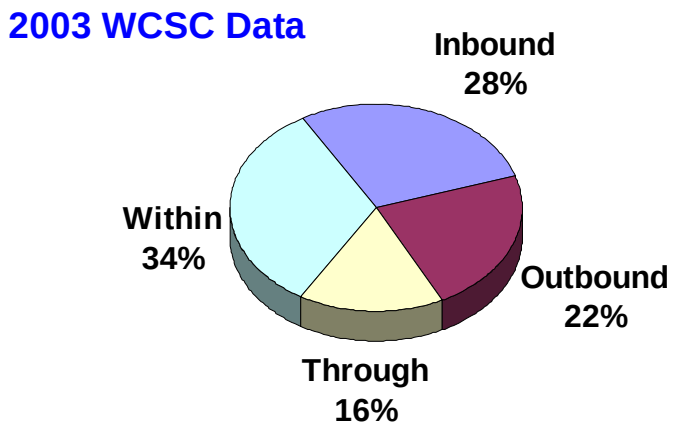
Figure 4-3
Ohio River Mainstem Plan and Profile



4.5 TONNAGE GROWTH AND COMMODITY MIX

The ORB states, parts of which are drained by the Ohio River and its tributaries, are home to over 31.5 million people. Pittsburgh, Cincinnati, Columbus, Indianapolis, Louisville, and Nashville are the region's largest cities. Waterborne commerce is made possible in the basin by a series of 56 lock and dam structures spread throughout the Ohio River and its 12 navigable tributaries (see **Figure 4-1** above). In recent years, barges on the Ohio River mainstem have carried an average of 238 million tons of bulk commodities. These commodities are the products of coal mines, petroleum refineries, stone quarries, cement plants, and farms and the raw material for construction companies, steel mills, electric utilities, paper plants, aluminum manufacturers, and chemical companies; the foundation of the region's economy. As can be seen in **Figure 4-4** below, a large percentage of this traffic (34 percent) is internal to or within the mainstem.

FIGURE 4-4
Inbound, Outbound, Through and Within
Ohio River Mainstem Traffic



Source: WCSC data.

Basin river transportation revolves around the movement of coal and other bulk commodities, traffic most efficiently carried by water. The ORS extends this efficiency deep into the interior of the North American continent. The availability of this form of transportation, along with the availability of rich deposits of coal (approximately 70 billion tons of demonstrated reserves), has made Pittsburgh, Pennsylvania and Huntington, West Virginia, the second and fourth largest coal ports, respectively, in the United States. Most of the basin's coal moves to domestic markets -- primarily to the electric utility industry. Over the last 30 years, much of the region's electricity generating capacity has moved away from small streams and large cities to the more rural areas of the Ohio River and its system of navigable rivers. Dependable supplies of cooling water and access to low-cost transportation are the primary attractions. In fact, electric utility companies account for nearly half of system traffic.

The main artery of the Ohio River System is the mainstem Ohio. Eighty-nine percent of ORS traffic moves on the Ohio River mainstem (see **Table 4-2**). Long term growth on the Ohio River has proceeded at a faster pace than the system as a whole, reflecting the early development of the mainstem as compared with some of the tributary streams like the Monongahela and Kanawha rivers. While growth in the last thirteen years on the mainstem Ohio has slowed considerably from its 1940-2004 annual growth rate of 3.4 percent, it continues to support substantial commercial traffic (see **Table 4-3**).

TABLE 4-2
Historic Ohio River System and Mainstem Ohio Traffic
(Million Tons)

Year	ORS	Ohio River	% ORS
1940	51.2	29.5	58%
1950	66.1	48.6	74%
1960	105.3	79.5	75%
1970	163.9	129.6	79%
1980	200.5	160.7	80%
1990	257.8	225.7	88%
2000	271.7	236.5	87%
2004	269.9	239.0	89%
Annual Growth:			
- 1940-04	2.7%	3.4%	
- 1990-04	0.1%	0.1%	

Source: USACE Waterborne Commerce Statistics

TABLE 4-3
Historic Ohio River Mainstem Traffic by Commodity
(Million Tons)

Year	Coal	Petrol	Aggs	Grain	Chem	Ores	Iron	Other	Total
1965	46.6	20.5	14.2	2.6	6.0	7.6	3.4	2.3	103.2
1970	59.0	25.3	17.2	3.6	10.6	3.9	4.4	5.5	129.5
1975	73.3	19.6	16.5	4.1	9.1	3.5	3.9	10.1	140.1
1980	86.1	18.3	21.2	6.7	11.5	3.2	4.1	9.6	160.7
1985	98.2	12.5	20.9	11.7	12.7	3.5	5.0	13.4	177.9
1990	135.1	14.4	30.4	13.2	9.3	5.5	6.5	11.2	225.6
1991	131.6	13.9	27.0	10.2	9.0	5.7	6.2	14.8	218.4
1992	134.7	13.3	28.1	11.3	9.6	5.5	5.8	18.1	226.4
1993	130.3	14.2	29.5	14.0	10.5	5.9	7.5	17.6	229.5
1994	134.8	14.2	32.2	12.0	10.2	6.8	9.6	17.0	236.8
1995	130.0	13.6	33.3	12.0	10.2	6.7	10.1	18.2	234.1
1996	134.8	13.2	37.3	10.7	9.4	7.5	9.7	15.1	237.7
1997	135.1	12.8	39.9	10.9	9.6	6.8	9.5	15.4	240.0
1998	132.7	20.2	42.9	13.9	9.8	5.9	10.2	6.3	241.9
1999	124.8	20.6	43.2	15.2	10.0	6.6	12.1	8.4	240.9
2000	118.9	20.2	40.9	15.6	10.2	6.9	14.3	9.5	236.5
2001	128.0	20.3	40.8	18.0	9.7	6.8	10.9	7.9	242.4
2002	131.0	19.7	39.1	16.9	9.7	6.4	12.4	7.6	242.8
2003	118.5	16.3	41.7	13.8	10.3	7.4	13.9	6.8	228.8
Avg. Ann. Growth Rate									
(1965 - 2003)	**2.5%**	**-0.6%**	**2.9%**	**4.5%**	**1.4%**	**-0.1%**	**3.8%**	**2.9%**	**2.1%**
(1993 - 2003)	**-0.9%**	**1.4%**	**3.5%**	**-0.1%**	**-0.2%**	**2.3%**	**6.4%**	**-9.1%**	**0.0%**

Source: WCSC data.
Note: Asphalt was reclassified as Petrol in 1998. Previously asphalt was grouped in Other.

SECTION 5
VESSEL FLEET AND LOCK UTILIZATION

5.1 INTRODUCTION

Tows moving on the inland waterway system are configured to operate as efficiently as possible along each waterway segment. Lock size and channel dimensions are critical in establishing the most efficient tow configuration. Currently, the Ohio River fleet consists largely of jumbo barges, 15 of these barges comprising a typical tow. This section describes the existing characteristics of barges and tows using mainstem locks and their performance in processing commercial traffic. Detailed discussions of the vessel fleet and lock utilization are presented in **Attachment 2 Capacity Analysis** of this economics appendix.

5.2 VESSEL FLEET

5.2.1 Introduction

The Ohio River vessel fleet consists of different types of barges and towboats arranged in a variety of tow sizes determined by market conditions consistent with lock sizes and channel dimensions.

5.2.2 Barge Types

When mainstem locks were modernized in the 1950s, 1960s and 1970s the "standard" barge on the Ohio River was 175' long and 26' wide. Over the years, this barge type gave way to a larger 195'–200' long and 35' wide jumbo barge. Today, super and giant sized jumbo barges measuring 245'-260' long and 35'-52' wide are becoming more prevalent on the lower Ohio River, though jumbo barges remain more numerous. **Table 5-1** describes the dimensions, loading capacity and typical commodities carried by mainstem barges. The dominant barge type is overwhelmingly the jumbo hopper. These barges typically move coal, aggregates, ores, and iron and steel scrap and carry collectively 73 percent of mainstem tonnage Jumbo hoppers comprise 72 percent of the mainstem fleet. The larger super and giant jumbo hoppers are mainly used on the lower river and reflect the shippers and markets served in that region. **Table 5-2** describes the average annual number of trips and tons by barge type used on the mainstem from 1990 to 2000. Average annual loadings from 1990 to 200 for the barge types listed in tables 5-1 and 5-2 are displayed in **Figure 5-1**. The jumbo hopper on the mainstem averages about 1,550 tons per barge. Giant jumbo hoppers, found mostly on the lower Ohio, average almost 2,900 tons per loaded barge.

TABLE 5-1
Description of Barge Types

Barge Type	Dimension	Capacity (Ktons)	Typical Commodities
Hopper			
Irregular	135'x27'	867	Aggregates
Standard	175'x26'	1,069	Coal, Aggregates
Stumbo	195'x26'	1,121	Coal
Jumbo	**195'x35'**	**1,669**	**Coal, Aggregates, Ores & Iron**
Covered Jumbo	195'x35'	1,764	Grains, Chemicals
Super Jumbo	245'x35'	2,106	Coal, Aggregates
Giant Jumbo	260'x52'	3,329	Coal, Grains, Aggregates and Coke
Tanker			
Jumbo	195'x35'	1,454	Petroleum Products & Chemicals
147'	147'x52'	1,711	Petroleum Products & Chemicals
175'	175'x54'	2,317	Petroleum Products & Chemicals
264'	264'x52'	2,820	Petroleum Products & Chemicals
290'	290'x54'	3,295	Petroleum Products & Chemicals

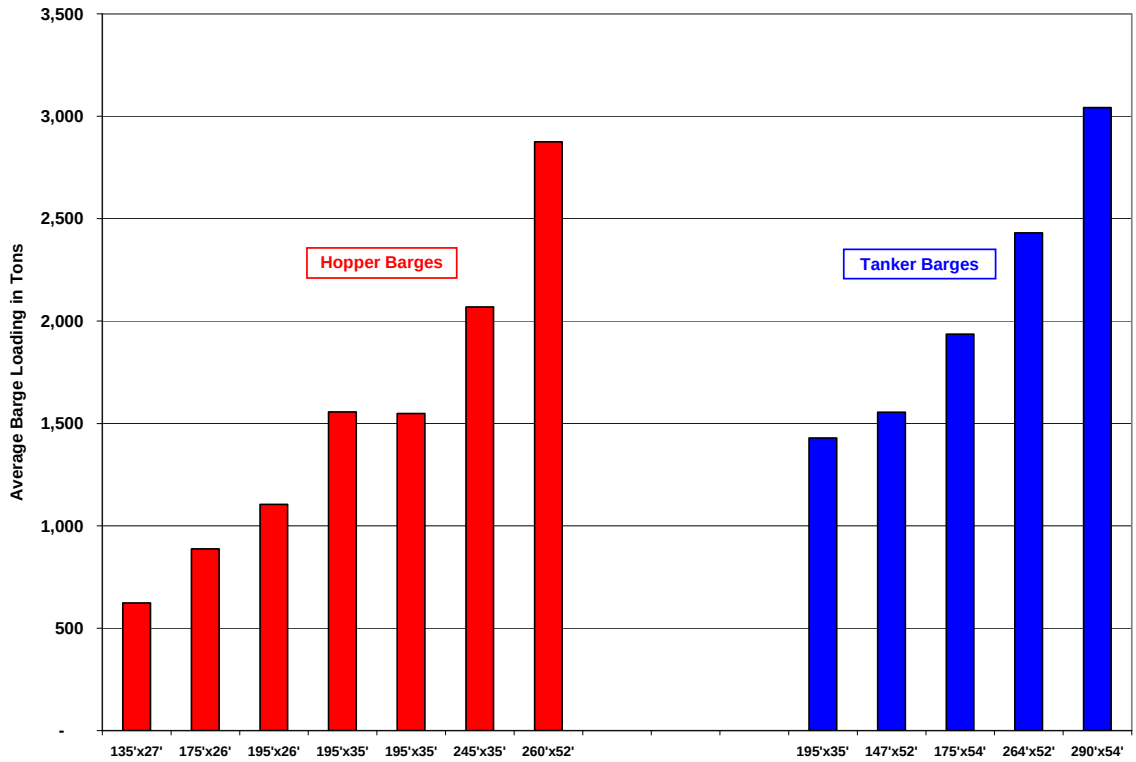
Source: COE LPMS Data.

TABLE 5-2
Annual Ohio River Trips and Tonnage by Barge Type
Averaged Over 1990 – 2000

Barge Type	Dimension	Avg. Annual		Percent of Total	
		Trips	Tons*	Trips	Tons
Hopper					
Irregular	135'x27'	3,215	2,004,284	2%	1%
Standard	175'x26'	5,571	4,943,714	4%	2%
Stumbo	195'x26'	8,535	9,428,949	6%	5%
Jumbo	**195'x35'**	**97,691**	**151,960,762**	**72%**	**73%**
Covered Jumbo	195'x35'	7,752	12,002,606	6%	6%
Super Jumbo	245'x35'	390	807,399	0%	0%
Giant Jumbo	260'x52'	869	2,497,370	1%	1%
Sub-Total		124,023	183,645,084	91%	88%
Tanker					
Jumbo	195'x35'	5,005	7,153,370	4%	3%
147'	147'x52'	1,734	2,695,467	1%	1%
175'	175'x54'	643	1,244,841	0%	1%
264'	264'x52'	1,188	2,886,932	1%	1%
290'	290'x54'	3,749	11,405,339	3%	5%
Sub-Total		12,319	25,385,949	9%	12%
Total		136,341	209,031,033	100%	100%

Source: WCSC data
* excludes intra-pool traffic

FIGURE 5-1
1990-2000 Average Barge Loadings by Barge Type

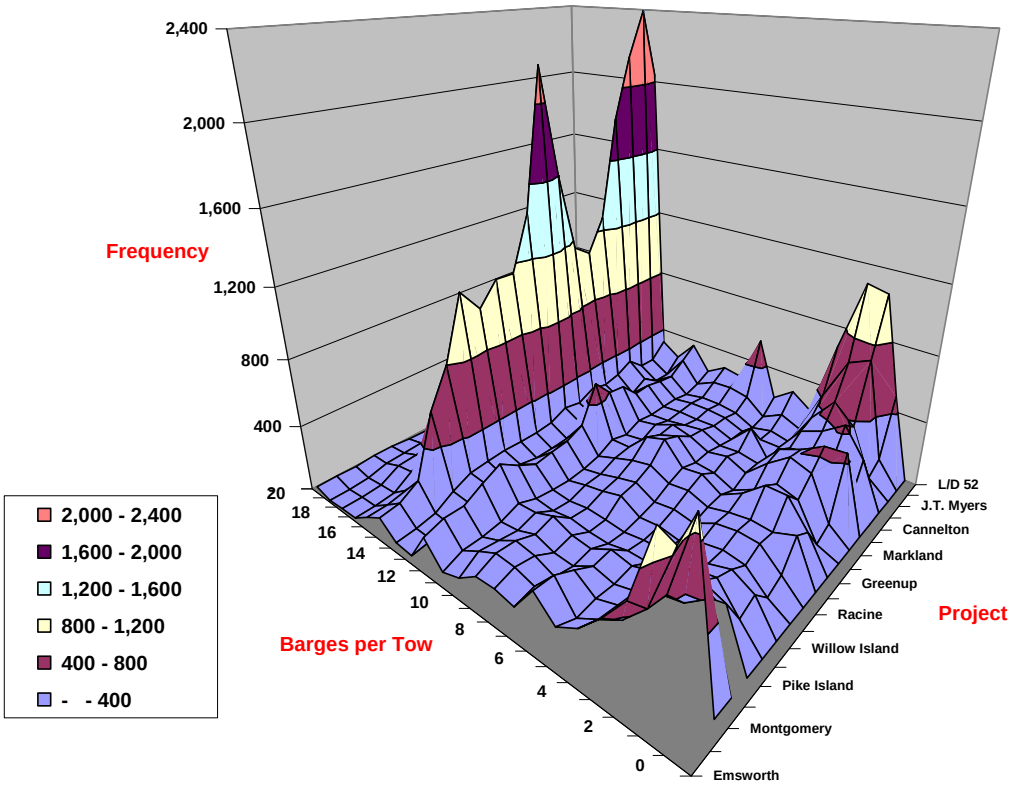


5.2.3 Tow Size Characteristics

Figure 5-2 displays tow size distributions for the mainstem projects. Tankers tend to move in 2 barge tows and they typically move petroleum products, chemicals, and asphalt on the upper and lower Ohio. Four-barge tows are normally sand-flats (irregulars). Jumbos tend to move in 12- or 15-barge tows. A fifteen-barge tow is the most common for all projects except at the upper three locks – Emsworth, Dashields and Montgomery (EDM). Ohio River tows tend to take advantage of the 1200-foot main lock chambers. These chambers can accommodate up to 17 jumbo barges, 12 super jumbo barges, or 8 giant jumbo barges in a single lockage.

Average tow sizes are shown in **Table 5-3**. The average tow size tends to increase going downstream as the percentage of 15-barge tows increases along with the use of giant jumbo hoppers and the percentage of empty barges decreases.

FIGURE 5-2
Tow Size Distributions



Source: COE LPMS Data.

TABLE 5-3
Average Tow Sizes

Project	Total Barges Per Tow	Loaded Barges Per Tow	Tons Per Tow	Tons Per Loaded Barge
Emsworth	6	4	4,845	1,352
Dashields	6	4	5,298	1,327
Montgomery	7	4	5,861	1,375
New Cumberland	9	5	7,901	1,472
Pike Island	9	6	8,667	1,482
Hannibal	11	7	11,099	1,494
Willow Island	11	8	11,527	1,502
Belleville	11	8	11,971	1,508
Racine	11	8	11,482	1,511
R.C. Byrd	11	7	11,481	1,556
Greenup	11	7	10,409	1,585
Meldahl	11	7	11,505	1,603
Markland	10	7	10,702	1,593
McAlpine	10	7	10,678	1,594
Cannelton	11	8	11,916	1,569
Newburgh	11	7	11,058	1,565
J.T. Myers	11	8	12,187	1,606
Smithland	11	7	11,250	1,613
L/D 52	10	6	9,999	1,616

Source: COE LPMS Data.

5.2.4 Traffic Statistics

Commodity traffic flow at mainstem projects is largely determined by geographic location. The commodity mix, in turn, influences barge type and tow configuration. Greenup, Meldahl, and Markland locks are characterized by predominantly downbound traffic. Most of the traffic at these facilities moves to docks on the lower Ohio River. All other mainstem projects, above and below these three locks, are characterized by mostly upbound traffic. Above Greenup is a heavy concentration of shipments from the port of Huntington which includes the Big Sandy and Kanawha rivers. Below Greenup is Cincinnati, a large consumption and destination area for barge commerce. **Table 5-4** summarizes commodity traffic by direction at the projects from 2000 to 2004. Downbound coal originating on the Big Sandy and Kanawha rivers dominates Greenup, Meldahl, and Markland traffic while that of lower river projects have more upbound coal.

TABLE 5-4
2000-2004 Average Commodity Traffic by Direction
(Ktons)

Project	Direction	Coal	Petrol	Aggs	Grains	Chem	Ores & Minerals	Iron & Steel	Other	Total
Emsworth	Up	7,463	689	1,170	31	598	557	362	283	11,153
	Down	8,519	130	622	1	179	49	360	133	9,992
Dashields	Up	7,415	818	2,075	37	666	591	391	317	12,310
	Down	8,560	161	248	1	190	64	411	126	9,760
Montgomery	Up	8,027	975	1,786	41	901	737	708	532	13,708
	Down	8,899	198	120	3	219	59	470	167	10,135
New Cumberland	Up	16,110	1,541	1,384	80	1,563	997	1,427	1,514	24,615
	Down	6,694	607	82	23	292	55	708	288	8,749
Pike Island	Up	19,910	1,774	1,432	93	1,589	1,093	3,173	1,826	30,890
	Down	7,299	718	97	28	246	64	1,264	339	10,055
Hannibal	Up	16,583	1,818	1,663	94	1,577	1,564	3,153	2,045	28,496
	Down	17,878	660	224	28	381	69	1,351	510	21,099
Willow Island	Up	16,556	1,819	1,852	103	1,437	1,600	3,147	2,421	28,935
	Down	14,890	747	177	31	391	78	1,352	544	18,209
Belleville	Up	17,059	2,334	2,624	109	2,082	1,756	3,350	2,586	31,899
	Down	15,037	607	144	28	357	93	1,358	557	18,181
Racine	Up	17,117	2,367	2,335	111	2,074	2,028	3,395	2,659	32,086
	Down	15,082	603	788	28	366	113	1,350	568	18,899
R.C. Byrd	Up	16,426	3,447	4,364	137	2,738	2,074	3,453	3,093	35,734
	Down	17,274	618	181	36	389	114	1,382	631	20,625
Greenup	Up	4,981	1,613	4,544	166	3,215	2,180	4,489	2,807	23,996
	Down	34,543	5,285	196	48	572	160	1,504	656	42,964
Meldahl	Up	2,988	1,782	4,178	170	3,287	2,308	4,635	2,310	21,658
	Down	28,405	5,191	317	57	577	186	1,445	849	37,028
Markland	Up	3,264	2,199	4,019	262	4,881	3,135	5,542	3,155	26,456
	Down	16,342	2,859	216	2,170	530	168	1,693	917	24,896
McAlpine	Up	7,847	2,365	3,296	328	5,254	3,443	6,448	3,412	32,392
	Down	10,660	2,928	427	2,870	748	179	2,097	910	20,820
Cannelton	Up	10,277	3,096	1,251	311	5,554	3,446	6,387	2,945	33,268
	Down	9,770	1,257	4,403	2,907	757	298	2,137	1,034	22,562
Newburgh	Up	17,695	3,597	1,230	585	5,957	4,563	6,579	3,396	43,601
	Down	7,921	1,236	4,063	3,663	747	359	2,179	1,182	21,351
J.T. Myers	Up	16,972	4,591	1,240	445	6,748	4,972	6,783	3,517	45,268
	Down	11,547	1,028	715	6,361	758	363	2,303	1,170	24,246
Smithland	Up	16,326	4,608	973	439	6,824	4,993	6,817	3,521	44,500
	Down	18,015	1,025	4,227	6,935	773	351	2,297	1,250	34,873
L/D 52	Up	16,941	7,104	1,950	3,270	8,413	5,855	8,173	4,430	56,135
	Down	9,347	875	12,376	8,014	1,333	383	2,758	2,141	37,227

Source: COE LPMS Data.

Table 5-5 shows the average annual growth of traffic at all mainstem projects from 1994 to 2004 and the higher level of traffic on the lower river.

TABLE 5-5
1994 - 2004 Ohio River System Traffic by Project
(Ktons)

Project	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Annual Rate 1994-2004
Emsworth	24,272	23,075	23,424	23,201	23,153	23,561	22,334	21,729	23,687	19,211	18,791	-2.5%
Dashields	25,602	24,551	24,765	24,452	24,563	24,528	23,230	22,839	24,516	20,012	19,679	-2.6%
Montgomery	27,313	25,515	27,132	26,480	26,866	26,560	25,974	25,555	26,709	21,093	20,260	-2.9%
New Cumberland	37,272	36,745	36,584	35,564	35,425	33,906	34,062	33,854	35,251	32,189	31,478	-1.7%
Pike Island	43,643	43,309	43,729	41,345	43,027	41,276	41,460	41,682	43,634	39,062	38,912	-1.1%
Hannibal	47,783	42,783	46,596	44,812	47,627	47,258	48,344	49,476	51,200	48,884	50,101	0.5%
Willow Island	45,802	44,534	43,932	42,299	44,766	44,320	45,635	46,975	48,422	46,592	48,123	0.5%
Belleville	48,641	47,122	47,869	45,511	48,688	47,983	49,201	49,243	51,118	49,482	51,380	0.5%
Racine	49,845	48,000	48,933	46,644	49,517	48,646	50,022	50,239	51,764	50,625	52,308	0.5%
R.C. Byrd	56,079	58,649	59,406	56,337	57,855	55,970	57,879	58,108	54,898	53,164	57,775	0.3%
Greenup	68,695	67,573	67,262	69,891	70,635	70,044	71,713	70,563	65,915	62,135	64,502	-0.6%
Meldahl	64,627	63,376	61,270	62,246	63,739	62,784	63,391	63,813	57,771	53,222	55,262	-1.6%
Markland	60,011	57,757	54,680	55,090	55,119	54,850	56,062	55,807	49,625	45,248	50,050	-1.8%
McAlpine	61,943	57,609	53,980	52,823	52,857	54,835	55,790	56,170	51,893	49,482	52,753	-1.6%
Cannelton	64,257	59,513	56,782	56,240	54,386	56,650	55,786	56,653	55,841	54,002	56,888	-1.2%
Newburgh	76,779	72,052	68,300	65,407	64,131	64,509	64,433	66,527	64,200	62,475	67,151	-1.3%
J.T. Myers	85,718	82,108	77,603	76,218	74,151	71,393	72,447	75,290	68,961	62,655	67,880	-2.3%
Smithland	93,337	89,145	85,077	84,931	84,606	82,115	82,610	85,915	79,040	72,305	77,020	-1.9%
L/D 52	101,267	97,467	94,052	94,770	97,695	95,125	94,687	96,715	93,382	87,420	94,954	-0.6%

Source: LPMS Data.

Average lock performance characteristics averaged for each lock from 2000 to 2004 are listed in **Table 5-6**. The number of empty barges indicates the level of backhaul opportunities. The percentage of empty barges is an important statistic when estimating lock capacity, where lock capacity is defined as an annual tonnage throughput based partially on fleet characteristics. Fifty-percent empty indicates the absence of backhaul opportunity with barges moving loaded in one direction and empty in the opposite direction. Mainstem projects range from 30 to 40 percent empty indicating some backhaul opportunity. This is largely due to the fact that mainstem projects tend to serve regions that are both production and consumption oriented, like the Gulf Coast and the Tennessee Valley, so that greater opportunities exist for loaded backhauls. Backhauling imported ore and steel products during the latter 1990s reduced the percentage of empty barges at lower Ohio projects.

5.2.5 Lock Transit Time

The time required for a tow to transit a lock has two components: processing time and delay time. Average processing and delay times from 2000 to 2004 for all the mainstem projects are provided in **Table 5-6**. Processing time is the amount of time a lock is obligated to serve a particular tow. Delay time is the time a tow must wait to be served. Under normal operation, mainstem locks experience an average 30-45 minutes of “residual” delay; delay due to a tow arrival when the lock is in use. More variability is seen in average delay time compared to average processing time. Heavier use of the auxiliary chamber during main chamber closure accounts for most increases in processing time as single-cut tows configured for the main

chamber require two cuts when using the auxiliary chamber. Higher than normal delays are generally attributable to a main chamber closure.

TABLE 5-6
2000-2004 Average Lock Performance Characteristics

Project	No. Tows	Number of Barges			Avg. Barges /Tow	Ktons	Avg. Tons /Tow	Avg. Time /Tow (min.)			Comm. Lockages	Avg Lock Cuts/Tow
		Loaded	Empty	Total				Delay	Process	Total		
Emsworth	4,433	15,524	9,419	24,942	5.6	21,145	4,770	54.7	59.9	114.6	5,301	1.2
Dashields	4,279	16,521	10,188	26,709	6.2	22,055	5,154	37.7	62.0	99.7	5,132	1.2
Montgomery	4,325	17,272	9,713	26,985	6.2	23,925	5,532	69.6	66.3	135.9	5,432	1.3
New Cumberland	4,324	22,582	15,577	38,159	8.8	33,367	7,717	28.0	58.8	86.8	4,402	1.0
Pike Island	4,852	27,520	18,266	45,786	9.4	40,950	8,440	29.3	55.0	84.3	4,954	1.0
Hannibal	4,503	33,118	15,694	48,813	10.8	49,596	11,013	21.1	53.0	74.1	4,503	1.0
Willow Island	4,098	31,384	13,594	44,978	11.0	47,147	11,505	32.6	58.4	91.1	4,154	1.0
Belleville	4,182	33,210	14,684	47,894	11.5	50,079	11,974	23.1	54.8	77.8	4,185	1.0
Racine	4,381	33,774	15,090	48,864	11.2	50,974	11,634	32.0	60.8	92.8	4,381	1.0
R.C. Byrd	4,931	36,292	16,005	52,297	10.6	56,356	11,428	36.6	58.0	94.6	4,983	1.0
Greenup	6,279	42,223	26,491	68,714	10.9	64,957	10,345	108.7	51.2	159.9	6,514	1.0
Meldahl	5,119	36,522	20,363	56,885	11.1	58,686	11,464	94.9	58.5	153.4	5,393	1.1
Markland	4,783	32,155	14,803	46,958	9.8	51,348	10,736	53.3	57.8	111.2	4,844	1.0
McAlpine	5,026	33,276	13,827	47,103	9.4	53,182	10,581	72.6	58.0	130.6	5,012	1.0
Cannelton	4,816	35,465	16,173	51,638	10.7	55,800	11,585	40.1	59.7	99.8	4,880	1.0
Newburgh	5,915	41,377	22,619	63,996	10.8	64,919	10,975	35.5	50.6	86.2	6,078	1.0
J.T. Myers	5,778	43,294	21,853	65,147	11.3	69,412	12,014	80.4	52.5	133.0	6,032	1.0
Smithland	7,147	49,249	25,513	74,763	10.5	79,350	11,103	11.9	48.0	59.8	7,276	1.0
L/D 52	9,269	57,818	31,157	88,975	9.6	93,405	10,077	118.1	22.3	140.4	9,171	1.0

Source: LPMS Data.

5.2.5.1 Processing Time

Processing time encompasses the amount of time it takes to approach, enter, chamber, and exit the chamber. At smaller chambers where multiple cuts of the tow must be performed chambering time includes all intermediate entries and exits. For example, a 15-jumbo barge tow (approximately 1140' in length) is processed in one lockage operation through a 1200' main chamber and two lockage operations to process through a smaller 600' auxiliary chamber. As a result, extra entry, exit, and chamber turnback times are experienced.

Processing times are also affected by site characteristics like hydraulic conditions, lift, number of valves, chamber size, and the location of arrival points. Tow sizes also affect processing times. Smaller tows can generally be processed faster.

Average processing time for a given lock chamber can vary from year to year depending on a number of factors. Most important are tow size, the share of the project's total tows locked through the smaller auxiliary, and the number of recreational boats relative to the number of tows. The larger the tow, the higher the average processing time since larger tows take longer to lock and in the event of a main chamber closure, would require multiple lockages to lock through the auxiliary chamber. The greater the number of recreation boats vis-à-vis tows, the shorter the average processing times because recreation vessels can lock through more quickly.

5.2.5.2 Delay Time

Delays are recorded in the Lock Performance Monitoring System (LPMS) data whenever a tow reaches a given lock's arrival point and must wait for service. Once the lock is available for service and the tow begins its approach, the period of delay ends. Delays are encountered for a variety of reasons including: weather, hydraulics, accidents, lock maintenance, and an existing queue of tows waiting to use the lock. Delays are a problem at mainstem projects when the main chamber is closed for maintenance because at current traffic levels tows arrive faster than they can be processed with the smaller auxiliary chamber.

5.3 LOCK OPERATIONS

5.3.1 Towing Operations

During normal operations, the main chamber at mainstem projects is used predominantly by large tows and the auxiliary chamber is used by single cut tows of less than 600' in length, recreational traffic, and other smaller vessels like lightboats. The maximum number of cuts allowed is a single cut through the main chamber and a double cut through the auxiliary chamber except at the upper three projects where, due to smaller size, double cut lockages are allowed at the main chamber and five-cut lockages at the auxiliary lock chamber. Furthermore, multiple cut lockages are allowed in the auxiliary chamber during periods of closure of the main chamber. **Table 5-7** shows chamber utilization by vessel type averaged from 2000 to 2002.

TABLE 5-7
Usage by Chamber, 2000-2004

	Main Chamber			Auxiliary Chamber			Both Chambers		
Project	Tows	Lt. Boats	Rec. Boats	Tows	Lt. Boats	Rec. Boats	Tows	Lt. Boats	Rec. Boats
Emsworth	3,473	122	208	961	826	2,483	4,433	947	2,691
Dashields	3,495	67	127	782	544	1,949	4,277	611	2,076
Montgomery	3,522	79	59	800	526	1,268	4,321	605	1,327
New Cumberland	3,237	52	62	1,086	211	1,898	4,323	264	1,960
Pike Island	3,802	55	56	1,049	221	1,242	4,852	276	1,298
Hannibal	4,011	39	108	491	58	1,039	4,503	97	1,146
Willow Island	3,591	32	16	506	78	1,540	4,097	110	1,556
Belleville	3,898	27	28	284	49	867	4,182	76	895
Racine	3,995	45	99	384	83	697	4,380	128	797
Byrd	4,367	59	39	564	209	763	4,931	268	801
Greenup	5,648	117	75	630	297	579	6,278	414	655
Meldahl	4,764	98	615	349	98	2,439	5,112	195	3,054
Markland	4,373	21	208	406	35	2,902	4,780	56	3,110
McAlpine*	4,947	309	564	4	1	0	4,951	309	564
Cannelton	4,484	33	192	331	53	775	4,815	86	967
Newburgh	5,357	32	140	558	251	1,095	5,915	283	1,236
Myers	5,280	33	144	497	142	1,828	5,776	175	1,971
Smithland	3,418	136	816	3,726	146	728	7,144	282	1,544
L/D 52	7,927	467	263	1,290	330	440	9,218	797	703

* McAlpine auxiliary chamber closed due to construction of new 1200' x 110' chamber
Source: COE LPMS Data.

5.3.2 Lock Operating Hours

All mainstem projects are operated year-round on a 24-hour basis except during periods when a chamber is closed due to weather or for inspection and maintenance/repair work.

5.3.3 Lockage Policy

Tows are normally locked through on a first-come/first-serve basis. Typically tows under 600' use the auxiliary chamber and tows greater than 600' use the main chamber. Nearly all of the tows at mainstem projects other than Emsworth, Dashields and Montgomery, require one-cut. EDM tows typically require two cuts. During periods when the main chamber is closed for maintenance/repair, tow haulage units are used at EDM, lock masters implement n-up/n-down lockage policies and carriers implement a self-help program. This involves using the towboats in queue to extract the first cut of a two-cut lockage from the auxiliary chamber in order to speed up the lockage process. The program is planned in cooperation with the carriers and supervised by the lockmaster. **Table 5-8** lists chamber dimensions for mainstem projects.

TABLE 5-8
Mainstem Lock Chamber Dimensions

Project	Main	Auxiliary
Emsworth	600' x 110'	360' x 56'
Dashields	600' x 110'	360' x 56'
Montgomery	600' x 110'	360' x 56'
New Cumberland	1200' x 110'	600' x 110'
Pike Island	1200' x 110'	600' x 110'
Hannibal	1200' x 110'	600' x 110'
Willow Island	1200' x 110'	600' x 110'
Belleville	1200' x 110'	600' x 110'
Racine	1200' x 110'	600' x 110'
Byrd	1200' x 110'	600' x 110'
Greenup	1200' x 110'	600' x 110'
Meldahl	1200' x 110'	600' x 110'
Markland	1200' x 110'	600' x 110'
McAlpine*	1200' x 110'	1200' x 110'
Cannelton	1200' x 110'	600' x 110'
Newburgh	1200' x 110'	600' x 110'
Myers	1200' x 110'	600' x 110'
Smithland	1200' x 110'	1200' x 110'
Olmsted*	1200' x 110'	1200' x 110'

* new 1200' x 600' chamber became operational in 2009

5.4 VESSEL FLEET, LOCK PROCESSING TIME AND CAPACITY

Chamber dimensions, vessel fleet characteristics and lock processing time are the major factors that determine a project's capacity for annual tonnage throughput. Lock capacity, in this study, is defined as the level of tonnage where the tonnage-delay curve reaches its vertical asymptote and average tow delay increases without bound. Lock capacity analysis, developed using the WAM, is more fully discussed in **Attachment 2, Capacity Analysis**. This definition of capacity is a useful descriptive measure but does not measure economic capacity. Despite sharing identical physical dimensions, Mainstem locks can be expected to have different capacities based upon significant differences in vessel fleets and processing times (see **Table 5-9**). Given this definition of capacity, differences in capacity estimates can be attributed to differences in barge loadings, tow sizes, percent empty barges (more backhaul opportunity) and lock processing times. The three upper Ohio projects have the lowest capacity owing to their smaller size. Available capacity and traffic levels tend to be higher at the downstream projects.

TABLE 5-9
Comparative Mainstem Lock Capacity

Project	Main	Auxiliary	Both
Emsworth	39.4	12.6	45.8
Dashields	46.5	12.9	51.7
Montgomery	43.9	12.9	47.6
New Cumberland	78.5	44.5	132.9
Pike Island	99.5	47.9	151.2
Hannibal	103.1	52.4	152.1
Willow Island	107.5	54.2	155.1
Belleville	114.6	56.3	167.2
Racine	110.5	54.0	151.1
Byrd	116.3	55.5	151.0
Greenup	113.3	54.3	144.2
Meldahl	116.3	55.5	151.0
Markland	119.0	57.1	160.5
McAlpine*	120.0	123.0	225.5
Cannelton	124.0	59.0	162.1
Newburgh	135.6	61.7	169.8
Myers	137.3	63.6	170.6
Smithland	143.4	132.9	264.4
Olmsted*	NA	NA	274.9

* under construction

SECTION 6

HISTORIC and PROJECTED TRAFFIC

6.1 GENERAL

This section discusses historic, existing, and projected future traffic on the ORS and the Ohio River mainstem. Historic developments that led to the growth of waterborne traffic on the ORS are also discussed. The methodology used in projecting future traffic demands is summarized along with the projection results. A more detailed discussion of the traffic forecasts used in this analysis can be found in **Attachment 4 Traffic Demand Forecasts**.

6.2 EXISTING TRAFFIC

The mainstem Ohio River handled about 229 million tons of traffic in 2003, representing about 88 percent of the traffic on the Ohio River System (ORS). The Ohio River handled all of the petroleum fuels moving on the ORS in 2003, and nearly all of the grains, chemicals, ores and minerals, and iron and steel traffic. The mainstem handled a considerably smaller share of the system's coal and coke and aggregates traffic. The commodity traffic distribution for the Ohio River and the ORS are shown in **Figure 6-1**. **Table 6-1** shows 2003 traffic by commodity group for the Ohio River and the ORS.

Figure 6-1
Commodity Traffic Distribution, 2003

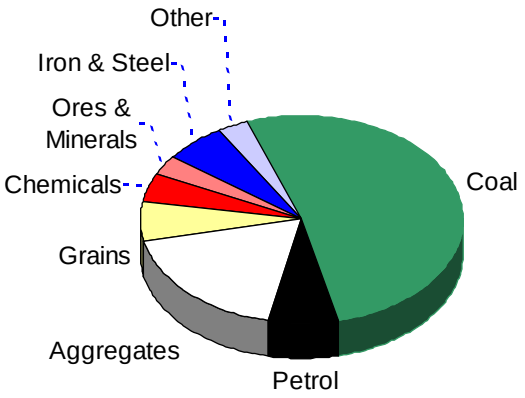


TABLE 6-1 Commodity Traffic on Ohio River Mainstem and the ORS, 2003 (Million Tons)			
Commodity	**ORS**	**Ohio River**	**Ohio River % of ORS**
Coal & Coke	140.9	118.5	84.1%
Petroleum	16.8	16.3	97.0%
Aggregates	47.4	41.7	88.0%
Grains	14.1	13.8	97.9%
Chemicals	11.4	10.3	90.4%
Ores & Minerals	7.4	7.4	100.0%
Iron & Steel	14.3	13.9	97.2%
Other	7.4	6.8	91.9%
TOTAL	259.7	228.7	88.1%

Source: WCSC data

The leading commodity group on the Ohio River in 2003 was coal and coke, which accounted for about 52 percent of total traffic. A large majority of this traffic (over 83 percent) was utility steam coal. Other destinations were coking plants (7 percent), industrial facilities (6 percent), and the export market (1 percent). Aggregates were about 18 percent of total Ohio River traffic, followed by petroleum products (7.1 percent), iron and steel products (6.1 percent), grains (6.0 percent), and chemicals (4.5 percent). Collectively, these six commodity groups accounted for almost 94 percent of Ohio River tonnage.

6.3 HISTORIC TRAFFIC DEVELOPMENT

6.3.1 Historic Growth Factors

Since the end of the Second World War, fairly continual industrial expansion in the Ohio River Basin has produced significant increases in commodity traffic on the Ohio River. Dramatic increases occurred in the immediate post-war period as the navigation system accommodated the transportation needs of expanding basin industries, especially industries such as the primary metals industry in the Wheeling and Pittsburgh areas.

Between 1950 and 1965, traffic on the Ohio River doubled. Over the next 25 years, 1965-1990, traffic on the mainstem doubled once again. Most of this traffic growth was driven by massive investments in waterside coal-fired electric generating facilities that were expanding to accommodate the needs of an expanding economic base. Electric utilities were locating new plants along the Ohio River and expanding their existing waterside facilities to take advantage of the river as a source of water supply and for low-cost waterway transportation of coal. Since 1990, with no growth in coal traffic, the 0.6

percent annual growth in mainstem traffic has been driven by increases in aggregates, ores and minerals, and iron and steel traffic.

6.3.2 Total Traffic

Ohio River traffic for the period 1940-2004 is presented in **Table 6-2**. In 1940, mainstem traffic accounted for about 58 percent of traffic on the ORS, but throughout the 1990s and early 2000s, mainstem traffic normally accounted for 88-89 percent of total system traffic. Over the 64-year period, Ohio River traffic increased at an annual rate of about 3.4 percent, compared to a growth rate of 2.7 percent for the ORS. During the 1990s, the growth in mainstem traffic slowed substantially relative to the historic trend. Between 1990 and 2004, traffic on the Ohio River and the ORS grew at an annual rate of about 0.1 percent.

TABLE 6-2

Historic Ohio River and ORS Traffic
1940-2004
(Million Tons)

Year	ORS	Ohio River	% ORS
1940	51.2	29.5	58%
1950	66.1	48.6	74%
1960	105.3	79.5	75%
1970	163.9	129.6	79%
1980	200.5	160.7	80%
1990	257.8	225.7	88%
2000	271.7	236.5	87%
2004	269.9	239.0	89%
Annual Growth:			
- 1940-04	2.7%	3.4%	
- 1990-04	0.1%	0.1%	

Source: USACE Waterborne Commerce Statistics

6.3.3 Commodity Group Trends

6.3.3.1 General

Ohio River traffic by commodity group for selected years between 1970 and 2000 is shown in **Table 6-3**. On the mainstem, each of the major commodity groups increased in tonnage between 1970 and 2000, with the exceptions of petroleum fuels and crude petroleum. The completion of major pipeline projects into the ORB diminished the need for waterborne transport of petroleum fuels and crude petroleum. The highest annual growth rates over the 30-year period occurred for shipments in the all others category (principally cement, lime, asphalt and animal feeds); iron and steel; grains; and ores and minerals, followed by aggregates and coal and coke. Chemicals traffic was flat over the 30-year period and petroleum products and crude petroleum diminished, as previously mentioned. Between 1990 and 2000, traffic growth was dominated by iron and steel, ores and minerals, and aggregates, followed by chemicals and all others. Grains and petroleum fuels grew much more slowly over this 10-year span, while crude petroleum and coal and coke traffic diminished.

TABLE 6-

Historic Ohio River Commodity

1970 - 2000

(Million Tons)

						Annual % Growth	
Commodit	1970	1980	1990	1995	2000	1970-	1990-
Coal & Coke	59.0	86.1	136.7	130.3	121.8	2.4	-
Petroleum Fuels	15.5	17.7	13.4	13.4	14.1	-	0.5
Crude Petroleum	7.1	0.6	0.5	0.2	0.4	-	-
Aggregates	17.2	21.2	28.7	33.4	38.9	2.8	3.1
Grains	3.6	6.7	10.3	12.0	10.8	3.7	0.5
Chemicals	10.6	11.5	9.3	10.7	10.8	0.0	1.5
Ores & Minerals	3.9	3.2	5.5	6.7	9.1	2.9	5.2
Iron & Steel	4.4	4.1	6.5	10.1	14.3	4.0	8.2
All Others	5.5	9.6	17.0	19.0	18.9	4.2	1.0
TOTAL	126.8	160.7	225.7	235.8	236.5	2.1	0.6

SOURCE: USACE Waterborne Commerce Statistics

6.3.3.2 Coal and Coke

Over the 30-year span between 1970 to 2000, coal and coke typically accounted for around one-half of Ohio River commodity traffic. The traditional dominance of coal and coke on the Ohio River is explained, in large part, by the resource base. The eight ORB states have demonstrated reserves totaling about 237 billion tons, or about 47 percent of the nation's total. Coal production in the ORB states totaled about 488 million tons in 2001, or 43 percent of the nation's total.

Table 6-3 shows mainstem traffic in coal and coke increasing at an annual rate of 2.4 percent between 1970 and 2000 to 121.8 million tons. Over this 30-year time span, coal and coke traffic was influenced by a number of factors. During the 1970s and 1980s, utilities were expanding their coal-fired electric generating capacity along the Ohio River. The oil embargo of the mid-1970s and efforts at oil conservation increased interest in coal as an energy source. In the early 1980s, changes in the steel industry brought about greatly reduced requirements for coke (and therefore coking coal) in steel making processes. Passage of the Clean Air Act amendments (particularly the 1990 amendments) and subsequent regulations increased interest in low-sulfur coal from mines in the western U.S. and Central Appalachia, resulting in higher levels of waterborne coal traffic. Coal exports, as well, increased rapidly from the mid-1980s to the mid-1990s, at which time an economic downturn in Asia and intense competition from foreign producers caused ORS exports to diminish.

Between 1990 and 2000, **Table 6-3** shows coal and coke traffic diminishing at a rate of 1.1 percent per annum. This reflected the near disappearance of the export market for ORS coal, as well as the loss of domestic utility steam coal markets outside of the ORS, and reduced movement of Illinois Basin and Northern Appalachian coal on the system.

6.3.3.3 Petroleum Fuels

Petroleum fuels traffic on the Ohio River has diminished as a share of total traffic from about 12 percent in 1970 to 6 percent in 2000. Currently, only three refineries have direct access to the Ohio River, while two other refineries have pipeline connections to the river. The Ohio River competes with pipeline for distribution of petroleum fuels into the Ohio River Basin.

Between 1970 and 2000, petroleum fuels traffic diminished at an annual rate of 0.3 percent to 14.1 million tons. The reduction in petroleum fuels traffic on the Ohio River began in the early 1970s, when several petroleum products pipelines opened for delivery of products in the ORB states. A further decline in petroleum fuels traffic in the 1980s came about as a result of large-scale conservation measures; a recession in the early 1980s; a concentration of refinery capacity in the Gulf Coast; and the closure of some water-oriented ORB refineries. In the decade between 1990 and 2000, Ohio River petroleum fuels traffic increased at an annual rate of 0.5 percent.

6.3.3.4 Crude Petroleum

In the early 1970s, crude petroleum traffic on the Ohio River was about 6 percent of total traffic, but by 2000 had diminished to less than 1 percent. There was both a relative and absolute reduction in traffic that came about as a result of the completion of some important crude petroleum pipelines from the Gulf Coast into the ORB states to serve basin refineries. Between 1970 and 2000, crude petroleum traffic diminished at an annual rate of 9.4 percent to about 400,000 tons. Most of this traffic is internal to the ORS.

6.3.3.5 Aggregates

Aggregates traffic on the Ohio River, made up primarily of crushed limestone and sand and gravel, increased as a share of total traffic from 14 percent in 1970 to about 16 percent in 2000, making it the second largest commodity group on the Ohio River. Limestone and sand and gravel are fairly widespread throughout the Ohio River Basin, although materials suitable for specialty uses, such as coal desulfurization or cement manufacture, are more limited in availability. The primary usage of these materials is as construction aggregate, and consequently, they typically move relatively short distances from quarries or dredge sites to construction activities.

Table 6-3 shows aggregates traffic growing at a rate of about 2.8 percent per year between 1970 and 2000 to 38.9 million tons. Most of this growth was driven by the requirements for construction materials in the ORB, particularly for such activities as highway construction. Between 1990 and 2000, annual growth in aggregates accelerated to around 3.1 percent. In addition to expansions in construction activities, this reflects, in part, the reduction in ORS coal traffic, since hauling aggregate materials is an alternative usage of coal barges. It also reflects increased movement of limestone for coal desulfurization.

6.3.3.6 Grains

Grains traffic on the Ohio River increased from 3 to 5 percent of total traffic between 1970 and 2000. Within the ORB, the states of Illinois, Indiana, and Ohio are characterized as being part of the nation's Corn Belt, and all three states are important producers of corn and soybeans. Wheat is much less prominent. Grain traffic on the Ohio River is inbound or through traffic destined for Ohio or Tennessee River processors, or outbound traffic destined for the export market. Very little traffic is internal to the system.

Between 1970 and 2000, **Table 6-3** shows that grains traffic on the Ohio River increased at a rate of about 3.7 percent per year, to about 10.8 million tons. Much of this growth is associated with the expansion of grain processors on the ORS. **Table 6-3** also shows grains traffic growing much more slowly during the 1990s than during the overall 30-year period. This is explained, in large part, by a drop in export grains traffic.

6.3.3.7 Chemicals

Chemicals traffic, made up of chemical fertilizers and industrial chemicals, dropped as a share of total Ohio River traffic from 8 percent to 5 percent between 1970 and 2000, although the volume of traffic was essentially unchanged. The chemical fertilizers traffic is made up of the chemical inputs used to formulate fertilizers. This traffic originates in the Gulf Coast and moves to Ohio River fertilizer terminals. The industrial chemicals traffic is basic chemicals or intermediate chemicals used in other manufacturing activities. This traffic originates on the Gulf Coast or at chemical plants along the ORS.

The data in **Table 6-3** show that chemicals traffic grew only slightly between 1970 and 2000, reaching a level of 10.8 million tons. This is partially explained by the reclassification of alumina from the chemicals group to the ores and minerals group in 1990. Another partial explanation is the lack of growth in the movement of chemical fertilizers. The volume of chemical fertilizers consumed is related to the number of acres under cultivation, which in the ORB states has been diminishing.

6.3.3.8 Ores and Minerals

Ores and minerals traffic, which is made up primarily of salt, bauxite, and gypsum increased only slightly as a share of Ohio River traffic between 1970 and 2000, from 3 to 4 percent. Salt traffic originates on the Gulf Coast and moves to urban centers on the ORS for use as road salt or to chlor-alkali plants for the manufacture of chlorine and sodium hydroxide. Bauxite is entirely imported at this point and moves from the Gulf Coast to ORS aluminum plants. Gypsum sources are more widespread, but growth in this commodity group is resulting from coal desulfurization activities at ORS utility plants, where synthetic gypsum is produced as a by product.

Between 1970 and 2000, ores and minerals traffic increased at an annual rate of 2.9 percent to 9.1 million tons. This high growth rate is explained in part by the re-classification of alumina from the chemicals to the ores and minerals group in 1990 and by the introduction of synthetic gypsum traffic, which is a by-product of coal desulfurization at electric utilities. Synthetic gypsum is used in the manufacture of gypsum wallboard. Between 1990 and 2000, the growth rate for this commodity group increased to 5.2 percent, further underscoring the growth of synthetic gypsum traffic.

6.3.3.9 Iron and Steel

Iron and steel traffic, which includes iron ore, increased from 3.0 percent of total traffic in 1970 to about 6.0 percent in 2000. Iron and steel traffic on the Ohio River consists of imported and domestically-produced iron ore; the intermediate outputs of integrated steel mills and steel mini-mills, as well as imported products; and the iron and steel feed-stocks of steel mini-mills.

In the 30 years between 1970 and 2000, iron and steel traffic increased at an annual rate of 4 percent, reaching a level of 14.3 million tons. Over this 30-year span, iron and steel grew faster than any other group on the system. Traffic in iron and steel on the Ohio reflects the changes that have taken place in the steel industry over the last three decades.

Iron ore traffic diminished during the 1980s because a number of integrated steel mills closed, but subsequently rebounded as remaining producers turned to imported iron ore. Traffic in iron and steel scrap increased as steel mini-mills opened for operation. More intermediate steel products are moving on the system as imports have grown and steel processors have taken over some of the functions formerly carried out by integrated producers. Iron and steel traffic on the Ohio grew at an annual rate of 8.2 percent between 1990 and 2000, again fueled by growth in imported iron ore and intermediate products, as well as growth in scrap movements to mini-mills.

6.3.3.10 All Others

Traffic in the all others category, made up in large part of cement, lime, asphalt, and processed animal feed increased from 4 percent to 8 percent of Ohio River traffic between 1970 and 2000.

The data in **Table 6-3** show that traffic in the all others category grew at a faster rate (4.2 percent per annum) than any other commodity group in the 1970-2000 period. Much of the growth is associated with the opening of grain processors on the ORS that supply by-product animal feed to the export market and with the installation and operation of lime-based coal desulfurization units by the electric utilities. During the 1990-2000 period, the growth of traffic in the all others category slowed to about 1 percent per annum. The reduction in growth is attributable to a fall-off in the export market for ORS animal feed.

6.4 LOCK-LEVEL TRAFFIC

Table 6-4 shows total commodity traffic at Ohio River mainstem projects for the period 1970-2000. The highest growth rates for the 30-year period occurred at projects in the middle Ohio Valley, while the uppermost Ohio River projects had the lowest. The highest growth rates were experienced at the Greenup and Meldahl facilities. These were followed by Hannibal and Pike Island on the upper river, and Myers and Smithland on the lower river. Lock-level commodity traffic growth has been hampered in the 1990s by a substantial drop-off in export coal and grain traffic, the loss of some domestic utility steam coal markets outside of the ORS, and a reduction in the usage and waterborne movement of Illinois Basin and Northern Appalachian coals by electric utilities. The projects most severely affected during the 1990s were the lower river projects. Traffic at the uppermost Ohio River projects remained very nearly flat over the 10-year period.

6.5 PROJECTED TRAFFIC DEMANDS

6.5.1 Introduction

This section presents the current traffic demand forecasts for the Ohio River. In total, five alternative traffic demand forecasts for utility steam coal and flue gas desulfurization (FGD) sorbent materials were developed. These forecasts were combined with a single forecast for all other commodity traffic. The alternative utility-related traffic

demand forecasts reflect two distinct approaches to the forecasting problem. One is founded on extensive survey input from the utilities themselves and the other is based on a highly-detailed linear programming approach.

6.5.2 Forecasting Methodology

The ORS traffic demand forecasts presented here represent a comprehensive update of previous forecasts completed in the spring of 1999. New forecasts were prepared for all commodity groups, but because of the dominance of utility steam coal on the system and the uncertainties surrounding the regulatory future, alternative scenarios were developed only for utility coal and sorbent materials (lime and limestone) used for coal

TABLE 6-4
Historic Traffic at Ohio River Projects, 1970-2000
(Million Tons)

Project	1970	1980	1990	1995	2000	Annual % Growth 1970-	Annual % Growth 1990-
Emsworth	19.6	20.0	21.8	21.6	21.9	0.4	0.1
Dashield	20.2	21.0	23.2	22.8	22.4	0.3	-
Montgomery	17.4	20.4	25.0	25.2	25.2	1.2	0.1
New	19.2	23.2	30.4	36.5	34.2	1.9	1.2
Pike	19.8	26.4	36.0	43.9	42.3	2.6	1.6
Hanniba	22.4	30.4	36.3	47.9	49.8	2.7	3.2
Willow	25.6	31.6	34.5	45.6	47.0	2.0	3.1
Bellevill	26.1	32.6	37.0	48.4	50.9	2.3	3.2
Racin	27.0	34.0	38.2	49.0	51.5	2.2	3.0
Byrd	28.9	37.4	42.3	60.3	59.1	2.4	3.4
Greenu	28.7	34.8	56.2	71.0	74.0	3.2	2.8
Meldah	28.5	34.6	55.2	65.0	64.6	2.8	1.6
Marklan	29.4	37.8	53.6	58.8	56.0	2.2	0.4
McAlpin	33.0	41.5	58.4	60.0	55.2	1.7	-
Cannelto	38.1	43.2	62.4	60.5	54.1	1.2	-
Newburg	32.8	43.9	74.3	73.5	63.0	2.2	-
Myers	34.8	50.3	83.6	85.0	72.0	2.5	-
Smithland	39.1	58.5	91.2	89.9	81.4	2.5	-
L/D	45.9	63.0	101.4	98.2	91.8	2.3	-
L/D	43.3	53.6	87.8	87.9	85.3	2.3	-
Ohio	126.8	160.7	225.7	235.8	236.5	2.1	0.6
Ohio River	163.1	200.5	260.3	263.5	271.8	1.7	0.5

SOURCE: USACE Waterborne Commerce Statistics

desulfurization. The current round of adjustments to the utility coal forecasts was necessitated by existing and likely future regulatory changes affecting the electric utility

industry. Environmental issues are acknowledged by industry experts to be the dominant issues expected to affect future coal utilization and sourcing on the part of the electric utilities. In light of this, five alternative forecast scenarios were developed, three of which directly reflect alternative legislative approaches to emissions reductions.

The basic forecasting framework for developing waterway traffic demand forecasts is similar in most instances, the major exceptions being three of the alternative utility coal forecasts, which are based on a linear programming approach. The procedure starts with a set of base-year waterway traffic commodity flows and information about the economic prospects of the industries and individual companies consuming these waterborne commodities. The first steps in projecting waterway traffic demands are to identify the industry and market that each dock serves and to adjust commodity flows to these docks to represent base-level expectations for each facility. Adjustments are based on examination of historical flows and the results of extensive shipper surveys. Industry and market prospects are analyzed by examination of relevant industry and economic/demographic forecasts and the company-specific information obtained by means of shipper surveys. Finally, future traffic demands are generated based both on the information obtained in the shipper surveys and the application of appropriate forecast growth.

Since utility coal dominates the traffic picture on the ORS, the most detailed analyses were conducted for the utility-related commodities, i.e., utility coal and lime and limestone used in coal desulfurization. Two distinct approaches were taken to forecasting ORS utility coal traffic. One approach involved surveying the utilities themselves, soliciting information from them regarding their future coal sourcing plans in light of the environmental regulations, and using this information in the ORS utility coal model to generate future coal burn, sources and flows. The second approach involved using the output of Hill and Associates' linear programming techniques, based on the use of their National Power Model and other related models. The linear programming approach determines a least cost combination of inputs in a market context, including coal by type and source, to meet electricity demands through time.

These two basic approaches were used to generate the five alternative forecasts of ORS utility coal traffic demands. The first two of these, dubbed the Utility-Based and Utility-Based High scenarios, makes use of utility survey information and the ORS utility coal model to generate a forecast that reflects the utilities' view of the environmental regulatory future. The Utility-Based High scenario assumes high economic growth. The Hill scenarios reflect the impact of three alternative futures on ORS coal flows. The first of these is a continued application of existing law, which in this case is the National Ambient Air Quality Standards. This scenario is referred to as the NAAQS scenario. The second Hill scenario reflects implementation of the administration's multi-emissions proposal, the Clear Skies Initiative, as an amendment to the Clean Air Act. This proposal, referred to as the Clear Skies scenario could be expected to have a fairly profound impact on the use of coal by electric utilities, largely because of the proposal's implied mercury emissions restrictions. The final Hill scenario would be implementation of the Clear Skies initiative without the severe mercury restrictions that are included under Clear Skies. This scenario is referred to as the No Mercury Limitations Scenario. Additional details on the development of alternative traffic forecast scenarios are provided in **Attachment 4 Traffic Demand Forecasts**.

One additional step in the forecasting methodology involved the identification of potential induced traffic for the Upper Ohio River segment. The Emsworth, Dashields and Montgomery projects on the Upper Ohio are the only mainstem projects without 1200'x110' lock chambers. Consequently, these projects form substantial constraints to system traffic because of delays and downtime resulting from more lockage cycles at the projects. In light of this, efforts were made to identify and forecast potential traffic that could be induced to use the waterway by improvements at these projects. A separate shipper survey was conducted to identify potential induced commodity movements. As a result of the survey and subsequent screening of potential movements, almost 1 million tons of traffic were identified that would make use of an improved upper Ohio segment. Additional details on this survey and the traffic identified are provided in **Attachment 4 Traffic Demand Forecasts**.

6.5.3 Forecast Results

6.5.3.1 ORS Traffic Demands

Projected traffic demands for the ORS under each of the five alternative forecast scenarios for the period 2000-2060 are displayed in **Table 6-5**. It should be noted that these forecasts do not include the induced traffic identified as a result of the survey effort described previously. **Figure 6-2** shows historical and projected ORS traffic under each of the alternative scenarios. Over the longer term, the high and low alternatives that emerge

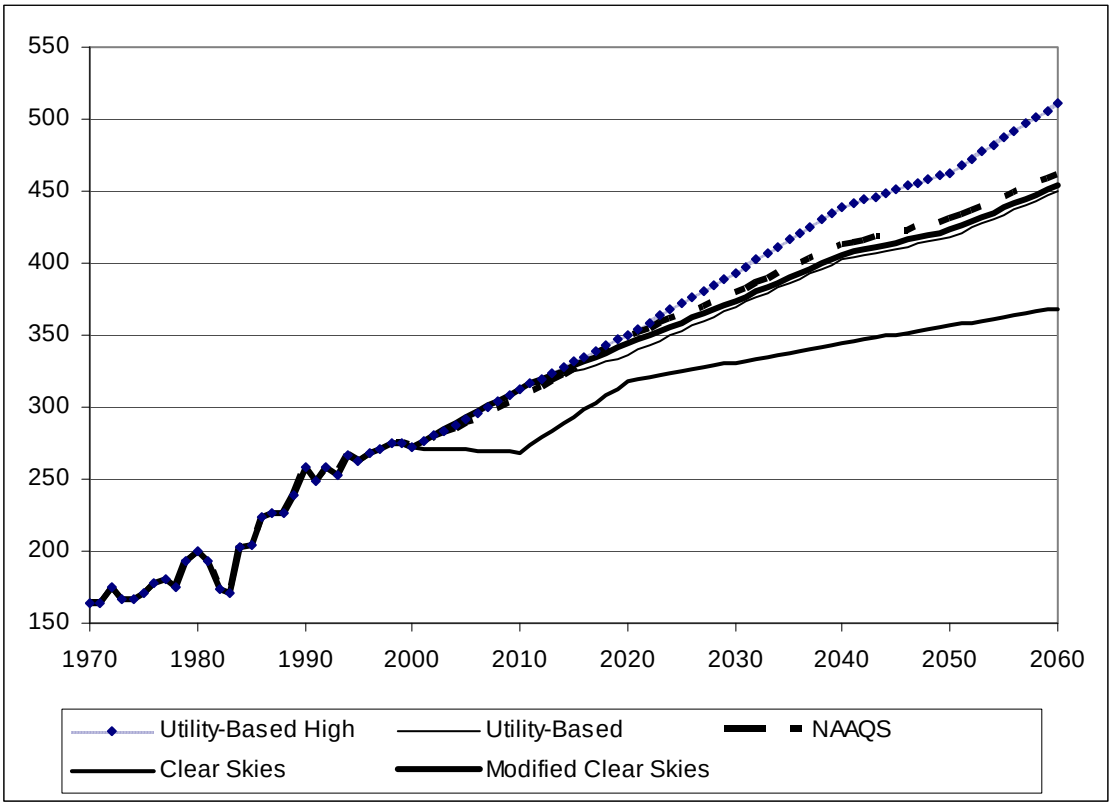
TABLE 6-5
Actual and Projected ORS Traffic Demand, 1970-2060
(Million Tons)

	Actual								Annual % Growth	
									Actual	Projected
Scenario	1970	2000	2010	2020	2030	2040	2050	2060	1970-2000	2000-60
Utility-Based High	163.9	271.8	312.5	350.4	393.1	439.3	463.1	511.0	1.70	1.06
Utility-Based	163.9	271.8	312.5	336.4	369.8	402.2	418.0	449.9	1.70	0.84
NAAQS	163.9	271.8	305.7	348.5	379.3	412.4	429.9	461.5	1.70	0.89
Clear Skies	163.9	271.8	268.7	318.0	331.2	344.5	356.5	368.7	1.70	0.51
Modified Clear Skies	163.9	271.8	313.1	344.4	373.5	406.1	423.0	454.0	1.70	0.86

SOURCE: USACE Waterborne Commerce Statistics and LRD Navigation Planning Center

FIGURE 6-2

ORS Traffic Demand Forecasts



are the Utility-Based High scenario and the Clear Skies scenario. The first of these forecasts reflects the outlook of the major utility users of the ORS along with the application of the ORS utility coal model in a high economic growth framework. The second reflects implementation of the administration's Clear Skies Initiative with its expected negative impact on coal usage. In year 2020, the forecasts range between 318 million tons under the Clear Skies scenario to 350.4 million tons under the Utility-Based High scenario. By year 2060, the range is between 368.7 and 511.0 million tons for these same scenarios. Annual growth for the 2000-2060 period ranges from 0.51 percent to 1.06 percent. This is compared to annual growth over the 1970-2000 period of 1.7 percent per year.

6.5.3.2 Ohio River Traffic Demands

Table 6-6 shows total projected traffic demands for the mainstem Ohio River. Traffic demands for the mainstem show similar patterns to those for the ORS. Ohio River mainstem traffic annually accounts for about 87 percent of total system traffic throughout the forecast period. In 2020, traffic demands range between 273.6 million tons under the Clear Skies scenario to 306.1 million tons under the Utility-Based High scenario. In

TABLE 6-6
Actual and Projected Ohio River Mainstem Traffic Demand, 1970-2060
(Millions of Tons)

	Actual								Annual % Growth	
									Actual	Projected
Scenario	1970	2000	2010	2020	2030	2040	2050	2060	1970-2000	2000-60
Utility-Based High	129.6	239.0	273.3	306.1	342.2	380.0	403.4	443.2	2.06	1.03
Utility-Based	129.6	239.0	273.3	294.9	323.2	350.8	368.0	394.7	2.06	0.84
NAAQS	129.6	239.0	267.0	302.6	327.8	355.6	373.1	399.8	2.06	0.86
Clear Skies	129.6	239.0	235.1	273.6	286.1	298.9	310.6	322.3	2.06	0.50
Modified Clear Skies	129.6	239.0	271.3	297.4	320.5	347.5	364.6	390.5	2.06	0.82

SOURCE: USACE Waterborne Commerce Statistics and LRD Navigation Planning Center

2060, the range is between 322.3 and 443.2 million tons. Annual growth between 2000 and 2060 under Clear Skies is 0.5 percent and under the Utility-Based High scenario 1.03 percent. Over the 1970-2000 period, growth rates for traffic on the Ohio River mainstem were substantially higher than for the ORS overall (2.1 versus 1.7 percent per annum). For the forecast period, growth rates for the ORS are slightly higher under all scenarios, indicating that traffic demand growth rates for tributary streams, especially the Tennessee River, are higher than the mainstem.

6.5.3.3 Ohio River Traffic Demands by Commodity Group

Table 6-7 shows Ohio River mainstem traffic demands by commodity group. All of the commodity group forecasts are identical across the alternative forecasts except for coal and coke, aggregates and all other. Variation in the aggregates and all others forecasts occurs because the sorbent materials used in coal desulfurization are linked to the utility steam coal forecasts and these commodities, limestone and lime, fall into the aggregates and into the all others commodity groups.

The projected growth in coal and coke traffic ranges from 1.18 percent per year under the Utility-Based High scenario to 0.07 percent under the Clear Skies scenario. The growth rates for aggregates show similar patterns to the coal, 0.93 percent under the High Growth Scenario and 0.88 under Clear Skies. The growth rates are more similar to one another because aggregates traffic is dominated by construction aggregates. Growth rates for the all others group are nearly identical, ranging between 0.71 percent per annum under the NAAQS scenario and 0.71 percent under the Utility-Based and Utility-Based High scenarios. Commodity traffic in the all others category is heavily dominated by commodities other than lime used for coal desulfurization and it is assumed that any new scrubbers will be limestone and not lime-based. With respect to the other commodity

TABLE 6-

Ohio River Mainstem Traffic Demand by Commodity
2000 - 2060
(Million Tons)

Commodit	Actua 2000	Projected 2010	2020	2030	2040	2050	2060	Annual Chang 2000-
Utility-Based High:								
Coal &	121.8	137.2	153.9	177.6	203.7	217.2	246.5	1.18
Petroleum	14.1	14.7	15.4	16.2	17.0	17.7	18.5	0.45
Crude	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.27
Aggregates	38.9	49.2	57.2	61.4	63.8	65.8	67.7	0.93
Grain	10.8	12.4	14.2	16.5	19.3	20.4	21.8	1.18
Chemicals	10.8	11.9	12.5	13.4	14.8	16.3	17.9	0.86
Ores & Minerals	9.1	10.5	11.4	12.5	14.0	15.6	17.3	1.08
Iron & Steel	14.3	16.6	18.4	20.0	21.4	22.9	24.5	0.90
All	18.9	20.5	22.7	24.3	25.7	27.1	28.5	0.69
TOTAL	239.0	273.3	306.1	342.2	380.0	403.4	443.2	1.03
Utility-Based:								
Coal &	121.8	137.2	143.0	158.9	174.8	182.2	198.5	0.82
Petroleum	14.1	14.7	15.4	16.2	17.0	17.7	18.5	0.45
Crude	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.27
Aggregates	38.9	49.2	56.9	61.1	63.4	65.4	67.3	0.92
Grain	10.8	12.4	14.2	16.5	19.3	20.4	21.8	1.18
Chemicals	10.8	11.9	12.5	13.4	14.8	16.3	17.9	0.86
Ores & Minerals	9.1	10.5	11.4	12.5	14.0	15.6	17.3	1.08
Iron & Steel	14.3	16.6	18.4	20.0	21.4	22.9	24.5	0.90
All	18.9	20.5	22.6	24.3	25.7	27.1	28.5	0.69
TOTAL	239.0	273.3	294.9	323.2	350.8	368.0	394.7	0.84
NAAQS:								
Coal &	121.8	131.1	151.0	163.8	180.1	187.4	203.9	0.86
Petroleum	14.1	14.7	15.4	16.2	17.0	17.7	18.5	0.45
Crude	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.27
Aggregates	38.9	48.7	56.4	60.4	62.6	64.9	66.6	0.90
Grain	10.8	12.4	14.2	16.5	19.3	20.4	21.8	1.18
Chemicals	10.8	11.9	12.5	13.4	14.8	16.3	17.9	0.86
Ores & Minerals	9.1	10.5	11.4	12.5	14.0	15.6	17.3	1.08
Iron & Steel	14.3	16.6	18.4	20.0	21.4	22.9	24.5	0.90
All	18.9	20.8	22.9	24.5	26.0	27.4	28.8	0.71
TOTAL	239.0	267.0	302.6	327.8	355.6	373.1	399.8	0.86

TABLE 6-7

Ohio River Mainstem Traffic Demand by Commodity
2000 - 2060
(Million Tons)

Commodit	Actua 2000	Projecte 2010	2020	2030	2040	2050	2060	Annual Chang 2000-
Clear								
Coal &	121.8	99.6	122.5	122.7	124.1	125.6	127.3	0.07
Petroleum	14.1	14.7	15.4	16.2	17.0	17.7	18.5	0.45
Crude	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.27
Aggregates	38.9	48.6	56.0	60.0	62.0	64.4	65.9	0.88
Grain	10.8	12.4	14.2	16.5	19.3	20.4	21.8	1.18
Chemicals	10.8	11.9	12.5	13.4	14.8	16.3	17.9	0.86
Ores & Minerals	9.1	10.5	11.4	12.5	14.0	15.6	17.3	1.08
Iron & Steel	14.3	16.6	18.4	20.0	21.4	22.9	24.5	0.90
All	18.9	20.5	22.8	24.4	25.9	27.2	28.7	0.70
TOTAL	239.0	235.1	273.6	286.1	298.9	310.6	322.3	0.50
Modified Clear								
Coal &	121.8	135.3	145.8	156.6	172.2	179.1	194.9	0.79
Petroleum	14.1	14.7	15.4	16.2	17.0	17.7	18.5	0.45
Crude	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.27
Aggregates	38.9	48.7	56.4	60.4	62.5	64.9	66.4	0.90
Grain	10.8	12.4	14.2	16.5	19.3	20.4	21.8	1.18
Chemicals	10.8	11.9	12.5	13.4	14.8	16.3	17.9	0.86
Ores & Minerals	9.1	10.5	11.4	12.5	14.0	15.6	17.3	1.08
Iron & Steel	14.3	16.6	18.4	20.0	21.4	22.9	24.5	0.90
All	18.9	20.8	22.8	24.5	25.9	27.3	28.7	0.70
TOTAL	239.0	271.3	297.4	320.5	347.5	364.6	390.5	0.82

SOURCE: USACE Waterborne Commerce Statistics and LRD Navigation Planning Center

groups, the highest annual growth is forecast for grains (1.18 percent), followed by ores and minerals (1.08 percent), iron and steel (0.9 percent), chemicals (0.86 percent), petroleum fuels (0.45 percent), and crude petroleum (0.27 percent).

6.5.3.4 Lock-Level Traffic Demands

Traffic demand forecasts for the Ohio mainstem locks are displayed in **Table 6-8**. All of the forecast scenarios reflect the effects of coal switching by ORS-dependent utilities

TABLE 6-8

Projected Lock Traffic Demand
(Millions of Tons)

Project/Scenario	2000	2010	2020	2030	2040	2050	2060	Annual % Change 2000-60
Emsworth:								
Utility-Based High	21.9	24.6	25.7	27.8	29.7	30.8	33.3	0.70
Utility-Based	21.9	24.6	24.8	26.1	27.5	28.3	29.8	0.51
NAAQS	21.9	22.1	30.1	32.2	34.3	36.0	38.2	0.93
Clear Skies	21.9	19.2	24.8	24.9	25.2	25.6	26.0	0.28
Modified Clear Skies	21.9	23.9	26.9	28.6	30.4	31.9	33.8	0.72
Dashields:								
Utility-Based High	22.4	25.0	26.2	28.3	30.2	31.3	33.9	0.69
Utility-Based	22.4	25.0	25.3	26.6	28.0	28.8	30.3	0.51
NAAQS	22.4	22.5	30.6	32.7	34.8	36.5	38.8	0.92
Clear Skies	22.4	19.7	25.3	25.4	25.8	26.2	26.6	0.29
Modified Clear Skies	22.4	24.4	27.4	29.1	30.9	32.4	34.4	0.72
Montgomery:								
Utility-Based High	25.2	27.3	28.5	30.8	32.9	34.1	36.9	0.63
Utility-Based	25.2	27.3	27.6	29.1	30.6	31.6	33.3	0.46
NAAQS	25.2	26.0	34.7	37.0	39.4	41.3	43.9	0.93
Clear Skies	25.2	22.2	28.3	28.5	29.1	29.6	30.2	0.30
Modified Clear Skies	25.2	27.8	31.7	33.8	35.9	37.6	39.9	0.77
New Cumberland:								
Utility-Based High	34.2	35.8	37.0	40.1	43.0	44.5	48.5	0.58
Utility-Based	34.2	35.8	35.7	37.7	39.8	41.0	43.7	0.41
NAAQS	34.2	35.9	47.2	50.4	53.5	55.8	59.3	0.92
Clear Skies	34.2	23.5	38.2	38.6	39.3	40.1	40.9	0.30
Modified Clear Skies	34.2	42.5	43.8	46.6	49.4	51.6	54.7	0.79
Pike Island:								
Utility-Based High	42.3	46.7	48.8	53.0	56.5	58.9	64.0	0.69
Utility-Based	42.3	46.7	47.3	50.1	52.8	54.8	58.3	0.54
NAAQS	42.3	47.7	58.9	63.0	66.8	69.9	74.2	0.94
Clear Skies	42.3	35.4	51.0	51.8	53.1	54.3	55.7	0.46
Modified Clear Skies	42.3	54.3	55.8	59.5	63.0	65.9	69.9	0.84
Hannibal:								
Utility-Based High	49.8	63.0	64.8	71.4	77.1	82.1	90.7	1.00
Utility-Based	49.8	63.0	62.2	66.6	71.0	74.7	79.9	0.79
NAAQS	49.8	66.8	72.6	78.3	83.8	88.8	95.0	1.08
Clear Skies	49.8	52.0	60.6	61.6	62.9	64.3	65.8	0.47
Modified Clear Skies	49.8	70.3	75.0	80.9	86.5	91.7	98.0	1.14
Willow Island:								
Utility-Based High	47.0	59.1	61.4	67.5	72.8	77.4	85.1	0.99
Utility-Based	47.0	59.1	59.0	63.1	67.2	70.6	75.5	0.79
NAAQS	47.0	63.5	69.3	74.6	79.9	84.6	90.5	1.10
Clear Skies	47.0	48.7	57.4	58.3	59.7	61.2	62.7	0.48
Modified Clear Skies	47.0	67.0	71.7	77.2	82.7	87.5	93.6	1.15

TABLE 6-8 (cont)

Projected Lock Traffic Demand
(Millions of Tons)

Project/Scenario	2000	2010	2020	2030	2040	2050	2060	Annual % Change 2000-60
Belleville:								
Utility-Based High	50.9	63.3	65.7	72.0	77.5	82.3	90.1	0.96
Utility-Based	50.9	63.3	63.4	67.6	71.9	75.5	80.6	0.77
NAAQS	50.9	67.7	73.7	79.1	84.6	89.5	95.6	1.05
Clear Skies	50.9	52.9	61.7	62.9	64.4	66.0	67.8	0.48
Modified Clear Skies	50.9	71.2	76.1	81.7	87.3	92.4	98.6	1.11
Racine:								
Utility-Based High	51.5	63.9	66.3	72.6	78.1	82.9	90.8	0.95
Utility-Based	51.5	63.9	64.0	68.2	72.5	76.1	81.3	0.76
NAAQS	51.5	68.3	74.3	79.8	85.2	90.1	96.3	1.05
Clear Skies	51.5	53.5	62.3	63.5	65.1	66.7	68.4	0.48
Modified Clear Skies	51.5	71.8	76.7	82.4	88.0	93.0	99.3	1.10
Byrd:								
Utility-Based High	59.1	70.7	76.4	83.7	91.1	97.7	107.0	1.00
Utility-Based	59.1	70.7	73.4	78.6	84.1	88.6	94.7	0.79
NAAQS	59.1	56.9	63.2	67.3	71.9	76.0	80.8	0.52
Clear Skies	59.1	52.7	56.4	57.9	59.9	61.8	63.9	0.13
Modified Clear Skies	59.1	56.4	65.7	70.1	74.8	79.1	84.1	0.59
Greenup:								
Utility-Based High	74.0	83.9	92.9	103.0	114.2	124.2	137.0	1.03
Utility-Based	74.0	83.9	89.0	96.7	104.6	111.3	119.9	0.81
NAAQS	74.0	64.0	71.0	76.4	82.2	87.6	93.6	0.39
Clear Skies	74.0	58.5	64.6	67.4	70.6	73.6	76.9	0.06
Modified Clear Skies	74.0	63.8	72.4	78.0	83.8	89.3	95.4	0.43
Meldahl:								
Utility-Based High	64.6	72.1	77.7	85.6	94.7	102.5	112.5	0.93
Utility-Based	64.6	72.1	75.0	81.3	87.7	93.1	99.9	0.73
NAAQS	64.6	55.6	61.8	66.4	71.1	75.8	80.9	0.37
Clear Skies	64.6	50.2	54.9	57.5	60.4	63.3	66.4	0.05
Modified Clear Skies	64.6	55.4	62.6	67.3	72.0	76.7	81.9	0.40
Markland:								
Utility-Based High	56.0	65.6	68.9	75.4	82.9	88.0	95.9	0.90
Utility-Based	56.0	65.6	67.3	72.8	78.5	82.8	88.4	0.76
NAAQS	56.0	56.9	69.7	75.3	80.9	86.0	91.7	0.82
Clear Skies	56.0	51.7	63.6	66.8	70.2	73.5	76.9	0.53
Modified Clear Skies	56.0	56.2	66.8	72.0	77.3	82.2	87.6	0.75
McAlpine:								
Utility-Based High	55.2	65.3	70.2	76.8	84.4	90.5	98.4	0.97
Utility-Based	55.2	65.3	68.6	74.4	80.4	85.2	91.2	0.84
NAAQS	55.2	68.8	82.3	89.1	96.2	103.1	110.3	1.16
Clear Skies	55.2	54.7	72.8	76.3	80.1	83.9	87.6	0.77
Modified Clear Skies	55.2	71.0	77.2	83.5	90.1	96.4	103.0	1.05

TABLE 6-8 (cont)

Projected Lock Traffic Demand
(Millions of Tons)

Project/Scenario	2000	2010	2020	2030	2040	2050	2060	Annual % Change 2000-60
Cannelton:								
Utility-Based High	54.1	66.1	71.7	78.6	86.7	92.8	101.2	1.05
Utility-Based	54.1	66.1	70.0	76.1	82.4	87.3	93.6	0.92
NAAQS	54.1	71.5	85.1	92.4	100.0	107.1	114.8	1.26
Clear Skies	54.1	58.0	72.8	76.5	80.5	84.2	88.2	0.82
Modified Clear Skies	54.1	74.1	80.9	87.7	94.8	101.5	108.7	1.17
Newburgh:								
Utility-Based High	63.0	75.1	83.7	93.2	103.3	110.2	121.0	1.09
Utility-Based	63.0	75.1	81.3	89.0	97.0	102.4	110.2	0.94
NAAQS	63.0	85.4	100.0	109.6	119.4	126.9	136.7	1.30
Clear Skies	63.0	69.8	83.0	86.9	91.4	95.4	99.7	0.77
Modified Clear Skies	63.0	87.7	96.3	105.5	115.0	122.1	131.5	1.23
Myers:								
Utility-Based High	72.0	85.1	97.9	110.4	125.5	131.5	145.5	1.18
Utility-Based	72.0	85.1	94.4	104.6	115.6	119.8	129.5	0.98
NAAQS	72.0	93.6	106.1	117.2	129.0	135.7	146.5	1.19
Clear Skies	72.0	77.6	88.6	93.0	98.4	103.2	107.8	0.68
Modified Clear Skies	72.0	94.3	102.0	112.6	124.0	130.3	140.7	1.12
Smithland:								
Utility-Based High	81.4	95.3	110.3	124.9	143.1	148.9	165.3	1.19
Utility-Based	81.4	95.3	105.9	118.0	130.7	134.5	145.6	0.97
NAAQS	81.4	105.8	119.9	133.2	147.4	152.0	164.6	1.18
Clear Skies	81.4	88.8	101.6	106.4	112.1	116.4	121.0	0.66
Modified Clear Skies	81.4	106.9	115.4	127.5	141.0	145.3	157.2	1.10
L/D 52: 1/								
Utility-Based High	91.8	107.5	121.2	134.7	148.9	158.4	172.4	1.06
Utility-Based	91.8	107.5	118.7	130.3	142.1	150.2	160.9	0.94
NAAQS	91.8	114.1	129.7	141.9	154.7	163.7	175.4	1.09
Clear Skies	91.8	98.5	113.1	120.6	128.5	135.1	142.1	0.73
Modified Clear Skies	91.8	116.2	127.2	138.7	151.2	159.9	171.3	1.05
L/D 53: 1/								
Utility-Based High	85.3	93.2	103.0	112.5	123.0	132.0	142.0	0.85
Utility-Based	85.3	93.2	102.1	111.1	120.5	128.5	137.1	0.79
NAAQS	85.3	92.0	102.8	108.0	117.1	124.0	132.1	0.73
Clear Skies	85.3	85.8	93.5	100.9	108.8	115.3	122.2	0.60
Modified Clear Skies	85.3	93.4	103.5	107.5	116.6	123.5	131.5	0.72

SOURCE: USACE Waterborne Commerce Statistics and LRD Navigation Planning Center

1/ Forecasts made with Ls/Ds 52 & 53 in place. Both will be replaced by Olmsted L/D in 2011.

to meet the requirements of existing or proposed environmental regulations. The utility-based forecasts reflect the outlook of the utilities themselves. The remaining forecasts are based on the solution of linear programming procedures that determine utility plants' least-cost combinations of inputs, including coal by type, in a market context. Since most of the forecasts were arrived at independently and since considerable coal switching takes place in some of the forecasts, the forecasts can align quite differently at the locks. For example, the high forecast at one lock may not be the high forecast at another.

Forecast growth rates tend to be the highest for the lowermost of the upper Ohio projects and for projects on the lower river. This reflects an anticipated increased interest in Northern Appalachian coal and Illinois Basin coal on the part of the utilities, as well as increases in the movement of western coal on the ORS. Utilities are expected to include more Northern Appalachian and Illinois Basin coal in their mixes because these coals are lower cost and because scrubbing becomes more widespread through time. The lowest growth rates occur at the uppermost Ohio River locks and locks on the middle river. The lower growth rates at the uppermost Ohio River locks reflects increased usage of local coals by plants on the Monongahela and the upper Ohio. Lower growth rates for projects in the middle river reflects diminished interest in Central Appalachian coals resulting from reduced availability and resulting increased production costs for these coals.

6.6 INDUCED TRAFFIC DEMAND

On the Ohio River, the Upper Ohio locks at Emsworth, Dashields and Montgomery are substantially constrained when compared to other projects on the river.
Each of these projects has a 600'x110' main chamber and a 360'x56' auxiliary chamber. All of the remaining projects on the Ohio River have at least one 1200'x110' lock chamber and normally have one 600'x110' auxiliary lock chamber. The small size of the chambers at the Upper Ohio projects produces high delays during operational periods. The high number of lockage cycles required at these locks has also resulted in substantially more down time at the Upper Ohio projects than at other main stem projects.

In light of this situation, a special traffic survey was conducted with the purpose of identifying traffic that could be induced by waterway improvements on the Upper Ohio segment. This survey was conducted by analysts at TVA. The induced traffic survey began with an analysis of available commodity traffic data, including regional waterway and rail traffic. From a list of 513 companies, 30 high-potential shippers were ultimately identified. The 30 high-potential shippers were contacted during the course of field interviews. Following the interviews, a list of potential shipments was constructed and movements totaling 954,000 tons were identified that were considered to be representative of the type and volume that could be expected to be induced to use the waterway by improvements on the Upper Ohio. A listing of the traffic is provided in **Table 6-9**

TABLE 6-9

Potential Induced Traffic

Commodity	Tonnage
Coal & Coke	25,000
Chemicals	80,000
Ores & Minerals	40,000
Iron & Steel	379,000
All Other	430,000
TOTAL	954,000

* additional details on the induced traffic are provided in Attachment 4, Addendum 3 of the Economics Appendix see page 11 of that document.

SECTION 7
SYSTEM MODELING, INPUTS, CALIBRATION AND OUTPUTS

7.1 INTRODUCTION

Cost-benefit analysis is used to identify the System Investment Plan (SIP) that maximizes net benefits (benefits minus costs) -- the NED plan. As the analytical technique implies, half of the analysis is the SIP cost estimates themselves and the other half is the benefit estimates.

The engineering team provided normal O&M, scheduled maintenance and scheduled improvement costs for the mainstem projects included in this analysis under three different proposed maintenance plans and several different new construction improvement plans. The Ohio River Navigation Investment Model (ORNIM) used engineering reliability and economic input data to estimate unscheduled repair costs under the three maintenance plans and several new construction improvement plans analyzed. The scheduled maintenance costs, scheduled improvement costs, normal O&M costs, and unscheduled repair costs collectively comprise the total project costs for each system investment alternative analyzed.[1]

Benefit estimates are a product of the system benefit analysis, which is conducted within the supply and demand framework discussed in Section 1, Introduction. The ORNIM is the system model used to keep track of all the traffic interactions and to estimate the NED benefits and navigation impacts for each of the structural and nonstructural project investment alternatives being evaluated in the SIP. It is an annual model that can be described as a spatially-detailed, partial equilibrium model. It is used to determine equilibrium traffic system transportation rate savings while optimizing investment alternatives.

On inland waterways, structural measures include new lock construction, construction that modifies existing structures (lock extensions), and small-scale investments like mooring cells, all of which improve lock throughput. Nonstructural measures, such as n-up/n-down lockage policies and the use of helper boats, can improve system throughput and encourage more efficient use of the existing infrastructure. ORNIM is able to evaluate and identify a broad range of structural and nonstructural alternatives that yield the optimum combination of capacity enhancements and nonstructural investments for the Ohio River.

[1] Random minor closure costs are also considered in developing total project costs. These costs are explained in Section 8.

The remainder of this section describes the development and structure of ORNIM, its inputs and the results of model calibration. **Attachment 1, Ohio River Navigation Investment Model**, presents a much more detailed discussion of ORNIM and its inputs.

7.2 THE SYSTEM MODEL

7.2.1 Model Development and Structure

ORNIM is based on a long history of model development within the Corps. The Tow Cost Model (TCM) and the Equilibrium Model (EQ), which had their beginnings in the 1970s, served as a starting point for ORNIM [*1*]. ORNIM takes advantage of additional and more refined data, in combination with state-of-the-art computer software, hardware, and computational algorithms, to move to a new frontier of navigation modeling. ORNIM allows users to do analyses not possible with earlier generation models, e.g. optimal selection and timing of a large number of potential river system improvements.

ORNIM was developed as a spatially-detailed partial-equilibrium model, which incorporates the following assumptions: (i) demand for individual movements, provided exogenously, is perfectly inelastic; (ii) willingness-to-pay for individual river movements is equal to the exogenously given least-cost alternative rail rate; (iii) supply of rail for individual movements is perfectly elastic at the exogenously given rail rate; and (iv) equipment idled during closure incur no cost. Empirical evidence on demand elasticity and willingness-to-pay[2] suggests that these assumptions are reasonable. In the short-run, individual movement demand appears fairly inelastic to rates and in the long-run, decisions to move cargo by water depend partly on river rates, and partly on other supply logistics and environmental and energy policies. Appropriately, the demand for waterway movements is exogenous to ORNIM as well; and the Corps' recent scenario-based demand approach enables the analysis of mode and source switching.

ORNIM is composed of three modules – the Waterway Supply Demand Module (WSDM), the Lock Risk Module (LRM), and the Optimal Module (OM) (see **Figure 7.1**). WSDM utilizes detailed information about the Ohio River network (a total of 56 locks with details about river sectors and nodes), towboat/barge operations (numerous tow types and barge configurations with different costs), lock operations, and cargo forecasts (nine commodities with some 31,000 potential movements per year) to estimate annual equilibrium traffic. LRM uses engineering inputs (e.g. reliability estimates, component hazard functions, and repair protocols) to determine the probabilities of unplanned closures for each lock for each year. Optimization identifies the optimal set of investment options (e.g. construction, rehabs, and maintenance) at each lock for a 60-year horizon.

7.2.2 Model Description

It is important to understand the function of each module and then to understand the process for combining the functions into an analytical process. The innovation of ORNIM is not only a more modern and efficient version of standard functionality, but it also

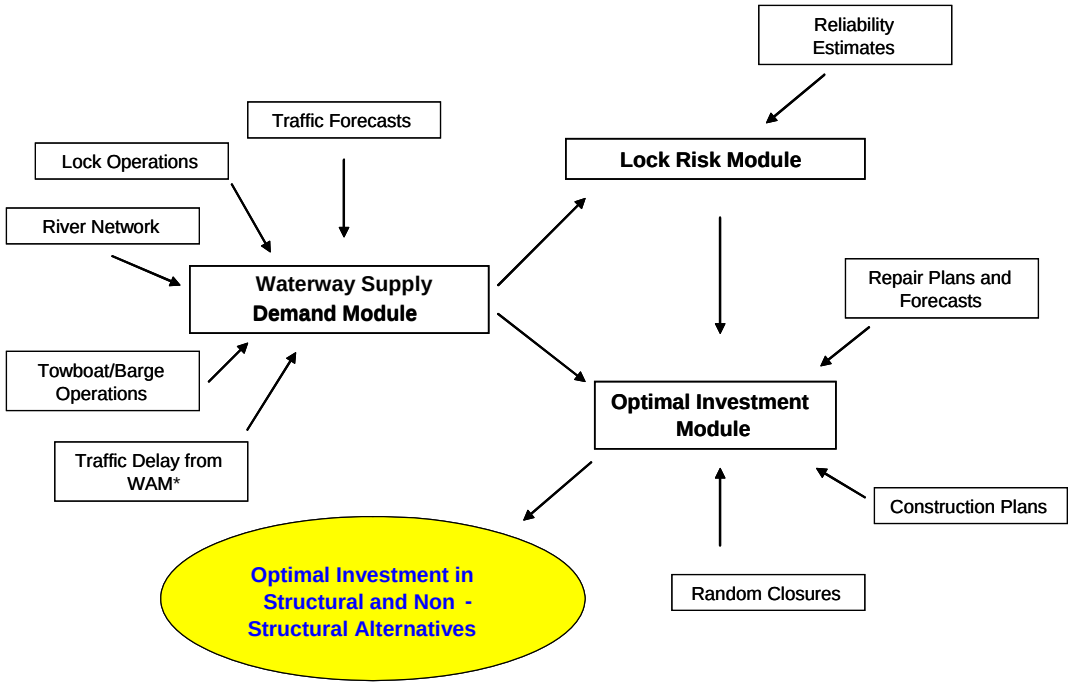
[2] See Attachment 7 Willingness to Pay for Water Transportation in the Ohio River Basin by Larry Bray and Chris Dager at TVA and Mark Burton at Marshall University.

leverages of these new capabilities into a new process for developing and assessing system investment plans.

7.2.2.1 Waterway Supply Demand Module (WSDM)

WSDM determines equilibrium waterway traffic levels under a given system configuration and forecast-scenario for each year in the analysis period, taking into account scheduled lock closures in the system. The first task of WSDM is to develop least-cost waterway shipping plans. WSDM computes the towing costs and determines the cost-effective tow configuration needed to transport each annual port-to-port commodity movement on the waterway network, honoring a set of towing and operating characteristics. Since shipping plans can contain multiple configurations over different sections of the river with configuration changes allowed at pre-specified re-fleeting points, ORNIM uses a dynamic programming approach to optimize the shipping plan. Once each movement's shipping plan and cost characteristics are determined, WSDM solves for equilibrium traffic levels. Equilibrium is reached when every movement fully assigned to the waterway has a lower cost-per-ton water routing than overland, resulting in a positive rate-savings, while every movement fully assigned to overland routing has a lower cost-per-ton than by water. Thus no single movement can lower its transportation costs by changing modes. Solving for equilibrium traffic is a difficult computational problem, requiring an iterative approach because the cost of shipping a movement by water depends on the aggregate traffic level at each lock on the movement's route. The process of equilibration eventually converges to a solution.

FIGURE 7-1
The ORNIM Systems Model



***** Traffic delay is input into WSDM through a family of tonnage-transit curves developed by the Waterways Analysis Model (WAM) – see Attachment 2, Capacity Analysis.

WSDM reads WAM developed tonnage-transit time functions for each lock. Tonnage-transit curves are developed for normal operating conditions (no closures) and for multiple closure durations anticipated over the analysis period. WSDM also reads scheduled maintenance closure data specifying the number and type of closures scheduled to occur at each lock chamber during the year. The scheduled maintenance closures are based on engineering analysis of the maintenance requirements of each structure and are alternative specific. WSDM uses the tonnage-transit curve data and the scheduled closure data to calculate the change in each movement's lock transit cost relative to the base-year rate-savings. Base-year rate-savings were developed from detailed transportation rate analysis. If the change in the towing costs exceeds the base-year rate-savings, the movement's waterway rate-savings erodes and becomes negative, and the model assumes the movement will divert to the overland mode. Determining equilibrium traffic flows begins by ranking the movements in descending order according to their base-year waterway rate-savings. The model then adds movements to the system, each time adjusting the lock traffic totals and determining if the movement will have a positive savings on the waterway. Once the end of the list is reached, the procedure begins at the top again this time removing or adding each movement to maximize the movement's savings. Some movements may have its tonnage split, achieving a net zero savings. The iterative process continues to go through the list of movements until a pass through does not produce a change. At this point equilibrium is reached (every movement that can move at a transportation savings over the all-overland alternative mode is moving via waterway).

WSDM produces equilibrium traffic and transportation rate savings limited by congestion costs associated with scheduled maintenance. The model uses average costs and average rate-savings such that the equilibrium achieved reflects the profit-maximizing actions of individuals and is not a social optimum because individual profit-maximizing behavior does not reflect the impact that one shipper's use of the system has on other shippers using the system. The equilibrium recognizes that individual shippers will not restrict waterway usage to the socially optimum level, but will continue to expand waterway volumes to the level at which their average towing costs equal their average rate-savings. This occurs because each individual carrier pays only its own average cost for moving on the waterway system, not the true marginal costs, which includes congestion costs imposed on others. The equilibrium traffic and associated waterway transportation costs are inputs to the Optimization Module.

7.2.2.2 Lock Risk Module (LRM)

To capture the economic consequences of structural reliability differences between alternatives, engineering hazard functions and event tree information for the major components of each lock chamber (gates, valves, electrical system etc.) are connected to ORNIM through the LRM. The hazard function gives the probability of failure of the component by year given that it has not yet failed and is a function of component age and/or usage (lock traffic). Given a failure from the hazard value, the event tree specifies degree of failure and its consequences in terms of closure duration, repair cost, and resulting reliability. A component fix may require multiple years of investment and multiple closures to implement. Full discussion of component hazard values and event trees is contained in **Attachment 3 Project Maintenance Analysis**.

LRM estimates the probability of each potential closure in each year of a component's life. Given the hazard functions and event tree information for each component considered in the system, the LRM uses Monte Carlo simulation to produce: i) expected repair costs by year and by component for each lock and chamber; and ii) the occurrence probability and duration of each unscheduled closure by age and use of the component. The closure occurrence probabilities allow the Optimization Module to calculate the transportation cost impacts of unscheduled closures. In addition the Optimization Module adds in the expected repair costs for each alternative analyzed.

7.2.2.3 Optimization Module (OM)

The Optimization Module systematically compares each project's investment permutations[3] and timing, selects the optimal investment strategy at each project and summarizes the results. To calculate the costs and benefits for a single investment option, the appropriate WSDM runs are gathered and adjusted for increased transit times caused by unscheduled closures (information passed from LRM). The transportation costs are then merged with expected repair costs (from LRM), scheduled maintenance costs and construction costs to determine the total costs associated with the investment permutation.

Investment strategies are developed from a set of maintenance/improvement alternatives. Underlying all investment strategies are the use of non-structural navigation improvements like industry self help and the appropriate lock operating policy during closure. The concept of an alternative is flexible in ORNIM and can be generally defined as a change to the waterway system which affects the transit time at a lock or locks. Alternatives can add, remove, or replace components and locks; change maintenance plans; change the lock transit curves; change the movement set; and change the waterway network (re-fleeting points, link capacities, tow size etc.). Multiple alternatives for a lock or set of locks can be linked together and the implementation of an alternative can begin any time within a user-specified window. Each alternative is associated with a year-by-year investment cost stream.

The flexibility in how the alternative can be defined provides a powerful modeling tool; however, calculating the resulting savings is a complex process. The complexity prevents the model from using a standard optimization approach. Instead, the optimization module builds a tree of alternatives, branching at each decision point, to efficiently calculate the net value of various paths through the selection and timing of alternatives. Each node in the tree represents a configuration of the waterway system in a particular year. The savings and costs for that year are estimated by combining the results of WSDM and LRM runs under different closure scenarios.

System equilibrium traffic is determined in WSDM given scheduled closures and their affect on transit times. When a solution set where every movement that can move with a transportation-rate-savings is found, the solution set is fixed. To determine the effects of unscheduled closures, LRM closure probabilities and durations are applied to the solution set and the increase in lock transit times leads to an adjustment in the transportation rate-savings for the solution set. The solution set movements are not allowed to divert off the waterway (switch transportation mode on-the-fly), even if they become

[3] Project investment permutations include all possible combinations of component repair, replace, rehab and new construction options.

negative rate-savers. For marginal shippers, it may have been better to have shipped overland, but the mode decision was made using expected transportation times (including scheduled closures) rather than actual transportation times (including unscheduled closures). In other words, the model assumes in the short-run, that modal choice is limited and that there is "little reaction time between the actual movement of goods and transportation decisions." It should be noted that in the development of the tonnage-transit curves, when scheduled and unscheduled closures are both simulated, the WAM re-schedules some shipments around the closure reflecting observed shipper behavior.

The efficient management of the model allows the analyst to quickly analyze investments under different assumptions (e.g. forecast scenarios). For the ORMSS, with sixteen projects, one thousand and six tonnage-transit curves, a total of one-hundred forty-seven components described with engineering reliability information, five traffic forecast scenarios and 31,503 unique movements, the management of even one investment permutation becomes unmanageable without an automated process.

7.3 MODEL INPUTS

ORNIM requires a considerable amount and variety of input. Model inputs can be grouped into five categories: i) infrastructure characteristics, ii) system operation characteristics, iii) movement characteristics, iv) reliability characteristics, and v) investment options. The inputs and their calibration results are briefly discussed in the following paragraphs.

7.3.1 Infrastructure Characteristics

Infrastructure characteristics include:

- Network data specifying the topology of the inland waterway network and the characteristics of its constituent locks, ports, reaches, and other components that affect towing operations and costs.
- Tonnage-transit curves describing the relationship between the average transit time per tow and the aggregate traffic level at a lock (transit time includes both lockage processing and delay) for a normal operational situation and under various closure durations.
- Vessel data specifying the classes of towboats and barges used for towing operations as well as the costs to industry of owning and operating the equipment.

ORNIM has the capability of storing various versions of the waterway network to represent different system configurations needed for analysis. The waterway network is represented as a sequence of nodes connected by links. ORNIM uses a specific nomenclature to define the various elements of the waterway network. Elements include river segments, sectors, links, junctions, ports, locks, and bends. The amount of network detail depends on the geographic scope of the study. The SIP network contains more detail of the Ohio River mainstem and less detail for the tributaries.

The lock nodes represent traffic constraint points on the waterway network and correspond to actual navigation structures where tows enter a chamber in which they are

raised or lowered in order to pass from one pool level to the next. The most important attribute of a lock is its tonnage-transit time relationship which is used to estimate its physical tonnage capacity[4]. Lock transit time has two components – lockage time and delay time. Given a specified tonnage, ORNIM looks up the tonnage on the tonnage-transit curve and pulls off the expected average transit time to use in its cost calculations.

Another type of data included in the infrastructure characteristics of the network is the cost of towboats and barges used to transport cargo on the waterway network. ORNIM uses data on towing equipment operating costs and physical characteristics to calculate waterway line-haul costs. Increasing waterway line-haul cost decreases base transportation rate savings.

7.3.2 System Operation Characteristics

System operation characteristics include:

- Fuel tax assumptions
- Congestion fees
- Construction budget

Operation characteristics include the inputs necessary to analyze certain cost-recovery options and to analyze construction budget constraints. Cost recovery options include fuel taxes, lockage fees and river fees. The current inland waterway fuel tax is 24.43 cents per gallon where it's been since 1995.

Congestion fee analysis is required by Corps planning guidance for all feasibility lock improvement studies requesting authorization. Although a detailed analysis of congestion fees has not been conducted for this study a general analysis of traffic management alternatives was completed and some preliminary determinations are presented in Section 9 of this Appendix.

ORNIM does not yet have the capability to constrain investment with a construction budget. Future plans are to modify the Optimization Module to identify an optimal set(s) of investment alternatives given a budget limit.

7.3.3 Movement Characteristics

Movement characteristics include:

- Commodity data specifying the commodity groups and their transportation characteristics
- Shipment data specifying the origin, destination, commodity group, annual tonnage, barge type, barge loading, and other characteristics of existing or projected port-to-port commodity movements
- Base transportation-rate savings (movement willingness to pay)

[4] In LRD, the Waterway Analysis Model (WAM) is the tool used to develop tonnage-transit time curves and a project's capacity.

A list of movements, existing and forecast traffic demand, is the main driving force of the model. Most of ORNIM's processing is directed toward determining and costing transportation resources needed to satisfy the movement requirements of moving commerce from point A to point B at a transportation-rate savings. The characteristics of the commodity being moved have an effect on shipping costs. Some commodities have a higher value than others. Hundreds of specific commodities are shipped on the mainstem. For modeling purposes, commodities are aggregated into classes with shared commodity values and shipping characteristics. These classes are: 1) Coal, 2) Petroleum Products, 3) Crude Petroleum, 4) Aggregates, 5) Grains, 6) Chemicals, 7) Ores and Minerals, 8) Iron and Steel, and 9) All Other. Coal and aggregates comprised over 70 percent of mainstem traffic in 2003. Coal, aggregates and petroleum products comprised almost 78 percent of mainstem traffic in 2003.

Movement data includes origin and destination port docks, commodity and barge type, tonnage shipped, barge loadings, waterway and alternate mode transportation rates, and a dedication factor to indicate the percentage of barges involved in the movement that will return empty even if a back-haul opportunity exists.

Forecasting future demand on the mainstem is far from certain. As a result, traffic forecast scenarios are developed based on different economic growth and legislative policy assumptions. The effects of these assumptions on waterway improvement benefits can be analyzed.

7.3.4 Reliability Characteristics

To capture reliability differences between different system configurations (alternatives) ORNIM compares lock chamber maintenance plans (scheduled closures) and probabilistic component reliability closures (unscheduled closures). Engineering reliability analysis provides hazard functions that describe probabilities of component failure and event trees that describe the costs and consequences associated with a failure. Unscheduled repair can alter a planned maintenance schedule. Engineering cost-closure information is used by ORNIM to optimize maintenance repair plans, time component replacement or indicate the need for new construction.

7.3.4.1 Hazard Functions

The reliability of a lock component is defined probabilistically by the Engineering Team. Engineering component models are loaded with the various strength measurements of each component along with the expected future loads for each component. A number of life-cycles are simulated and the timing and frequency of failures are recorded and tabulated as shown in the example shown in **Table 7-1**. The result is a "hazard function" (shown in **Figure 7-2**) which is the probability of failure in a specific year given that the component has not failed up to that year.

Component hazard values are projected out into the future and hence depend on expected future traffic levels and component utilization. Closures elsewhere in the waterway system can affect utilization levels. To account for this uncertainty in the economic analysis, five different forecast scenarios are considered and hazard values are

calculated for a low, medium and high utilization levels. ORNIM interpolates between hazard values depending on the forecast being used.

7.3.4.2 Event Trees

The hazard function only identifies a probability of failure and does not indicate the magnitude of the failure or the consequences. Failure consequences are described in event trees (**Figure 7-3**). The initial branch in the event tree (fail or not fail) is determined by the hazard function and is year specific. Given a failure, the level of failure is based on the branch probabilities for the different levels of failure.[5] The repair, in terms of closure duration and cost, is also described for the specific degree of failure. The event tree provides probabilities of different degrees of failure and the repair consequences.

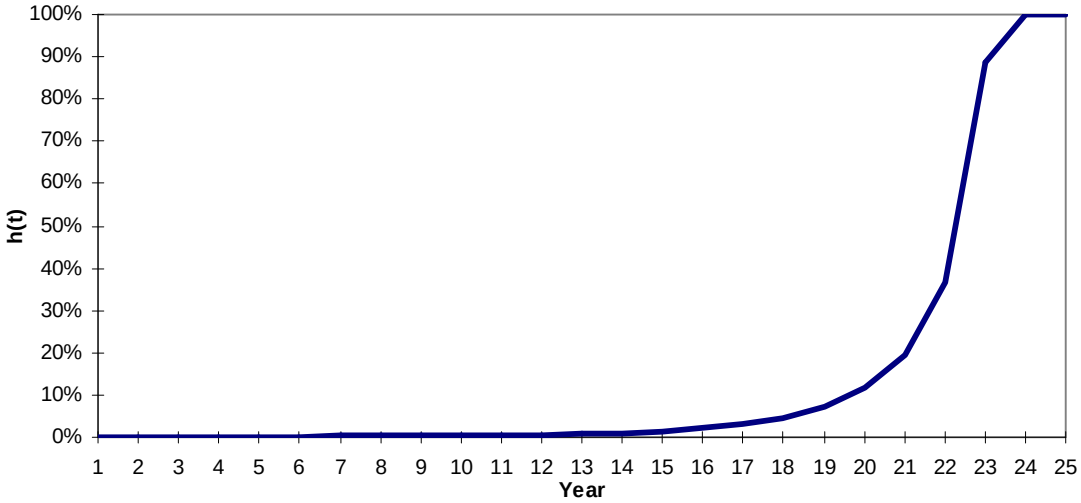
TABLE 7-1
Hazard Function Development

Yr	Failures		Cumulative Survivors	f(*t*) (or pdf)	F(*t*) (or CDF)	R(*t*) = 1 – F(*t*)	h(*t*) =	
	Count	Cumulative					(R(*t*-1)-R(*t*)) / R(*t*-1)	No. failures yr (*i*) / No. of survivors up to year (*i*)
0	0	0	528	0.00000	0.000	1.000	0.00000	0.00000
1	2	2	526	0.00379	0.004	0.996	0.00379	0.00379
2	2	4	524	0.00379	0.008	0.992	0.00380	0.00380
3	2	6	522	0.00379	0.011	0.989	0.00382	0.00382
4	2	8	520	0.00379	0.015	0.985	0.00383	0.00383
5	2	10	518	0.00379	0.019	0.981	0.00385	0.00385
6	2	12	516	0.00379	0.023	0.977	0.00386	0.00386
7	2	14	514	0.00379	0.027	0.973	0.00388	0.00388
8	2	16	512	0.00379	0.030	0.970	0.00389	0.00389
9	2	18	510	0.00379	0.034	0.966	0.00391	0.00391
10	2	20	508	0.00379	0.038	0.962	0.00392	0.00392
11	2	22	506	0.00379	0.042	0.958	0.00394	0.00394
12	2	24	504	0.00379	0.045	0.955	0.00395	0.00395
13	3	27	501	0.00568	0.051	0.949	0.00595	0.00595
14	4	31	497	0.00758	0.059	0.941	0.00798	0.00798
15	5	36	492	0.00947	0.068	0.932	0.01006	0.01006
16	7	43	485	0.01326	0.081	0.919	0.01423	0.01423
17	9	52	476	0.01705	0.098	0.902	0.01856	0.01856
18	12	64	464	0.02273	0.121	0.879	0.02521	0.02521
19	17	81	447	0.03220	0.153	0.847	0.03664	0.03664
20	24	105	423	0.04545	0.199	0.801	0.05369	0.05369
21	34	139	389	0.06439	0.263	0.737	0.08038	0.08038
22	49	188	340	0.09280	0.356	0.644	0.12596	0.12596
23	72	260	268	0.13636	0.492	0.508	0.21176	0.21176
24	107	367	161	0.20265	0.695	0.305	0.39925	0.39925
25	161	528	0	0.30492	1.000	0.000	1.00000	1.00000
				1.00000				

NOTES - F(t) must be zero or greater but can never go above 1.0. R(t) must start at 1.0 and can never go below 0.0. h(t) must be greater than 0.0 but can never get greater than 1.0.

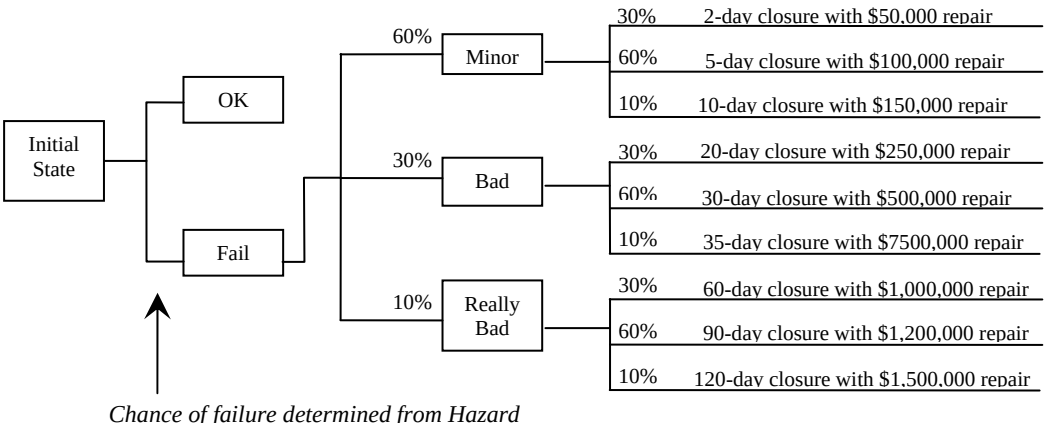
[5] Failure mode Degree of failure branch probabilities can vary by year.

FIGURE 7-2
Example Hazard Function Curve



The level of failure generally determines the repair response. Minor failures generally require a minimal repair with a short-duration chamber closure. The probability of failure in the subsequent years might remain the same (the hazard function is not changed). A moderate failure generally requires a larger repair with a longer duration chamber closure. This repair might increase the reliability of the component, but not to the reliability of a new component. In this case, the hazard function might be re-set to *n*-years earlier. For a catastrophic failure, a high repair cost with a long duration closure is usually the consequence. In the case of catastrophic failures, the repair typically calls for replacement of the component, in which case, the hazard function is set to 100-percent reliable[6].

FIGURE 7-3
Example Consequence Event Tree



[6] While no component will be 100 percent reliable, once it is replaced as part of a new project / major rehabilitation / component replacement, it is assumed to be reliable given regular maintenance. New components are assumed to be designed to current standards and with applicable standards and with applicable safety factors. A chance of significant failure is remote and would occur far into the future if at all.

7.3.5 Investment Options

Investment options specify possible investments that can be made and their effects on reliability, forecasts, and shipping characteristics. The investment can specify different investments that can affect a change in component reliability, a move to a different forecast, or a switch in shipping characteristics.

7.4 MODEL CALIBRATION / VALIDATION

ORNIM is a behavioral as well as a predictive model: it requires validation that it is capable of replicating observed shipper behavior and system operating characteristics. Waterborne Commerce Statistics Center (WCSC) data provides annual origin-to-destination barge flows by commodity; however, information on tow-size, towboat utilization, and empty return characteristics is not available for individual movements. These characteristics are recorded by the Lock Performance Monitoring System (LPMS) at each of the locks. LPMS data provides vessel fleet characteristics of the flow. The goal of calibration is to determine if the WSDM generated shipping plans produces tow characteristics at each lock similar to historical tow characteristics. The shipping plans determine the cost characteristics of each movement used to assess the effects of increased shipping times in the waterway system.

As already mentioned, the first task of WSDM is to develop least-cost waterway shipping plans for each annual port-to-port commodity movement on the waterway network honoring a set of towing and operating characteristics. Calibration is a sequential process involving several iterative steps. At each step, certain static components of the model's waterway system towing and operating characteristics are adjusted or fine-tuned, the model is exercised, and specific results are compared with corresponding target values from LPMS data for the designated baseline or calibration year. The calibration process is designed to ensure that the relevant measures match their corresponding target values as best as possible.

7.4.1 Dedication Factor Calibration

A total barge count (loaded and empty) is necessary to accurately model waterway congestion. WCSC data provides detailed loaded barge information but empty barge data is not as readily available. For this reason, the modeling process has a method for generating empty barge flows based on loaded barge flows and this process needs calibrated to yield accurate estimates of total barge flows.

The first step in calibration is to determine the empty barge flows in the system. Empty barges are determined from a "dedication" factor assigned to each annual port-to-port commodity movement, which specifies how dedicated the barges are to the movement. If the dedication factor is 0, when the loaded trip is complete, the barges are free to move another movement. If the dedication factor is 1, the barges are totally dedicated to the movement, meaning that when the loaded trip is complete, the barges are required to move empty back to the movement's origin. If the dedication factor is between

0 and 1, the barges are partially dedicated, and the dedication factor indicates what portion of the set of barges must make the trip back to the movement's origin empty.

The dedication factor is assigned in a WSDM pre-processor using two linear programming problems. In the first the objective is to minimize the deviation from the target number of empty barges at each navigation project, given the path that each of the movements is taking. Solving this, the program determines a total "best deviation from targets" value. In general, there may be several assignments of dedication factors to movements that will achieve this best deviation. Tanker barges are more likely to be dedicated than are hopper barges, due to the nature of the cargo that they carry. The second linear program attempts to maximize the dedication factors for the tanker classes of barge, and minimize the dedication factors for the hopper classes of barges. Using this objective and the added constraint that the total deviation is equal to the "best deviation" found in the first linear program, the model determines a final setting of the dedication values. These values are then stored.

7.4.2 Tow-size and Towboat Utilization Factor Calibration

The second component of the calibration process is the calibration of the tow-sizes and the average towboat horsepower levels. If the limits set were based solely on the physical limitations of the river, WSDM would tend to produce shipping plans with larger tows than historically observed. To account for the factors encouraging shippers to use slightly smaller tows, WSDM uses another calibration routine to generate a set of tow-size limitations that produce tows comparable to the historically observed fleet at each lock.

There are a number of factors that limit the size of a tow. Each towboat has a limit on the number of barges it can tow, regardless of where in the river system it is working. There are tow-size limits by barge type for each sector of the river that limit the total number of barges in a tow on that river segment. And finally, there are towboat capacity utilization factors that are characterized by towboat and river segment that restrict a towboat's towing capacity. Adjusting the tow-size limits and towboat capacity utilization factors affects the size of the tows that are used, as well as the type of towboat selected for a particular movement.

Because the determination of the shipping plan is a complex process, an analytic procedure similar to that used to set the dedication factors could not be used. Instead, the calibration of the tow-sizes and horsepower is done in an iterative process, by making a small change to a tow-size limit, running WSDM with the changed value, and noting whether the result is closer to the targets than before the change. This is done for every barge type on every river segment. A similar process determines the effect of changing the towboat capacity utilization factors for each towboat on each river segment. Once all of the possible changes have been examined, the calibration program chooses the change that will result in the most improvement, changes that value in the database, and then begins again. When the improvements are negligible, the program stops.

Once the three calibration parameters are determined, validation against LPMS targets can be accomplished. **Figures 7-4 and 7-5** display the summary report showing the 2001 calibration/validation results of ORNIM.

FIGURE 7-4
ORNIM 2001 Calibration/Validation

Lock	Tons/Barge			Transit Time			LoadedBarges		
	Model	Target	%	Model	Target	%	Model	Target	%
Emsworth	1,343	1,341	0.1%	151	151	0.0%	15,985	16,007	-0.1%
Dashields	1,349	1,344	0.4%	114	114	0.0%	16,336	16,394	-0.4%
Montgomery	1,402	1,397	0.4%	115	115	0.0%	17,824	17,893	-0.4%
New Cumberland	1,512	1,502	0.7%	74	74	0.0%	22,117	22,261	-0.6%
Pike Island	1,541	1,532	0.6%	72	72	0.0%	27,338	27,502	-0.6%
Hannibal	1,577	1,569	0.5%	74	74	0.0%	32,330	32,489	-0.5%
Willow Island	1,590	1,582	0.5%	83	83	0.0%	30,190	30,341	-0.5%
Belleville	1,600	1,592	0.5%	74	74	0.0%	31,812	31,976	-0.5%
Racine	1,601	1,593	0.5%	91	91	0.0%	32,239	32,404	-0.5%
Byrd	1,645	1,636	0.6%	93	93	0.0%	36,322	36,516	-0.5%
Greenup	1,668	1,645	1.4%	105	105	0.0%	44,190	44,808	-1.4%
Meldahl	1,687	1,658	1.7%	154	154	0.0%	38,362	39,015	-1.7%
Markland	1,648	1,615	2.0%	115	115	0.0%	33,943	34,634	-2.0%
Mcalpine	1,645	1,606	2.4%	141	141	0.0%	33,425	34,236	-2.4%
Cannelton	1,595	1,569	1.7%	106	106	0.0%	34,915	35,503	-1.7%
Newburgh	1,604	1,584	1.3%	100	100	0.0%	40,854	41,355	-1.2%
Myers	1,650	1,628	1.4%	238	238	0.0%	45,438	46,065	-1.4%
Smithland	1,648	1,636	0.7%	48	48	0.0%	51,772	52,161	-0.7%
L/D 52	1,655	1,650	0.3%	197	197	0.0%	57,167	57,194	0.0%
Olmsted	1,665	1,651	0.8%	29	29	0.0%	49,326	49,599	-0.6%

FIGURE 7-5
ORNIM 2001 Calibration/Validation

Lock	Tows			Horsepower			Tow Size		
	Model	Target	%	Model	Target	%	Model	Target	%
Emsworth	3,764	4,526	-16.8%	2,062	1,741	18.4%	6.7	5.5	21.8%
Dashields	3,946	4,147	-4.8%	2,054	1,833	12.1%	6.5	6.2	4.8%
Montgomery	4,280	4,109	4.2%	2,037	2,095	-2.8%	6.5	6.8	-4.4%
New Cumberland	4,081	4,244	-3.8%	2,829	2,924	-3.2%	9.1	8.8	3.4%
Pike Island	5,067	4,726	7.2%	2,776	3,070	-9.6%	8.9	9.5	-6.3%
Hannibal	4,487	4,388	2.3%	3,411	3,372	1.2%	10.8	11.0	-1.8%
Willow Island	3,970	4,004	-0.8%	3,491	3,516	-0.7%	10.9	10.8	0.9%
Belleville	4,206	4,046	4.0%	3,485	3,582	-2.7%	10.9	11.4	-4.4%
Racine	4,275	4,275	0.0%	3,491	3,538	-1.3%	10.9	10.9	0.0%
Byrd	4,751	4,895	-2.9%	3,577	3,657	-2.2%	11.1	10.8	2.8%
Greenup	6,843	6,850	-0.1%	3,443	3,484	-1.2%	11.0	11.1	-0.9%
Meldahl	5,609	5,415	3.6%	3,494	3,831	-8.8%	11.1	11.6	-4.3%
Markland	4,600	5,292	-13.1%	3,666	3,716	-1.3%	11.5	10.1	13.9%
Mcalpine	4,127	5,166	-20.1%	3,724	3,703	0.6%	11.5	9.4	22.3%
Cannelton	4,322	4,638	-6.8%	3,715	3,967	-6.4%	11.6	11.0	5.5%
Newburgh	5,257	5,869	-10.4%	3,872	4,132	-6.3%	12.1	10.9	11.0%
Myers	5,778	5,985	-3.5%	3,849	4,259	-9.6%	11.9	11.6	2.6%
Smithland	6,914	7,384	-6.4%	3,705	4,002	-7.4%	11.6	10.9	6.4%
L/D 52	7,994	9,281	-13.9%	3,514	3,626	-3.1%	11.0	9.5	15.8%
Olmsted	6,679	6,681	0.0%	3,422	4,208	-18.7%	10.8	10.8	0.0%

7.5 MODEL OUTPUTS

ORNIM optimizes investment strategies developed from a set of maintenance/improvement alternatives. The model analyzes engineering reliability, scheduled maintenance, economic traffic forecasts, and lock capacity data to predict system performance. System equilibrium traffic and transportation rate-savings limited by congestion costs associated with scheduled maintenance are outputs of WSDM. The LRM produces expected repair costs and the occurrence probability and duration of each unscheduled closure. The OM calculates transportation cost impacts of unscheduled closures, selects an optimal investment strategy, and summarizes results.

System performance statistics generated by ORNIM include equilibrium tonnage, savings and transit days. These statistics are generated for each of 5 traffic forecast scenarios. Sections 8 and 9 present summary system statistics for each of the maintenance/investment alternatives analyzed. Section 10 presents the recommended system investment plan for the Ohio River mainstem from 2010-2070.

SECTION 8
IDENTIFICATION AND EVALUATION OF THE WITHOUT-PROJECT CONDITION

8.1 INTRODUCTION

The without-project condition (WOPC) is that future condition deemed most likely to exist in the absence of any proposed project(s) or any change in existing authority or public policy. By regulation, the Corps as steward of the inland navigation waterways must make best use of the existing facilities for overall public interest concerns, including economic efficiency, safety and environmental impacts. Accurate description of the most likely future WOPC is important because it is used as the baseline for comparing benefits, costs and net benefits of alternative investments.

8.1.1 WOPC Formulation

Formulation of the WOPC begins with the existing locks and their current performance and structural condition. It involves maintenance of the existing system in the absence of new investment. Any reasonably expected and economically justified nonstructural measure within Corps authority is assumed implemented at the appropriate time. The WOPC includes all operational measures which are routinely employed during periods of congestion. These include the use of helper boats and revised lockage policies to improve project performance and ensure the best use of the existing facilities during main chamber closures. The WOPC also includes all authorized improvements that are either under construction or are pending appropriation. The most likely WOPC will not include any proactive maintenance requiring an investment decision, such as replacing major operating components and major rehabilitations.

8.1.2 Reliability Assessment

The mainstem Ohio River is a system of 20 locks and dams that create a series of navigation pools over the 981-mile length of the Ohio River. Today's system will be reduced to 19 lock and dam projects upon completion of Olmsted L/D and the removal of L/Ds 52 and 53. Specifically, the ORMSS system investment plan (SIP) evaluates the major maintenance, major rehabilitation, and new construction investment needs for 17 of these navigation locks and dams.[1] With existing traffic levels, most Ohio River locks experience high traffic delays when main lock chambers must be closed for routine (scheduled) or emergency (unscheduled) repairs or accidents. Mainstem navigation locks and dams are becoming increasingly unreliable due to age and cycles of use, which is

[1] The authorized Olmsted, Myers auxiliary extension and Greenup auxiliary extension and main chamber rehab are assumed on-line from the beginning of the period of analysis (2010-2070).

manifest in an increasing frequency of lock chamber closures for inspection and repair. Assessing the structural reliability of these structures is an important component of the without-project evaluation. These assessments suggest some locks need more immediate, near term attention than other locks. Of course, a complete evaluation of near term needs at specific locks is influenced not only by their structural condition, but also by expected levels of traffic demand and auxiliary lock capacity. It is important to note that engineering reliability modeling was not performed on navigation dam components in this analysis due to funding and schedule constraints. The primary focus was on the lock components from an engineering standpoint since maintenance closures of these structures can significantly effect traffic, whereas, routine schedule maintenance of dams usually has no effect on traffic delays. It is highly recommended that both navigation dams and all the Ohio River tributary locks and dams have a detailed reliability assessment completed for them as a follow-on action in order to incorporate the entire Ohio River system.

8.2 EXISTING CONDITION

As navigation projects age, component reliability worsens and maintenance requirements and unscheduled closures typically increase. Degradation of lock components can come from fatigue through utilization and/or age (e.g. corrosion). As lock components degrade, the question arises if and when they should be repaired or replaced.

Development of a system WOPC begins with an assessment of existing condition, capacity, and demand; each a key input to the economic modeling. Lock reliability and capacity, traffic, and traffic delays are discussed for all mainstem sites. Ultimately, a lock's performance capability is limited by two factors: i) physical capacity and ii) structural reliability. The former is influenced by chamber dimensions, hydraulic conditions, vessel fleet characteristics, weather conditions, and accident frequencies; while the latter is affected by a given project's structural condition and intensity of maintenance efforts. The capability to process traffic juxtaposed with traffic demand tests a lock's performance. Transit time and lock delay are used to measure lock performance. This subsection describes the existing condition of the mainstem Ohio in terms of project age and reliability, project capacity, and traffic demand and delay.

8.2.1 Project Age and Reliability

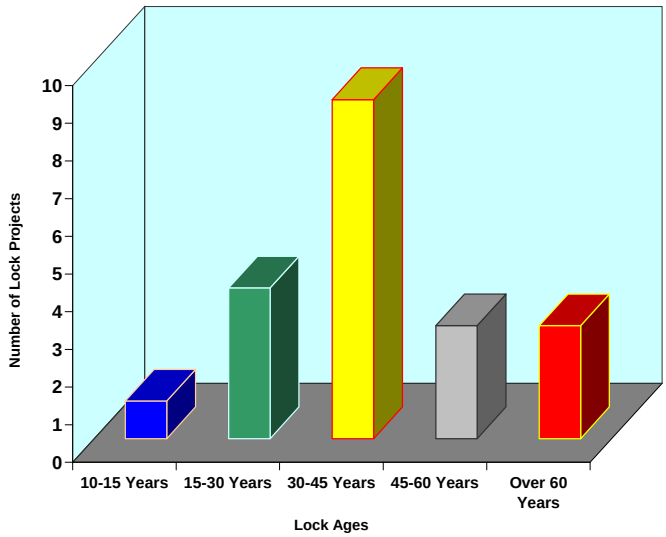
Lock performance is affected by lock availability for service. Availability is reduced due to random minor events like accidents, adverse weather, flow conditions, and maintenance-related closures. Maintenance closures, scheduled or unscheduled, are more likely to be lengthy closures that more dramatically affect lock performance than the random minor closure events which are short duration closures. Age and level of use can act as an indicator of maintenance and rehabilitation needs. **Figure 8-1** shows that six mainstem projects are currently over 45 years old. By 2010, Emsworth, Dashields, and Montgomery (EDM) will each be over 80 years old and nine more locks will be at or near their original design life of 50 years.[2]

[2] EDM were rehabilitated in the 1980s - new miter gates, culvert valves, and re-facing some of the lock concrete structures. These rehabilitations did not address all known structural issues. There are still serious concerns regarding the structural integrity and stability of the concrete structures at these three sites.

The main chamber miter gates at Markland, Meldahl, Greenup, and McAlpine have reached the end of their effective service life (see **Table 8-1)**. They are currently maintained through emergency measures that include inspection dives and dewatering the lock chamber on a much more frequent basis than other Ohio River locks. All gates are operational, however, the physical repair costs and navigation impacts associated with maintaining these gates causes a significant portion of the annual O&M funds to be dedicated to them. This, in turn, means that the backlog of proactive maintenance for other important projects continues to increase. Even with increasing maintenance of these gates, they remain highly susceptible to a catastrophic failure given their current condition and continued high level of use.

Typically, Ohio River main chamber locks are dewatered every 5 years for maintenance and/or inspections. Markland's main chamber is dewatered annually to inspect and repair the gates and Greenup is dewatered every two years. Meldahl is expected to move to a more aggressive maintenance schedule in the near future. Markland has been approved by Corps HQ for new main chamber gates and valves but has not yet been funded.[3] Most major maintenance work at Ohio River lock and dam projects has been deferred until a later date.

FIGURE 8-1
Existing Mainstem Lock Ages



Greenup Locks experienced a costly 34-day unscheduled emergency repair in 2003. Emergency repairs at McAlpine Lock closed the Ohio River completely for 11 days in 2004. Hannibal Locks had an unscheduled total river closure lasting 5 days in November 2005. The Hannibal closure was due to a failure of a load bearing quoin seal on one of the main chamber miter lock gates while the auxiliary chamber was down for scheduled maintenance. Reacting to emergency repairs diverts scarce O&M resources from other

[3] 7 July 2000 Corps Headquarters approved and requested the Assistant Secretary of the Army to include in the program as a new start major rehabilitation.

scheduled maintenance work. Any growth in the maintenance backlog adds risk of costly unscheduled closures for emergency repair to Ohio River navigation infrastructure.

8.2.2 Project Capacity

Lock performance capability is largely determined by lock chamber dimensions, approach conditions, and service availability. The three uppermost Ohio River projects, Emsworth, Dashields, and Montgomery (EDM) each have a main chamber measuring 600' x 110' and an auxiliary lock measuring 360' x 56'. They are the lowest capacity locks on the Ohio River (see **Table 8-1**). Modern fifteen barge tows must double-lock through the main chambers at EDM, while in the auxiliary chambers tows are limited to 5 barges and can only be locked through one barge at a time. Smithland, with the greatest capacity on the river, has twin 1200' x 110' chambers. Once authorized construction is completed, both McAlpine L/D and the new Olmsted L/D (replacing L/Ds 52 and 53) will also have twin 1200' x 110' chambers. Auxiliary lock extensions are authorized but not yet under construction at Greenup and Myers locks. All other locks on the mainstem Ohio have a 1200' x 110' main chamber and a 600' x 110' auxiliary chamber (a configuration commonly referred to as a 1200' and a 600').

Three non-structural measures to improve capacity are part of the existing system and are included in the development of the WOPC. They are: i) helper-boats during a main chamber closure; ii) n-up and n-down lockage policy during main chamber closure; and iii) re-scheduling of shipments during a long duration, scheduled main chamber closure. The use of helper-boats, through an industry self-help program, effectively maximizes the capacity of the small 360' x 56' auxiliaries on the upper Ohio and the 600'x 110' auxiliaries elsewhere.[4] An n-up and n-down lockage policy, when queues exist in both directions, also effectively increases capacity during a main chamber closure. These practices, along with limiting tow sizes to five cuts during a main chamber closure on the upper Ohio, are reflected in lock capacities reported in **Table 8-1**. Some voluntary re-scheduling by industry occurs because of navigation notices mailed out six-months to one-year in advance of the scheduled closure. Industry re-scheduling during a closure serves to re-distribute tows on either side of the closure. Annual throughput, or capacity is unaffected but average delay-per-tow during the closure is lower than it would be otherwise.

8.2.3 Traffic Demand and Delays

Total traffic on the Ohio River doubled between 1968 and 2004[5], when it reached 237.9 million tons. This growth has not been spread evenly along the river. Upper river projects experienced 1.0 to 2.0 percent average annual growth from 1987 to 2004. Mid-river lock traffic growth was more robust, between 2.0 and 3.0 percent. Lower river projects traffic grew the slowest at less than 1.0 percent a year. Much of this is attributable to electric utilities' reaction to the latest round of Clean Air Act Amendments (CAAA). Despite this uneven growth in traffic, Myers, Greenup, and Newburgh locks remain the top three mainstem projects in terms of total traffic among projects with small

[4] The self-help program at EDM includes a restriction on tow sizes to 5 barges per tow.
[5] This is according to WCSC data.

600' auxiliary chambers. **Figure 8-2** displays 2004 tonnage at all the projects with 600' auxiliary chambers. Capacity of a 600' project is around 50 million tons a year. **Figure 8-2** shows where current traffic levels exceed auxiliary capacity at mainstem projects. High delays are experienced at these projects when main chambers close for maintenance or repair.

TABLE 8-1
Ohio River Mainstem Locks - 2004
Age, Chamber Dimension and Capacity, 2004 Tonnage
(Million Tons)

Lock Project	Age	Chamber Dimension		Chamber Capacity			2004 Tonnage
		Main	Auxiliary	Main	Auxiliary	Both	
Emsworth	84	600x110	360x56	39.4	12.6	45.8	18.8
Dashields	76	600x110	360x56	46.5	12.9	51.7	19.7
Montgomery	69	600x110	360x56	43.9	12.9	47.6	20.3
New Cumberland	46	1200x110	600x110	78.5	44.5	132.9	31.5
Pike Island	40	1200x110	600x110	99.5	47.9	151.2	38.9
Hannibal	33	1200x110	600x110	103.1	52.4	152.1	50.1
Willow Island	33	1200x110	600x110	107.5	54.2	155.1	48.1
Belleville	37	1200x110	600x110	114.6	56.3	167.2	51.4
Racine	38	1200x110	600x110	110.5	54.0	151.1	52.3
R.C. Byrd	12	1200x110	600x110	116.3	55.5	151.0	57.8
Greenup	46	1200x110	600x110	113.3	54.3	144.2	64.5
Meldahl	43	1200x110	600x110	116.3	55.5	151.0	55.3
Markland	46	1200x110	600x110	119.0	57.1	160.5	50.1
McAlpine	44	1200x110	1200x110	120.0	123.0	225.5	52.8
Cannelton	34	1200x110	600x110	124.0	59.0	162.1	56.9
Newburgh	30	1200x110	600x110	135.6	61.7	169.8	67.2
J.T. Myers	30	1200x110	600x110	137.3	63.6	170.6	67.9
Smithland	26	1200x110	1200x110	143.4	132.9	264.4	77.0
Olmsted[1/]	0	1200x110	1200x110	na	na	na	95.0

1/ Currently under construction, 2004 tonnage is for L/D 52

Delays are a function of a project's capacity, fleet utilization, reliability, and traffic demand. Delays during normal traffic operations typically range from less than 10 to not more than 75 minutes at mainstem locks. **Figure 8-3** displays average lock delays from 1994-2004 at mainstem projects. Excessive delays develop when the main chamber is closed at any of these locks. Delays are most severe on the upper Ohio (EDM) and at the high traffic locks below Byrd L/D. In 2003, a 34-day unscheduled closure of Greenup's main chamber caused a 43 hour average delay per tow and cost industry over $42 million in additional transportation and other logistical costs. This is not surprising given that the physical capacity of the small auxiliary chamber at Greenup is estimated at 54 million tons, an annual ability overwhelmed by demand in 2003 that reached almost 63 million tons. These delays dramatically increase tow transit times and, therefore, tow transit costs.

FIGURE 8-2
2004 Traffic at Ohio River Mainstem Projects with 600' Auxiliary Chamber

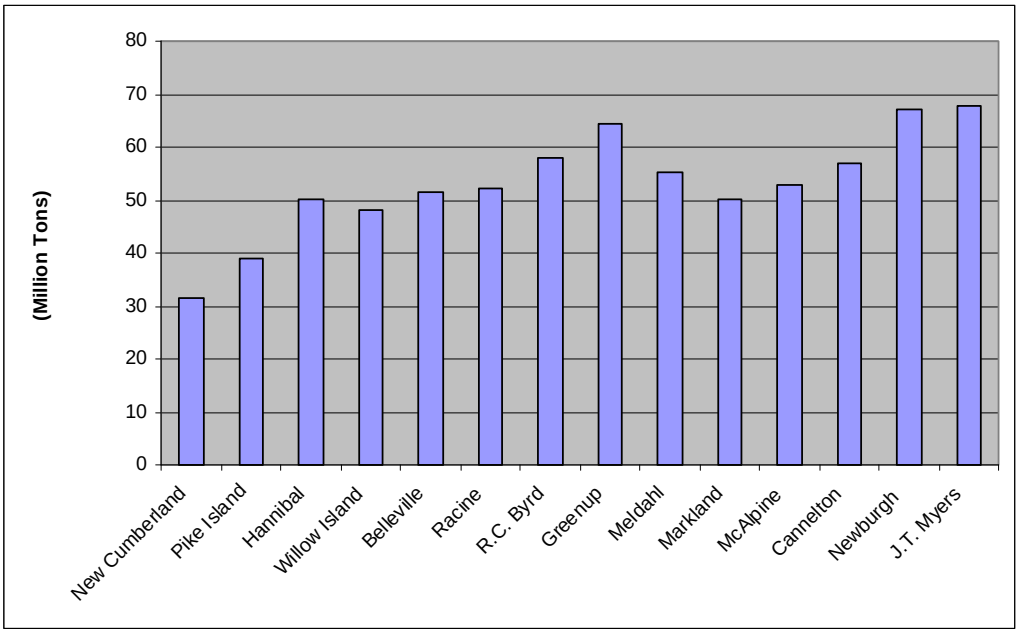
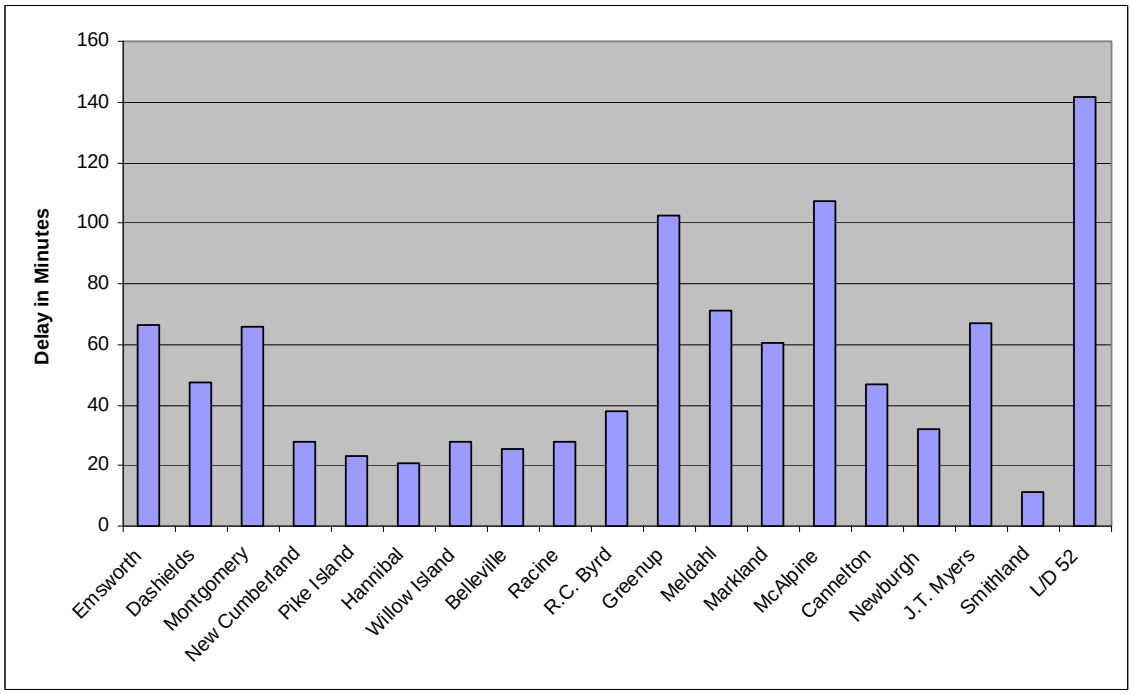


FIGURE 8-3
Ohio River Mainstem, Average Lock Delays per Tow, 1994 – 2004



8.3 MAINTENANCE AND OPERATIONAL MEASURES

Maintenance and its effect on the performance of aging locks is a key concern to sustainable navigation. The efficient operation of the existing locks and dams is an important consideration and this is especially true during times when the main chamber is closed for maintenance and all traffic is processed through the smaller auxiliary chamber.

Three different maintenance plans were developed and analyzed for the SIP. They include reactive maintenance, advanced maintenance or component replacement, and rehabilitation maintenance (bundled components) that exceed the major rehab monetary threshold as set forth in USACE guidance, currently $10.6 million for inland navigation projects. Both advanced component replacement and major rehabilitation require an investment decision and, because of this, were not considered included in the WOPC. Instead, these two proactive maintenance plans are considered to be with-project alternatives and are evaluated by comparison to the WOPC like all other new investment decisions. In the absence of new investment, a reactive maintenance plan where components are repaired or replaced "after they fail", is assumed to be the base maintenance plan for the WOPC and is the standard against which the alternatives are measured. Maintenance and investment costs, reactive maintenance, and operational measures associated with the WOPC are described in the following sub-sections.

8.3.1 Maintenance and Investment Costs

Component level reliability evaluations were conducted on 17 mainstem projects[6] to estimate probable project performance and maintenance requirements from 2010 to 2070. A detailed discussion of engineering reliability modeling is presented in the **Engineering Appendix** and greater detail on the reactive, advanced, and rehabilitation maintenance plans is presented in **Attachment 3 Project Maintenance Analysis** of the Economics Appendix.

Reactive maintenance and each alternative investment analyzed contains normal (or routine) O&M costs, scheduled lock maintenance costs, scheduled dam maintenance costs, unscheduled lock repair costs, random minor costs, and scheduled lock improvement costs at each project throughout the study period. All Federal maintenance and investment costs are described below:

- Normal O&M or routine operation costs are the annual fixed costs to operate the project with some incidental maintenance that doesn't impact traffic. Corps normal O&M policy operates a project as efficiently as possible in the absence of any repair or maintenance that improves project reliability.[7]
- Scheduled Lock Maintenance costs are costs related to periodic or cyclical chamber inspections that close a chamber, including any some relatively minor maintenance/repair costs. Cyclical maintenance procedures typically do not address

[6] No reliability work was done on the authorized Olmsted, Greenup and Myers auxiliary chamber.
[7] Normal (or routine) O&M is a fixed-cost to operate the project and includes labor, utilities, mowing the grass, and basic project supplies.

the long term failure probabilities (reliability) associated with fatigue/fracture and the end of useful design life and therefore it is assumed that cyclical maintenance does not have a significant affect on the overall reliability of the structures[8]. However, it is noted that schedule maintenance does help keep the major features in working order and operating as originally designed. The reliability analysis was carried out for the situation where the components are no longer cost effective to repair.

- Scheduled Dam Maintenance costs are attributed to maintenance and rehabilitation of dam components (dam gates, operating machinery, concrete piers, etc.) This maintenance is critical to sustainable navigation but does not typically require a lock chamber closure because the repair fleet can tie up outside the river wall keeping them open to traffic. Reliability modeling was not performed on dam components because it was decided by the overall ORMSS team that the effort should initially focus on the lock components since their performance affects traffic. Since much of the work done under ORMSS was developmental and state-of-the-art, there was not enough time or funding to analyze the dam components for their reliability. As noted earlier, it is highly recommended that follow-on funds be provided to model Ohio River dam components and the tributary projects so the entire system is analyzed in the same manner. In lieu of dam reliability analysis, deterministic scheduled dam maintenance costs are estimated from engineering judgment and are the same in all maintenance and improvement plans analyzed. Dam maintenance costs are included in the analysis to account for the full cost of operating the system. It is noted that some information developed from recent Ohio River dam major rehabilitation studies (Emsworth and J.T. Myers) has been included within the ORMSS analysis from a deterministic standpoint.
- Unscheduled Lock Repair costs are estimated from reliability modeling that determines when to repair or replace major lock components over a 60 year period of analysis. ORNIM is run to estimate unscheduled repair costs for each maintenance plan.
- Random Minor closures are separated into two categories. These are random minor closures that require maintenance and those that require no physical repair costs. The random minor closures with repair costs are intended to reflect lock closures for routine maintenance or testing. This is typically for on-site or contract personnel and not the large repair fleet. Random minor closures without repair costs are for things such as debris in lock, tow malfunctions, accidents, etc.
- Scheduled Lock Improvement costs include already authorized improvements at Greenup and J.T. Myers. J.T. Myers is already in construction and Greenup is in the final stages of design for its initial construction contracts. These costs are included in the WOPC because the investment decisions have already been made. Scheduled lock improvements involving future investment decisions include economically justified individual lock component replacements, chamber rehabilitations, lock extensions, and lock replacements are new investment decisions and are treated as alternatives to be compared to the WOPC. Scheduled lock improvements involving future investment decisions are discussed in Section 9 - Identification and Evaluation of Alternative Investment Plans.

[8] This is mainly due to the fact that we are looking at failure modes that are associated with fatigue and fracture of critical members (miter gates and valves in particular)

8.3.2 Reactive Maintenance

Under reactive maintenance, components are fixed or replaced after they perform unsatisfactorily. The Engineering Team analyzed 20 components (**Table 8-2**) at each mainstem lock chamber; however, the reliability of some components (lock walls, approach walls, etc…) was found to be highly reliable and did not require a follow-on economic analysis. The product of this detailed analysis is a series of site and component specific reliability models that were used to calculate expected component failures through time, estimate the cost and type of repair required, and determine whether the failure caused a chamber closure. This information was used by ORNIM to calculate the unscheduled repair/replace costs and industry costs associated with an unanticipated lock closure under reactive maintenance plan. The reactive maintenance plan as developed in the WOPC, serves as a baseline against which to compare more proactive maintenance plans and structural improvement investments.

Under reactive maintenance, normal O&M is performed, along with scheduled cyclical maintenance. Unscheduled lock repairs and their costs are estimated from reliability modeling. Repairs designed to correct the cause of a failure are made at the time of failure and not deferred through a short-term repair. Scheduled lock improvements for the mainstem include only the authorized improvements at Greenup and J.T. Myers. No lock rehabilitation occurs, though individual components may be replaced upon failure. Scheduled dam maintenance, based upon engineering judgment and experience from recent major rehabilitation studies, is included in project costs.

TABLE 8-2
Mainstem Lock Components
Reliability Analysis

Main Chamber		Auxiliary Chamber
Upper Guard Wall		Upper Guide Wall
River Wall		Land Wall
Lower Guard Wall		Lower Guide Wall
Middle Wall		Middle Wall
Miter Gates (upper & lower)		Miter Gates (upper & lower)
Miter Gate Machinery		Miter Gate Machinery
Culvert Valves		Culvert Valves
Culvert Valve Machinery		Culvert Valve Machinery
Hydrauilic Systems		Hydrauilic Systems
Electrical Systems		Electrical Systems

8.3.3 Operational Measures Currently Implemented

During normal operation, with both chambers open, delay is not usually a problem and project capacity is sufficient to handle traffic efficiently at all mainstem projects throughout the 60-year period of analysis. During normal operation, tows are handled on a

first-come-first-served basis.[9] When a main chamber must be closed, tows must use the auxiliary chamber, which is smaller at all sites except Smithland L/D. At the lower and upper Ohio projects, where traffic demand exceeds the capacity of the smaller auxiliary chambers, delays occur. During main chamber closures, a number of effective supply-side measures designed to improve efficiency and reduce delay are currently employed at the locks and are included in the base-level WOPC analysis. These include lockage sequencing, tow-haulage, and helper boats. Traffic demand management measures, such as Notices to Navigation Interests[10] are used to reduce lock congestion by providing waterway users advance notice of scheduled closures. Notices to Navigation Interests allow towing companies and their customers to reschedule traffic to the extent possible around scheduled main chamber outages. The operational effect of rescheduling shipments in response to scheduled closures is captured in future traffic-delay relationships in the analysis through the tonnage-transit curves developed by the WAM, but the additional costs incurred by shippers to reschedule around a closure are not included in this analysis. These operational and other measures are discussed below.

8.3.3.1 Notice to Navigation Interests: Industry Coordination

Two years before a scheduled closure, the Corps sends a notice to waterway users announcing its intent to close a lock and the expected dates of closure. The notice includes anticipated delays during the closure, expressed as significant or minor, and the operational policies to be in effect. Around six months before the scheduled closure, the Corps and affected towing companies meet to finalize procedures for operating during the closure. Even with low levels of delay expected, special accommodations, such as cut limits, are required because the auxiliary chambers are typically one-half the size of the main chambers. If major delays are expected, the announcement will also state that tows have priority in lockage over recreational craft. This is an effort to provide industry information to better manage traffic during a scheduled closure.

8.3.3.2 Lockage Sequencing : N-up, N-down Lockage Policy

This strategy (to minimize delays at locks that develop queues) involves locking a given number (N) of tows in the same direction, then allowing the same number to lock through from the opposite direction. Lock sequencing takes advantage of the efficiency of proceeding with several successive “turnback” style lockages rather than running tows through in alternate directions when queued on either side of the lock. Use of this strategy has been proven to lower delays over a first-come-first-served policy at virtually zero cost. This is a supply management measure that has the effect of increasing capacity during closure. Lock sequencing is modeled at all mainstem projects during any main chamber closure and an optimal n-up/n-down strategy is developed.

Typically, as queues develop above and below a project during a main chamber closure, a 3-up and 3-down lockage policy is used to most efficiently and equitably pass traffic. The actual n-up and n-down policy used depends on the queue sizes and is under the discretionary authority of the lock master.

[9] FIFO – first-in-first-out
[10] Industry receives Notices to Navigation Interests from the Corps well in advance of a scheduled maintenance closure.

8.3.3.3 Helper-Boats: Industry Self Help

The use of helper boats complements the n-up/n-down lockage policy. Helper boat operations are a collaborative effort between industry and the Corps. Due to traffic levels and fleet size, industry implements a helper boat policy any time a main chamber is closed on the Ohio. The industry "self help" operation significantly reduces lockage times for multi-cut lockages and typically works as follows: the last towboat to arrive at a congested project in the direction opposite of an on-going lockage operation will disconnect from its barges and move up to the lock, where it serves as a "helper boat" by assisting the tow locking through the project by extracting un-powered cuts of barges from the lock chamber. It will then move the barges to a re-fleeting site away from the project so that reconstruction of the tow does not interfere with lockage operations. Industry self help is provided to each tow until all barges have moved through the lock. To be effective, the policy requires tows queued in both directions above and below the project. This is another supply-side measure that enhances capacity during a closure and is modeled at each mainstem project during a main chamber closure.

8.3.3.4 Tow Haulage

Tow haulage units are relatively low-cost pieces of equipment that can be used to expedite the two-cut lockage process when there are no other towboats to pull the un-powered cut out of the chamber. The units are not necessary at 1200' lock chambers as double cuts through those chambers are not permitted. There are two principal types of tow haulage systems: permanent and portable. Permanent units consist of rail tracks located directly alongside the chamber on top of the walls and a moveable tie-down unit that moves on the rails. The un-powered barges are tied to the moveable tie-down unit by a cable, and the unit moves along the rails to pull the barges out of the chamber. Portable systems consist of two winches that are anchored atop the upstream and downstream guide walls. The winches "crank" the cable, pulling the barges out of the chamber. The second set of barges, which are powered by a towboat, can then lock through the chamber unassisted. Upon completion of the second lockage, the first and second cuts are reconnected along the guide wall.

Permanent tow-haulage systems are only installed at the main chambers of Emsworth, Dashields, and Montgomery (EDM) where the main chambers are 600' in length compared to 1200' at all other mainstem projects. Double lockages through these main chambers are a common occurrence even during normal times. Additional permanent tow-haulage units are not considered necessary at any of the other lock chambers that are 600' long. At the 600' auxiliary chambers, such units would have their greatest need during closures of the main chambers. However, during those times queues generally develop at both sides of the lock providing a steady supply of tow boats and industry self-help is a much better measure to pull unpowered cuts from the auxiliary chambers as that process is faster than tow haulage. Permanent tow haulage units are not considered appropriate at the 360' x 56' auxiliary chambers at EDM because these chambers can only lock one barge at a time and oftentimes (during main chamber closures) tows require two to five cuts. Portable units are considered sufficient at these other small lock chambers.

8.3.3.5 Industry Adjustments During Main Chamber Closures

The towing industry also makes adjustments during main chamber closures to maintain as normal a delivery schedule as possible. Industry adjustments include reducing the number of empty barges, increasing barge loadings, shipping around closures, working off stockpiles, or shipping by other routings. These adjustments are accounted for in the LPMS data used to develop the closure related tonnage-transit curves.

8.3.3.6 Other Measures

Other measures intended to reduce commercial lockage delays include real-time lock reports on the Corps web page, mooring cells, and interchangeable miter gates. Information contained in the lock reports is updated every few hours and includes the number of tows waiting in queue and river flow conditions at each facility. Coordination with industry is conducted on a regular basis, not just during those times prior to an extended main chamber closure. These low-cost measures have proved useful and are accepted by the navigation industry.

Mooring cells are structures that provide vessels a place to tie off while waiting for their turn to lock through. Without such facilities, the towboats must either push into the riverbank, which can cause erosion and damage to the shoreline vegetation, or wait out in the currents of the river, which wastes fuel. Preliminary evaluations cited in the J.T. Myers and Greenup Locks Improvements – Interim Feasibility Report concluded that there is no potential for economic benefit from adding mooring cells at any lock and dam. However, mooring cells were considered appropriate for EDM from an environmental perspective and were modeled as a feature of the without-project condition (WOPC).

The Great Lakes and Ohio River Division (LRD) has begun to implement a system where miter gates can be changed out quickly, significantly reducing chamber downtime for miter gate maintenance and repair. There are two components to the miter gate quick change-out system (MGQCS): i) a derrick crane with gate-lifting capability and ii) spare gates at the projects. Currently, the MGQCS is only partially implemented. LRD has the gate lifter crane but not any spare gates. For this reason and the fact that considerable investment is required, a MGQCS is not included in the WOPC.

8.3.4 Operational Measures Not Currently Implemented

Price-related traffic demand management measures are not currently used on the mainstem. Using lock scheduling to reduce delays that occur during the normal course of using the Ohio River mainstem is not currently practiced and has not been thoroughly evaluated. A preliminary research effort into the physical practicality and economic feasibility of lock scheduling is underway as part of this study. Results-to-date can be found in **Attachment 5 Traffic Management** at the end of this appendix. The ultimate outcome of this effort and how far it is developed depends on future ORMSS SIP funding. This future effort is beyond the scope of this study.

8.4 SYSTEM-WIDE BASE-LEVEL WOPC

Historically, LRD lock improvement studies have assumed unconstrained funding for major maintenance and major rehabilitation in developing the WOPC. LRD optimized the WOPC in navigation feasibility studies through a mixture of non-structural and structural measures like component replacement and chamber rehabilitation not requiring congressional authorization. The Corps has authority for major rehabilitations and advanced component replacements but recent history shows the Administration considers some component replacements and all major rehabilitation as a new start and the Administration is not currently budgeting for new starts (e.g. Markland Major Rehabilitation).

Therefore, for purposes of this analysis, any maintenance beyond fixing-after-failing is assumed to require an investment decision and is not included in the base-level WOPC. Proactive maintenance plans like advanced maintenance and chamber rehabilitation require an investment decision and therefore, in this analysis, will be treated as with-project alternatives along with other structural improvements.

Given recent funding levels, a reactive maintenance future seems most likely. Accordingly, a base-level reactive maintenance WOPC will serve as the basis to compare more aggressive maintenance plans and structural improvement investments. The use of appropriate non-structural and operational measures and the assumption of authorized projects in-place are also part of the base-level WOPC.

The WOPC includes the following authorized Ohio River improvements:

- Olmsted L/D – Olmsted L/D is modeled throughout the period of analysis[11]. Since this investment is under construction, no federal costs are included. The locks and approach walls at Olmsted are completed and the dam is currently under construction.

- Myers auxiliary chamber extension – J.T. Myers auxiliary lock extension is under construction. J.T.Myers is included in the WOPC as a twin 1200’ x 110’ project. Federal costs for the chamber extension are included.

- Greenup auxiliary chamber extension and main chamber rehab – Greenup is included in the WOPC as a twin 1200’ x 110’ project with a rehabbed main chamber. Federal costs for the rehab are included.

- McAlpine lock replacement – The new lock chamber at McAlpine became operational in 2009.

[11] Period of analysis is 2010-2070

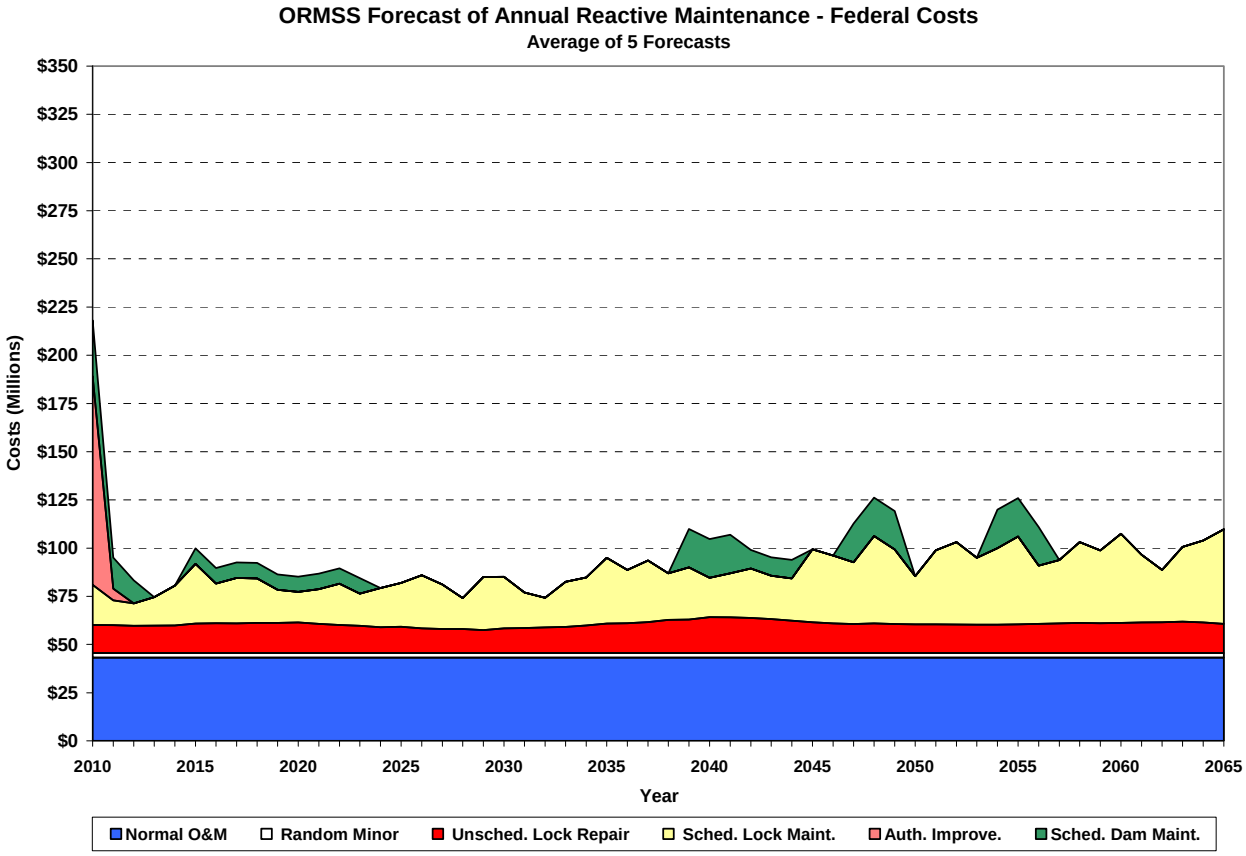
8.5 EVALUATING REACTIVE MAINTENANCE

The reactive maintenance plan can be described in terms of its Federal costs and its associated cost impacts on navigation. ORNIM uses engineering reliability data to predict emergency repair/replacement closures on an annual average basis. These unscheduled closures reduce system capacity and cause navigation delays that reduce system transportation rate savings by increasing waterway costs.

8.5.1 System Costs

ORNIM was run at each project to estimate expected unscheduled repair/replace costs under each of the five different traffic forecast scenarios. The unscheduled repair costs are added to other Federal maintenance costs to develop total system costs. **Figure 8-4** shows forecast reactive maintenance funding needs. Overall, this analysis shows an average annual expenditure of around $99.8 million is required to sustain navigation on the Ohio River from 2010-2070 with a reactive maintenance strategy and continued degradation of the major operating components.

FIGURE 8-4

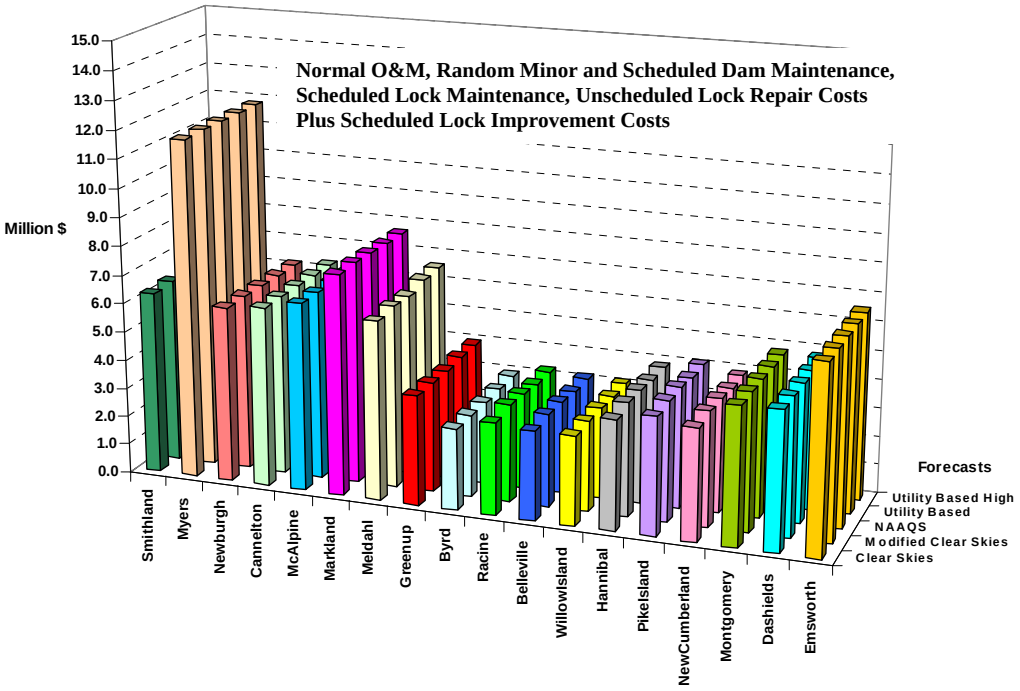


The Corps has a legal mandate to provide efficient navigation on the Ohio River. In the long run, a reactive maintenance strategy will result in more frequent scheduled and unscheduled closures than more proactive maintenance strategies. Such a maintenance strategy will not sustain the efficient level of navigation on which our stakeholders depend. In recent years, the Corps has been funding Ohio River O&M budgets at a level below the base-level reactive maintenance strategy described in this study. This alone will indicate to some the need for increased major maintenance on the Ohio River.

Figure 8-5 displays average annual Federal costs for the reactive maintenance strategy by project and by traffic forecast. The bar graph combines normal O&M, random minor, scheduled dam costs, scheduled lock maintenance costs, unscheduled lock repair costs and lock improvement costs. The scheduled lock maintenance costs and unscheduled lock repair costs represent potential cost savings that can be realized with more aggressive maintenance (upfront component replacement or major rehabilitation). The scheduled lock improvements are the authorized J.T. Myers and Greenup improvements. High reactive maintenance needs are seen on the upper and lower Ohio projects.

Section 4 of **Attachment 3 Project Maintenance Analysis** displays each project's component-level, expected transit costs and repair costs for each traffic forecast scenario with a reactive maintenance strategy.

Figure 8-5
Reactive Maintenance
Average Annual Project Costs
(2010-2070, 5 1/8%, FY 03$)

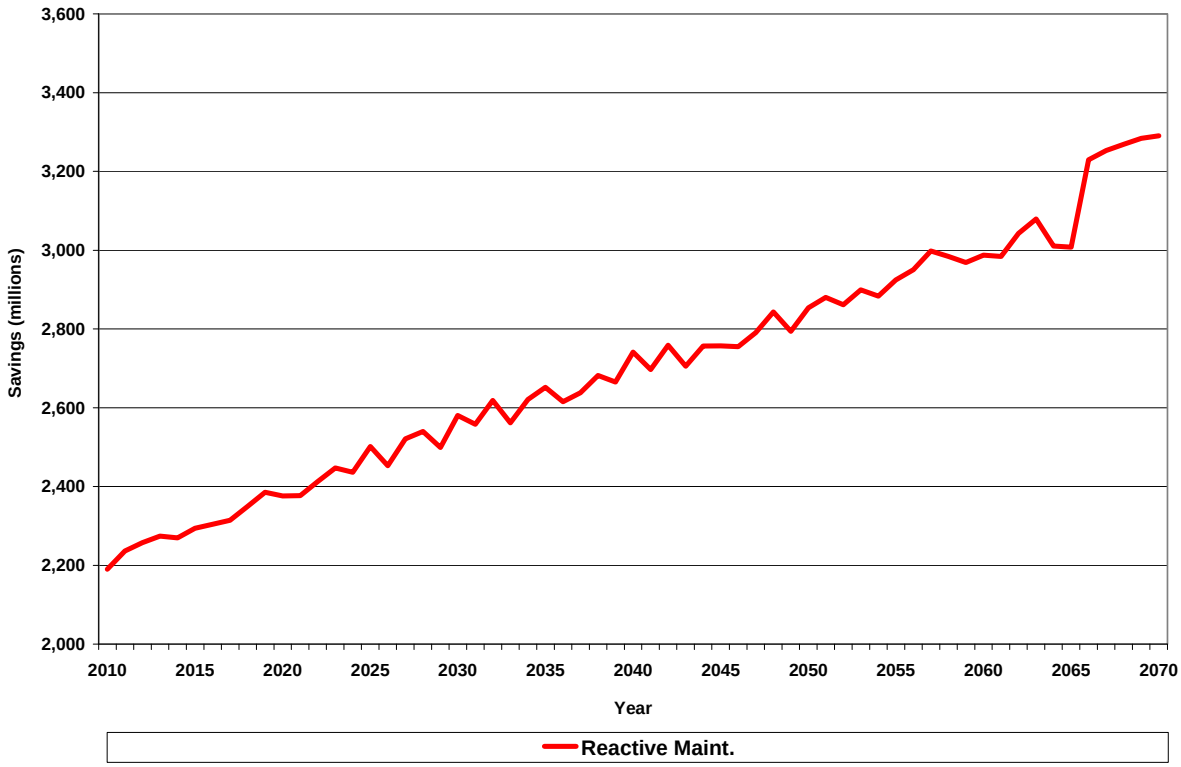


8.5.2 System Benefits

The primary benefit for Federal investment in the inland waterways is the collective transportation cost savings for barge shipment over the least-costly alternative routing. The benefit is referred to as transportation rate savings. Corps regulation recognizes transportation rate savings or cost reduction as a national economic development (NED) benefit.

In ORMSS, NED benefits are calculated from equilibrium waterway traffic transportation rate savings net of any reduced transportation savings from congestion or delay due to unscheduled repair closures. **Figure 8-6** displays system transportation savings averaged over all 5 traffic forecast scenarios for the base-level reactive maintenance WOPC. Average annual system NED benefits are $2.46 billion from 2010-2070.

FIGURE 8-6
Reactive Maintenance System Transportation Savings
Average of 5 Forecasts



8.5.3 System Statistics

Table 8-3 summarizes average annual expected system waterway costs and benefits of a reactive maintenance strategy at each mainstem project for each of the five traffic forecast scenarios. Total system benefits are equilibrium system NED transportation rate savings net of any transportation losses caused by congestion or delay due unscheduled repair closures. Average annual system benefits range from $2.25 to $2.46 billion.

Total system costs are the expected average annual Federal and Trust Fund expenditures needed to maintain Ohio River navigation infrastructure under the reactive maintenance strategy. The Federal costs represent the costs to the Federal government to maintain, repair, or improve the navigation projects under the reactive maintenance policy. Scheduled maintenance costs are what the Federal government pays for the scheduled cyclical maintenance of the mainstem projects. Scheduled improvement costs in the reactive maintenance strategy are the Federal and Trust Fund costs of authorized mainstem projects (Greenup and J.T. Myers). Unscheduled repair costs are the Federal costs associated with the unscheduled repair and replacement of lock components under the reactive maintenance strategy. Normal O&M is the day-to-day recurring cost to the Federal government to staff and supply the project regardless of the project's ability to accommodate any traffic – things like on-site labor, utility costs, cutting grass, etc. Average annual system costs range from $99.0 to $100.1 million. Net benefits range from $2.15 to $2.36 billion.

TABLE 8-3
Reactive Maintenance*
Average Annual Costs and Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Reactive Maintenance Benefits					
Equilibrium Waterway Savings	$2,328.6	$2,493.5	$2,476.0	$2,536.4	$2,580.5
Reduced Savings from Unscheduled Repair	($75.8)	($119.8)	($124.1)	($107.7)	($120.3)
Total System Benefits	**$2,252.8**	**$2,373.7**	**$2,351.8**	**$2,428.7**	**$2,460.1**
Reactive Maintenance Costs					
Scheduled Lock Maintenance	$ 23.1	$ 23.1	$ 23.1	$ 23.1	$ 23.1
Scheduled Dam Maintenance	$ 6.9	$ 6.9	$ 6.9	$ 6.9	$ 6.9
Scheduled Lock Improvements*	$ 5.8	$ 5.8	$ 5.8	$ 5.8	$ 5.8
Unscheduled Lock Repair	$ 14.0	$ 15.1	$ 15.0	$ 14.7	$ 15.0
Normal O&M	$46.7	$46.7	$46.7	$46.7	$46.7
Random Minor	$2.4	$2.4	$2.4	$2.4	$2.4
Total System Costs	**$99.0**	**$100.1**	**$100.0**	**$99.8**	**$100.1**
Net Benefits	**$2,153.8**	**$2,273.6**	**$2,251.8**	**$2,328.9**	**$2,360.1**
BCR	**22.7**	**23.7**	**23.5**	**24.3**	**24.6**

** Scheduled Lock Improvements are 50% cost shared with the Trust Fund and include the authorized 600' extension of the auxiliary chamber at Myers in 2010 and rehabilitation of the Greenup main chamber in 2010-11.*

SECTION 9
IDENTIFICATION AND EVALUATION OF ALTERNATIVE INVESTMENT PLANS

9.1 GENERAL

This section identifies and evaluates increasingly proactive maintenance plans and alternative improvement plans that address the navigation problems and needs of the Ohio River. The proactive maintenance plans include advanced maintenance where individual components can be replaced before failing and chamber rehabilitation where individual component replacements can be bundled into a major rehabilitation. The major rehabilitation category must meet the costs current threshold of $10.6 million for inland navigation projects, as outlined in USACE guidance. The alternative improvement plans include new 600' and 1200' chambers to replace the auxiliary chambers at Emsworth, Dashields and Montgomery. Each alternative requires an investment decision and therefore is considered a with-project alternative. The alternatives, as presented in this study, build on each other with each successive alternative incorporating cost effective investments of the previous alternative.

Evaluation of alternative investment plans will ultimately identify an optimal system mix of site-specific maintenance alternatives, non-structural improvements, and large-scale structural alternatives for each traffic forecast scenario.

9.2 OPTIMIZING COMPONENT MAINTENANCE

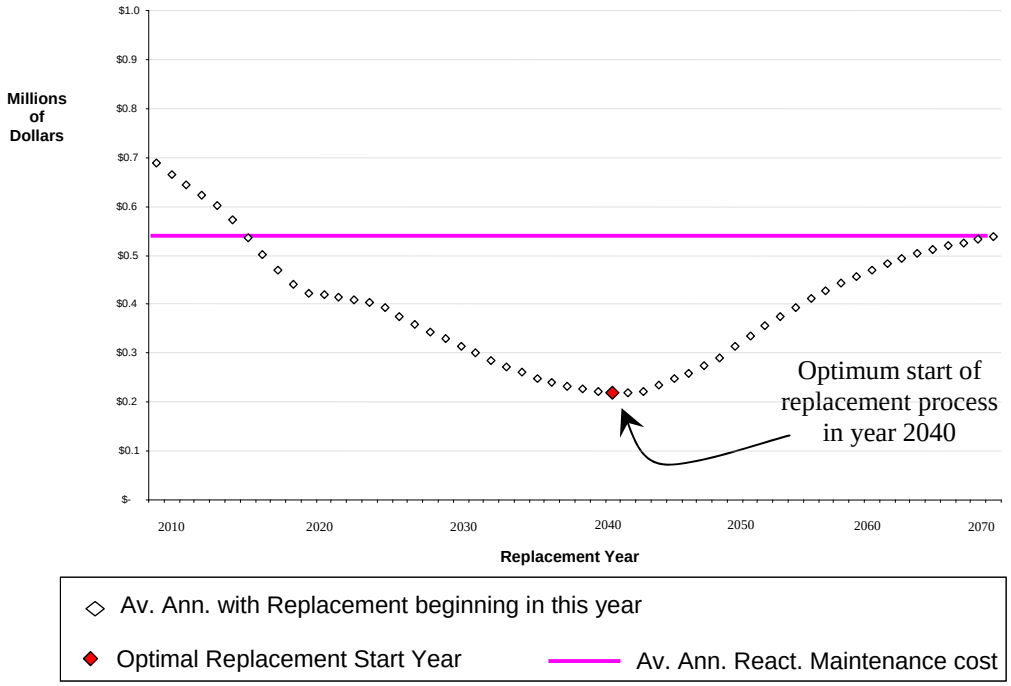
The ORNIM Lock Risk Module (LRM) simulates each year's expected repair costs and closure probabilities for each lock component analyzed. ORNIM's Optimization Module (OM) then calculates the annual expected equilibrium waterway savings (benefits) and total Federal reactive maintenance (RM) costs. This defines the expected net benefits for the reactive maintenance plan.

If the likelihood of a lock component's failure is high enough and assuming a scheduled component replacement has less consequence (i.e. lower cost and shorter chamber closure) than an unplanned replacement, it is better to replace a component before it failed. Unfortunately, it is impossible to determine precisely when a failure will occur. The next best option is to estimate the expected annual reactive maintenance costs of repair and transportation impacts over the planning period and compare them to the cost of proactive replacement. The least-cost alternative (reactive maintenance vs. replace in the 1st year vs. replace in the 2nd year, etc.) is the optimal maintenance plan for a component.

ORNIM compares the expected cost for the reactive maintenance plan with the costs for proactive component replacement in various years. If for example, the component replacement cost in 2020 is being calculated, the expected reactive maintenance costs up through 2019 are accumulated, the probability of the components survival in 2020 is calculated and the expected up-front replacement cost is calculated[1]. This amortized cost stream with a 2020 replacement is compared to the amortized RM cost stream. The least-cost alternative is the optimal maintenance alternative.

Figure 9-1 uses a hypothetical set of main chamber miter gates to illustrate an average annual RM cost ($0.54 million) relative to average annual miter gate replacement costs for each year in the period of analysis. In this example, repair, replacement, and transportation costs can be minimized with a proactive miter gate replacement starting in 2040. In this example, the optimum replacement means that a contract for gate construction occurs in 2040 and actual gate replacement occurs in subsequent years. In this case, a scheduled 30-day closure is modeled in 2041 to replace the upper gates and another scheduled 30-day closure is modeled in 2042 to replace the lower gates. All components were modeled this way; optimum replacement timing represents the year the replacement process starts. Gates and valves are the only components requiring two subsequent years for replacement; all other components are modeled as only needing one.

FIGURE 9-1
Hypothetical Main Chamber Miter Gates
Reactive Maintenance vs. 2010-2070 Replacement



[1] If the component's event tree contains a replacement of the component, there is a chance that the component is replaced before the scheduled up-front replacement date. In these simulations the scheduled replacement is canceled and replacement costs are not double counted.

Navigation projects, however, are composed of many components. Determination of optimal replacement timing of each component is a critical step, but it may not indicate the best maintenance alternative for the project. Combining individual component replacements might offer savings in mobilization and de-mobilization costs and result in fewer chamber closures. Also, a large enough bundling of component replacements might eliminate enough collective reactive maintenance costs to be economically justified even if the up-front replacement of the individual components not being justified. This type of condition analysis of individual components and bundled components is useful in formulating possible chamber rehabilitation or replacement strategies and can result in an overall least-cost maintenance strategy for the Ohio River which could consist of a combination of reactive maintenance, advanced maintenance (component replacement), and chamber rehabilitation alternatives.

9.3 ALTERNATIVES EVALUATED

9.3.1 Advanced Maintenance (Component Replacement)

The advanced maintenance strategy allows for a component to be replaced before it fails. A planned, up-front component replacement can minimize the adverse navigation impacts of an unscheduled, emergency repair. Before advanced maintenance can be fully formulated at a project, optimal individual component replacements must be determined. Optimal individual component replacement represents a piecemeal maintenance strategy which can be more efficient than reactive maintenance. It is considered a viable stand-alone alternative although there might be more efficient "bundles" of component replacements. The bundling of components can lead to a major rehabilitation strategy and this is discussed in the next sub-section.

The engineering team evaluated approximately twenty lock components and component systems at each mainstem project for reliability purposes, however on average, only ten were identified at each project as critical enough to warrant detailed economic analysis since many of the components were found to be highly reliable for the conditions evaluated as a part of ORMSS. For each of these components and/or component systems, ORNIM was used to calculate the expected costs of maintenance and repair and the additional transportation costs associated with the delays from the associated maintenance and repair closures. The amortized reactive maintenance costs are compared to up-front component replacement scenarios to determine if replacement is economically justified and if so, the optimal timing for the upfront replacement.

The advanced maintenance alternative combines reactive maintenance with economically justified component replacement. **Tables 9-1** through **9-5** show the year for beginning the recommended component replacement process and reactive maintenance (RM) schedules for each project and traffic forecast scenario. *The gray shaded cells represent components found to be highly reliable during the engineering reliability analysis and were not modeled in ORNIM*. RM in a cell represents reactive maintenance, which is the same thing as fixing the component after failing, and the numbers in the cells represent the year which optimizes the start of the proactive component replacement process.

TABLE 9-1
Advanced Maintenance
Scheduled Component Replacement
Forecast Scenario – Clear Skies

Ohio River Mainstem Project																		
Chamber Component	**Smithland**	**J.T. Myers ***	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup ****	**R.C. Byrd**	**Racine**	**Belleville**	**Willow Island**	**Hannibal**	**Pike Island**	**New Cumberland**	**Montgomery**	**Dashields**	**Emsworth**
MAIN																		
Gates	RM	**29**	**39**	**24**	-	**10**	**16**	-	**55**	**53**	**32**	**30**	**12**	**17**	-	-	-	-
Gate Machinery	RM	**18**	RM	**15**	RM	RM	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Hydraulic	RM	**16**	**15**	**15**	**30**	**36**	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Culvert Valve	**10**	**10**	**23**	**38**	**10**	**10**	RM	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	**15**	**15**	**15**	RM	**15**	**27**	-	**24**	**10**	**10**	**10**	RM	**15**	RM	RM	RM	RM
Valve Machinery	RM	RM	RM	RM	RM	RM	RM	-	-	RM	RM	-	RM	RM	RM	RM	RM	RM
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**18**	-	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**15**	**13**	**12**
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	**11**
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
AUX																		
Gates	**55**	-	-	-	-	RM	**10**	-	-	-	-	-	RM	RM	**37**	-	-	-
Gate Machinery	RM	-	-	-	-	RM	-	-	-	-	-	RM	-	RM	RM	-	-	-
Hydraulic	RM	-	RM	RM	-	RM	RM	-	-	RM	RM	RM	-	RM	RM	RM	-	RM
Culvert Valve	**10**	-	RM	RM	-	RM	-	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	-	RM	RM	-	RM	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	-	RM	-	-	RM	-	-	-	-	-	-	-	RM	-	-	-	-
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**58**	**38**	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Myers is authorized and scheduled for an auxiliary chamber extension by 2010 (includes replacemane of gates and the electrical system).

** Greenup is authorized and scheduled for an auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).

TABLE 9-2
Advanced Maintenance
Scheduled Component Replacement
Forecast Scenario – Modified Clear Skies

Ohio River Mainstem Project																		
Chamber / Component	**Smithland**	**J.T. Myers ***	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup ****	**R.C. Byrd**	**Racine**	**Belleville**	**Willow Island**	**Hannibal**	**Pike Island**	**New Cumberland**	**Montgomery**	**Dashields**	**Emsworth**
MAIN																		
Gates	**54**	**27**	**37**	**24**	-	**10**	**12**	-	**53**	**38**	**28**	**29**	**10**	**14**	-	-	-	-
Gate Machinery	RM	**10**	**15**	**22**	RM	**28**	**20**	-	RM	RM	**20**	RM	RM	RM	RM	RM	RM	RM
Hydraulic	RM	**10**	**15**	**15**	**30**	**10**	RM	-	RM	RM	**20**	RM	RM	RM	RM	RM	RM	RM
Culvert Valve	**10**	**10**	**22**	**37**	**10**	**10**	RM	-	-	**50**	-	RM	RM	-	-	-	-	-
Electrical	RM	**10**	**15**	**15**	RM	**10**	**10**	-	**10**	**20**	**10**	**23**	RM	**15**	**15**	RM	RM	RM
Valve Machinery	RM	RM	RM	RM	RM	RM	RM	-	-	RM	RM	-	RM	RM	RM	**17**	RM	**38**
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**14**	-	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
AUX																		
Gates	**51**	-	-	-	-	RM	**10**	-	-	-	-	-	**65**	**52**	**34**	-	-	-
Gate Machinery	RM	-	-	-	-	RM	-	-	-	-	-	RM	-	RM	RM	-	-	-
Hydraulic	RM	-	RM	RM	-	RM	RM	-	-	RM	RM	RM	-	RM	RM	RM	-	RM
Culvert Valve	**10**	-	RM	RM	-	RM	-	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	-	RM	RM	-	RM	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	-	RM	-	-	RM	-	-	-	-	-	-	-	RM	-	-	-	-
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**53**	**35**	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Myers is authorized and scheduled for an auxiliary chamber extension by 2010 (includes replacemane of gates and the electrical system).

** Greenup is authorized and scheduled for an auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).

TABLE 9-3
Advanced Maintenance
Scheduled Component Replacement
Forecast Scenario – NAAQS Growth

Ohio River Mainstem Project																		
Chamber Component	**Smithland**	**J.T. Myers ***	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup ****	**R.C. Byrd**	**Racine**	**Belleville**	**Willow Island**	**Hannibal**	**Pike Island**	**New Cumberland**	**Montgomery**	**Dashields**	**Emsworth**
MAIN																		
Gates	**54**	**27**	**37**	**24**	-	**10**	**12**	-	**52**	**39**	**28**	**29**	**10**	**14**	-	-	-	-
Gate Machinery	RM	**10**	**15**	**15**	RM	**24**	**22**	-	RM	**10**	**10**	RM	RM	**15**	RM	**15**	RM	RM
Hydraulic	RM	**10**	**15**	**15**	**30**	**20**	RM	-	RM	RM	RM	RM	RM	RM	RM	**15**	RM	RM
Culvert Valve	**10**	**10**	**22**	**36**	**10**	**10**	RM	-	-	**54**	-	RM	RM	-	-	-	-	-
Electrical	RM	**10**	**15**	**15**	RM	**10**	**10**	-	**24**	**10**	**10**	**23**	RM	**14**	**15**	RM	RM	RM
Valve Machinery	RM	RM	RM	RM	RM	RM	RM	-	-	RM	RM	-	RM	RM	RM	**15**	**35**	**16**
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**14**	-	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**11**	**10**	**14**
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
AUX																		
Gates	**50**	-	-	-	-	RM	**10**	-	-	-	-	-	RM	**52**	**34**	-	-	-
Gate Machinery	RM	-	-	-	-	RM	-	-	-	-	-	RM	-	RM	RM	-	-	-
Hydraulic	RM	-	RM	RM	-	RM	RM	-	-	RM	RM	RM	-	RM	RM	RM	-	RM
Culvert Valve	**10**	-	RM	RM	-	RM	-	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	-	RM	RM	-	RM	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	-	RM	-	-	RM	-	-	-	-	-	-	-	RM	-	-	-	-
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**53**	**34**	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Myers is authorized and scheduled for an auxiliary chamber extension by 2010 (includes replacemane of gates and the electrical system).

** Greenup is authorized and scheduled for an auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).

TABLE 9-4
Advanced Maintenance
Scheduled Component Replacement
Forecast Scenario – Utility Based

Ohio River Mainstem Project																		
Chamber Component	**Smithland**	**J.T. Myers ***	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup ****	**R.C. Byrd**	**Racine**	**Belleville**	**Willow Island**	**Hannibal**	**Pike Island**	**New Cumberland**	**Montgomery**	**Dashields**	**Emsworth**
MAIN																		
Gates	**54**	**28**	**37**	**24**	-	**10**	**10**	-	**48**	**52**	**31**	**29**	**12**	**18**	-	-	-	-
Gate Machinery	RM	**15**	**27**	**20**	RM	**15**	**15**	-	RM	**15**	RM	RM	RM	RM	RM	RM	RM	RM
Hydraulic	RM	**15**	**21**	**17**	**30**	**15**	**15**	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Culvert Valve	**10**	**10**	**23**	**36**	**10**	**10**	RM	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	**10**	**17**	**15**	RM	**10**	**14**	-	**19**	**15**	**15**	**15**	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	RM	RM	RM	RM	RM	RM	-	-	RM	RM	-	RM	RM	RM	**51**	RM	RM
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**19**	-	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
AUX																		
Gates	**51**	-	-	-	-	RM	**12**	-	-	-	-	-	RM	**57**	**37**	-	-	-
Gate Machinery	RM	-	-	-	-	RM	-	-	-	-	-	RM	-	RM	RM	-	-	-
Hydraulic	RM	-	RM	RM	-	RM	RM	-	-	RM	RM	RM	-	RM	RM	RM	-	RM
Culvert Valve	**10**	-	RM	RM	-	**45**	-	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	-	RM	RM	-	RM	RM	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	-	RM	-	-	RM	-	-	-	-	-	-	-	RM	-	-	-	-
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**58**	**38**	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Myers is authorized and scheduled for an auxiliary chamber extension by 2010 (includes replacemane of gates and the electrical system).

** Greenup is authorized and scheduled for an auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).

TABLE 9-5
Advanced Maintenance
Scheduled Component Replacement
Forecast Scenario – Utility Based High

Ohio River Mainstem Project																		
Chamber Component	**Smithland**	**J.T. Myers ***	**Newburgh**	**Cannelton**	**McAlpine**	**Markland**	**Meldahl**	**Greenup ****	**R.C. Byrd**	**Racine**	**Belleville**	**Willow Island**	**Hannibal**	**Pike Island**	**New Cumberland**	**Montgomery**	**Dashields**	**Emsworth**
MAIN																		
Gates	**51**	**27**	**37**	**24**	-	**10**	**10**	-	**45**	**52**	**30**	**29**	**12**	**16**	-	-	-	-
Gate Machinery	RM	**10**	**25**	**19**	RM	**15**	**14**	-	RM	**15**	**18**	RM	RM	RM	RM	RM	RM	RM
Hydraulic	RM	**10**	**19**	**16**	**28**	**15**	**14**	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Culvert Valve	**10**	**10**	**23**	**35**	**10**	**10**	**56**	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	**10**	**16**	**15**	RM	**10**	**10**	-	**14**	**15**	**15**	**15**	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	**33**	RM	RM	RM	RM	RM	-	-	RM	RM	-	RM	RM	RM	**35**	RM	**50**
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**17**	-	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM	RM
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	RM
AUX																		
Gates	**50**	-	-	-	-	RM	**10**	-	-	-	-	-	RM	**56**	**37**	-	-	-
Gate Machinery	RM	-	-	-	-	RM	-	-	-	-	-	RM	-	RM	RM	-	-	-
Hydraulic	RM	-	RM	RM	-	RM	RM	-	-	RM	RM	RM	-	RM	RM	RM	-	RM
Culvert Valve	**10**	-	RM	RM	-	**41**	-	-	-	RM	-	RM	RM	-	-	-	-	-
Electrical	RM	-	RM	RM	-	RM	**58**	-	RM	RM	RM	RM	RM	RM	RM	RM	RM	RM
Valve Machinery	RM	-	RM	-	-	RM	-	-	-	-	-	-	-	RM	-	-	-	-
Downstream Gates	-	-	-	-	-	-	-	-	-	-	-	-	-	**56**	**38**	-	-	-
Land Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middle Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upper Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-	-
Upper Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guard Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RM	-
Lower Guide Wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Myers is authorized and scheduled for an auxiliary chamber extension by 2010 (includes replacemane of gates and the electrical system).

** Greenup is authorized and scheduled for an auxiliary chamber extension by 2009 (which includes main chamber gate replacement in 2011).

9.3.2 Rehabilitation Maintenance

Sometimes the individual component replacement analysis indicates a potential cost savings if components can be bundled into a single closure. If a bundled component replacement exceeds $10.6 million the maintenance is considered a major rehabilitation.[2] Under major rehabilitation, where economically justified, all unreliable components are replaced. Unreliable components refers to any components determined economically justified for an up-front replacement

The opportunity for major rehabilitation was determined after the economics team identified components justified for individual replacement and the engineering team was able to bundle them into a single rehabilitation. Cost and closures for the rehabilitations were based on the cost to replace all the components and the time required to do it under one rehabilitation project. Since less mobilization and demobilization is required, rehabilitation costs and closures are usually improved over individual component replacements. If the bundled components did not exceed the rehabilitation threshold, then they were left as individual component replacements. ORNIM was run to determine rehabilitation justification and timing.

It should be noted that EDM was not evaluated for major rehabilitation maintenance because the physical condition of the lock walls at these project make a 2nd successful major rehabilitation unlikely. Note, that EDM was rehabilitated in the mid 1980s to early 1990s.

The rehabilitation maintenance alternative combines reactive maintenance with justified component replacements and chamber rehabilitations. **Table 9-6** summarizes recommended chamber rehabilitations for each traffic forecast scenario over the 2010-2070 timeframe. The gray shaded cells represent chambers not modeled because the individual component replacements would not exceed $10.6 million as required by major rehabilitation guidance. By the very nature of this analysis the results across forecasts are not always robust; there is variability between the traffic forecasts. Markland shows immediate rehabilitation justified in three of the five forecasts. The value of Table 9-6 is showing the relative sequencing of need for major rehabilitation studies with some projects in need of more accelerated study than others.

9.3.3 Auxiliary Lock Extensions – Lower Ohio

A 600’ extension of the existing auxiliary chamber results in a project with twin 1200’ chambers. The twin 1200’ configuration has the ability to efficiently process traffic during closures of either 1200’ chamber, as well as handle future, higher volumes of traffic during the later years of the project. Lock extension plans were evaluated at Meldahl, Markland, Cannelton, and Newburgh. Based on traffic forecasts, these projects were considered most likely in need of additional auxiliary capacity.

[2] $10.6 million is the FY06 budgetary threshold for major rehabilitation

No auxiliary lock extensions were justified when ORNIM compared this alternative to the rehabilitation alternative. This suggests that a reliable main chamber negates the need for additional auxiliary capacity under the traffic forecast scenarios used in this analysis. Auxiliary lock extensions were dropped from further analysis.

TABLE 9-6
Recommended Chamber Rehabilitations

Project / Chamber	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Smithland					
Main	-	-	-	-	-
Auxiliary					
Myers					
Main	2014	2011	2013	2013	2013
Auxiliary					
Newburgh					
Main	2025	2016	2016	2016	2016
Auxiliary					
Cannelton					
Main	2017	2017	2016	2017	2017
Auxiliary					
McAlpine					
Main					
Auxiliary					
Markland					
Main	-	-	2010	2010	2010
Auxiliary	-	-	-	-	2052
Meldahl					
Main	2013	2010	2010	2010	2010
Auxiliary					
R. C. Byrd					
Main	-	2044	2045	2030	2033
Auxiliary					
Racine					
Main	2020	2019	2020	2019	2019
Auxiliary					
Belleville					
Main	-	2017	2017	2017	2028
Auxiliary					
Willow Island					
Main	2027	2027	2027	2027	2028
Auxiliary					
Hannibal					
Main	2012	2011	2011	2012	2011
Auxiliary					
Pike Island					
Main	2016	2015	2015	2016	2015
Auxiliary	-	-	-	-	-
New Cumberland					
Main					
Auxiliary	-	-	-	-	-

9.3.4 New 600' Locks at EDM

New 600' locks riverward of the existing auxiliary chambers at EDM were compared to reactive and advanced maintenance strategies. New 600' chambers at EDM were evaluated as stand-alone projects. This plan involves replacing the smaller (360' x 56') auxiliary locks at EDM with 600'x110' chambers. EDM would become twin 600' projects. The benefits of this plan are improved reliability and additional capacity.

ORNIM was run to determine new 600' lock justification and timing. The analysis shows new 600' locks justified at EDM relative to reactive and advanced maintenance strategies. The replacement 600' locks at EDM are in addition to reactive maintenance, justified component replacements, and major rehabilitations elsewhere on the mainstem. **Table 9-7** displays the optimal timing for 600' lock replacements at EDM by forecast scenario.

TABLE 9-7
Recommended New 600' Locks

Project / Chamber	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Emsworth					
Main	-	-	-	-	-
New 600' Lock	2010	2010	2010	2010	2010
Dashields					
Main	-	-	-	-	-
New 600' Lock	2011	2010	2010	2010	2010
Montgomery					
Main	-	-	-	-	-
New 600' Lock	2010	2010	2010	2010	2010

9.3.5 New 1200' Locks at EDM

New 1200' locks riverward of the existing auxiliary chambers at EDM were compared to reactive and advanced maintenance strategies, as well. New 1200' chambers at EDM were evaluated as stand-alone projects. This plan involves replacing the smaller (360' x 56') auxiliary locks at EDM with 1200'x110' chambers. The benefits of this plan are improved reliability and additional capacity.

ORNIM was run to determine new 1200' lock justification and timing. The analysis shows new 1200' locks justified at EDM relative to reactive and advanced maintenance strategies. The new replacement 1200' locks at EDM are in addition to reactive maintenance, justified component replacements and major rehabilitations elsewhere on the mainstem. **Table 9-8** displays the optimal timing for the 1200' lock replacements at EDM by forecast scenario.

TABLE 9-8
Recommended New 1200' Locks

Project / Chamber	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Emsworth					
Main	-	-	-	-	-
New 1200' Lock	2010	2010	2010	2010	2010
Dashields					
Main	-	-	-	-	-
New 1200' Lock	2012	2010	2010	2010	2010
Montgomery					
Main	-	-	-	-	-
New 1200' Lock	2014	2010	2010	2010	2010

9.3.6 Optimum Lock Size at EDM

ORNIM was run to optimize between 1200' and 600' chamber lock replacements at EDM. The optimum lock size at EDM alternative combines reactive maintenance with justified component replacements, major rehabilitations, and either a new 1200' or 600' lock at EDM. **Table 9-9** displays the optimal timing for the justified replacement locks at EDM by forecast scenario.

TABLE 9-9
Recommended Optimum New 1200' – 600' Locks

Project / Chamber	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Emsworth					
Main	-	-	-	-	-
New 600' Lock	2010	2010	2010	2010	2010
Dashields					
Main	-	-	-	-	-
New 600' Lock	2011	2010	2010	2010	2010
Montgomery					
Main	-	-	-	-	-
New 600' Lock	2010	2010	-	2010	2010
New 1200' Lock	-	-	2010	-	-

9.3.7 Congestion Lockage Fees

Although a detailed analysis of congestion fees has not been conducted for this study, a general analysis of traffic management alternatives was completed (see **Attachment 5 Traffic Management Analysis**) and some preliminary determinations have been made. A congestion lockage fee could be used to influence shipping decisions for shippers with

marginal transportation rate savings. A lockage fee could cause shippers to shift to either alternative transportation modes or markets, thereby reducing the amount of lock congestion for all remaining waterway shipments. Thus it serves to ration lock use to those movements with the highest transportation savings. The result would be an increase in total rate savings net of delay costs for shippers that continue to use the waterway. A congestion lockage fee could reduce arrivals (queues) and, therefore, delay costs at a congested lock during closure.

Congestion fees are generally considered to be an alternative to providing additional capacity at a public facility that is characterized by persistent delays and queues. In the case of the Ohio River mainstem locks and dams, congestion is associated with periodic closures of the main chambers rather than persistent congestion due to a system approaching capacity. The best way to manage these short-term and periodic episodes of congestion is with temporary nonstructural management measures such as industry self-help and n-up/n-down lockage policies. The implementation of long-term congestion fees based on short-term and periodic congestion would tend to distort the transportation practices of shippers in an uneconomical way. Furthermore, congestion fees do not address the structural problems of aging mainstem infrastructure. The one exception where congestion fees might prove to be of value is on the three Upper Ohio locks, where additional capacity for the auxiliary locks is economic.

9.3.8 Summary

The following investment alternatives: i) two proactive maintenance strategies and ii) new 600' or 1200' chambers at EDM are carried forward for economic analysis and formulation of the with-project condition (WPC). Congestion fees are not carried forward as part of the SIP WPC because they do not address the maintenance and structural investment needs of the mainstem.

9.4 ECONOMICS OF THE WITH-PROJECT ALTERNATIVES

9.4.1 Advanced Maintenance (Component Replacement)

Under advanced maintenance, normal O&M is performed, along with scheduled cyclical maintenance. Scheduled lock improvements for the mainstem include the authorized improvements at Greenup and J.T. Myers plus any justified individual component replacements. Unscheduled lock repair costs are estimated from reliability modeling. No major rehabilitation occurs. Scheduled dam maintenance, based on engineering judgment, is included in project costs.

9.4.1.1 System Costs

ORNIM was run at each project to estimate expected unscheduled repair/replace costs and component replacement costs under each of the five different traffic forecast scenarios. The unscheduled repair costs and scheduled component replacement costs are

added to other Federal maintenance costs to develop total system costs. **Figure 9-2** shows forecast advanced maintenance funding needs. Overall, this analysis shows an average annual expenditure of around $100.6 million is required to sustain navigation on the Ohio River from 2010-2070 with an advanced maintenance strategy.

FIGURE 9-2

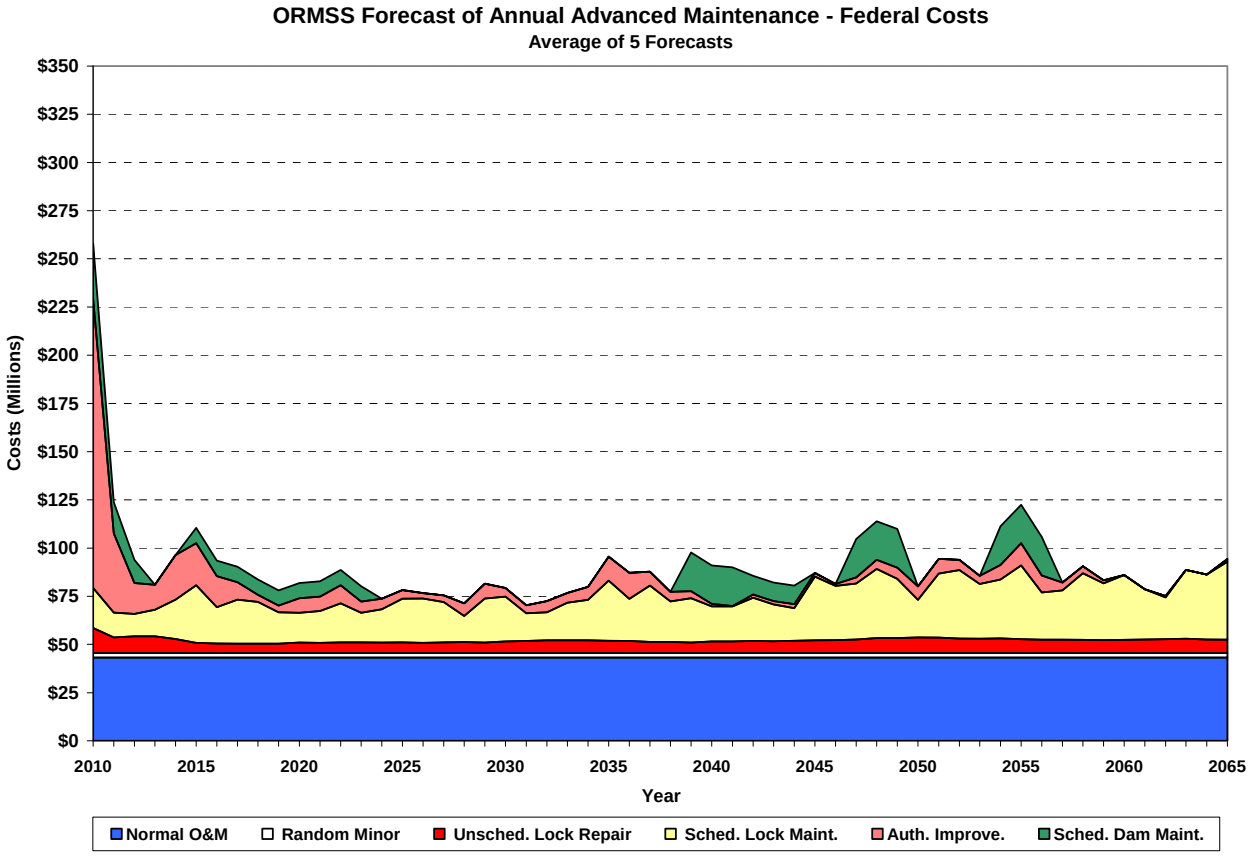
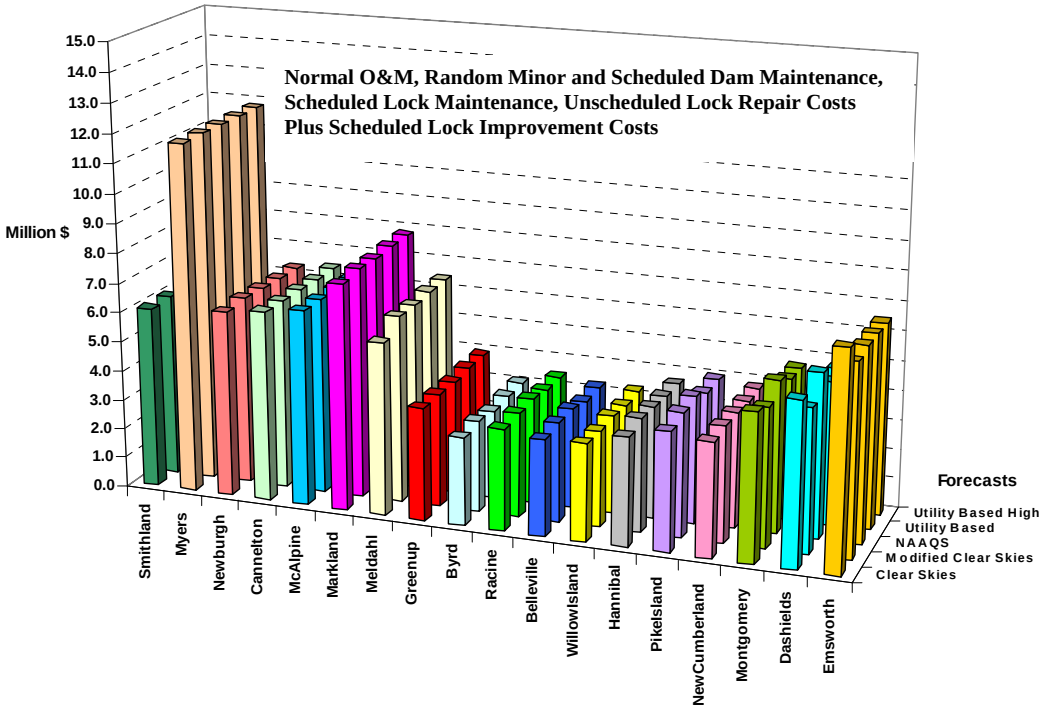


Figure 9-3 displays average annual Federal costs for the advanced maintenance alternative by project and by traffic forecast. The bar graph combines normal O&M, random minor, scheduled dam costs, scheduled lock maintenance costs, unscheduled lock repair costs, and lock improvement costs. The scheduled lock improvements are the authorized J.T. Myers and Greenup improvements and the economically justified component replacements displayed in Tables 9-1 through 9.5. Unscheduled lock repair costs and scheduled lock maintenance costs are lower because of proactive component replacement efficiencies. High maintenance needs are seen on the upper and lower Ohio projects. J.T. Myers shows authorized improvement costs.

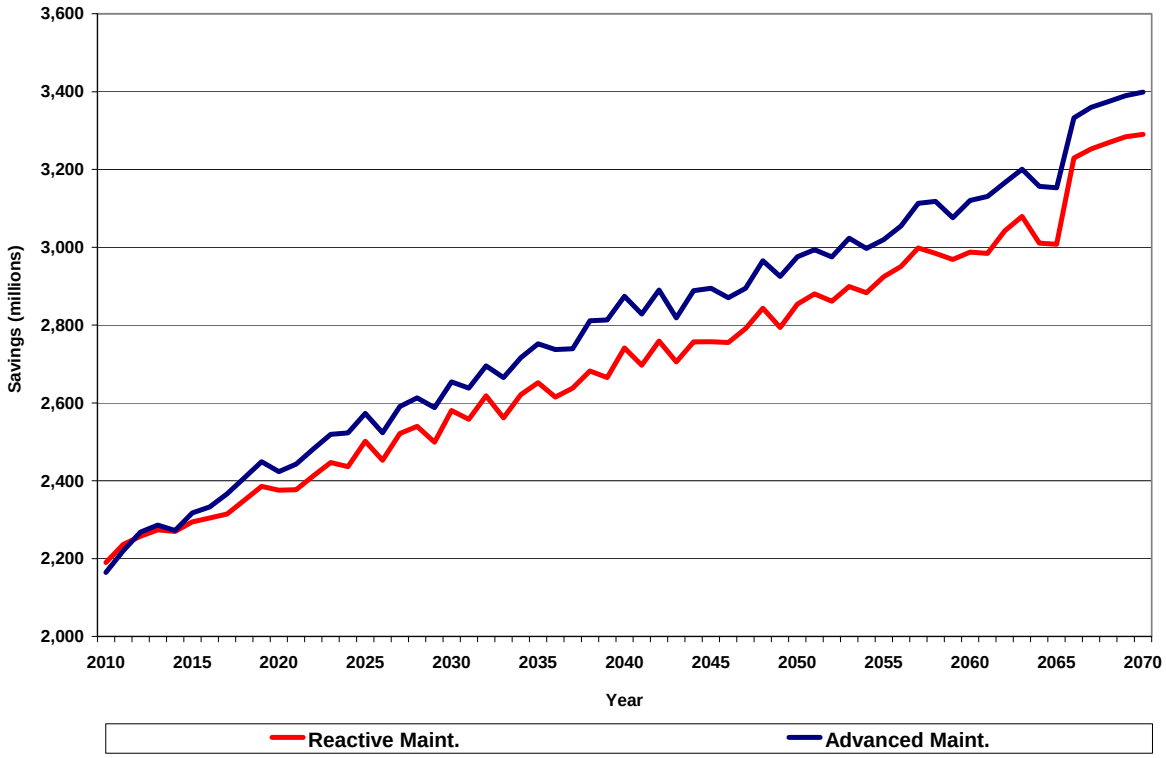
FIGURE 9-3
Advanced Maintenance
Average Annual Project Costs
(2010-2070, 5 1/8%, FY03 $)



9.4.1.2 System Benefits

System benefits are the equilibrium transportation rate savings net of any transportation losses caused by congestion or delay due to scheduled improvement and unscheduled repair closures. **Figure 9-4** displays system transportation benefits averaged over all 5 traffic forecast scenarios for the reactive and advanced maintenance strategies. The gap represents incremental system benefits attributable to the more aggressive advanced maintenance strategy.

FIGURE 9-4
ORMSS Forecast of Annual Advanced Maintenance Transportation Benefits
Average of 5 Forecasts



9.4.1.3 System Statistics

Individual component replacement optimization was done at the project level in a system context. The simultaneous effect of multiple piecemeal component replacements at each project and between each project is captured by locking the recommended replacements for all projects and re-equilibrating the transportation system. Given the results of individual up front component replacement analysis, ORNIM was run to calculate the expected system component replacement costs under each of the five traffic forecast scenarios. **Table 9-10** summarizes average annual system benefits and costs from an advanced maintenance strategy at each mainstem project over the five traffic forecast scenarios.

Advanced maintenance buys down risk with higher scheduled improvement costs that are 50 percent cost shared with the Trust Fund. Scheduled improvement costs for this alternative include Greenup and Myers and justified up-front component replacements shown in **Tables 9-1** to **9-5**. Scheduled lock maintenance and unscheduled lock repair costs are 100 percent Federal and decrease. Average annual benefits range from $2.37 to $2.58 billion. Average annual costs range from $100.3 to $101.7 million.

Table 9-11 displays incremental benefits and costs of advanced maintenance compared to reactive maintenance plans. Incremental costs are slightly positive because the higher improvement costs exceed slightly the lower scheduled lock maintenance and unscheduled lock repair costs, for all forecast traffic scenarios. In the long run, it is more

economic to pursue an up-front component replacement strategy rather than a reactive maintenance strategy. The table shows incremental net benefits of a planned component replacement ranging from $94.8 to $172.4 million annually.

TABLE 9-10
Advanced Maintenance*
Average Annual Costs and Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Advanced Maintenance Benefits					
Equilibrium Waterway Savings	$2,383.4	$2,543.2	$2,563.0	$2,590.8	$2,645.6
Reduced Savings from Unscheduled Repair	($17.6)	($74.4)	($37.0)	($56.3)	($61.2)
Total System Benefits	**$2,365.8**	**$2,468.8**	**$2,526.0**	**$2,534.5**	**$2,584.4**
Advanced Maintenance Costs					
Scheduled Lock Maintenance	$ 20.7	$ 20.9	$ 20.4	$ 21.1	$ 20.9
Scheduled Dam Maintenance	$ 6.9	$ 6.9	$ 6.9	$ 6.9	$ 6.9
Scheduled Lock Improvements*	$ 19.7	$ 15.0	$ 20.2	$ 15.2	$ 15.6
Unscheduled Lock Repair	$ 4.3	$ 8.4	$ 5.0	$ 7.6	$ 7.7
Normal O&M	$46.7	$46.7	$46.7	$46.7	$46.7
Random Minor	$2.4	$2.4	$2.4	$2.4	$2.4
Total System Costs	**$101.8**	**$100.4**	**$101.7**	**$100.0**	**$100.3**
Net Benefits	**$2,265.0**	**$2,368.4**	**$2,424.2**	**$2,434.5**	**$2,484.1**
BCR	**23.5**	**24.6**	**24.8**	**25.3**	**25.8**

** Scheduled Lock Improvements are 50% cost shared with the Trust Fund for the authorized 600' extension of the auxiliary chamber at Myers in 2010 and rehabilitation of the Greenup main chamber in 2010-11, plus any justified component replacements.*

TABLE 9-11
Advanced Maintenance
Average Annual Incremental Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Incremental Benefits over Reactive Maintenance	$113.0	$95.1	$174.1	$105.8	$124.3
Incremental Costs over Reactive Maintenance	$1.7	$0.3	$1.7	$0.3	$0.2
Net Incremental Benefit	**$111.3**	**$94.8**	**$172.4**	**$105.5**	**$124.1**

9.4.2 Rehabilitation Maintenance

Under rehabilitation maintenance, normal O&M is performed, along with scheduled cyclical maintenance. Scheduled lock improvements for the mainstem include the authorized improvements at Greenup and J.T. Myers, justified individual component replacements, plus any justified rehabilitations. Unscheduled lock repair costs are computed from reliability modeling. Scheduled dam maintenance, based on engineering judgment, is included in project costs.

9.4.2.1 System Costs

ORNIM was run at each project to estimate expected unscheduled repair/replace costs, component replacement costs and major rehabilitations under each of the five different traffic forecast scenarios. The unscheduled repair costs, the scheduled component replacement costs, and the major rehabilitation costs are added to other Federal maintenance costs to develop total system costs. **Figure 9-5** shows forecast rehabilitation maintenance funding needs. Overall, this analysis shows an average annual expenditure of around $98.1 million is required to sustain navigation on the Ohio River from 2010-2070 with a rehabilitation maintenance strategy. In the long run, a rehabilitation maintenance strategy is lower cost than either reactive or advanced maintenance.

FIGURE 9-5

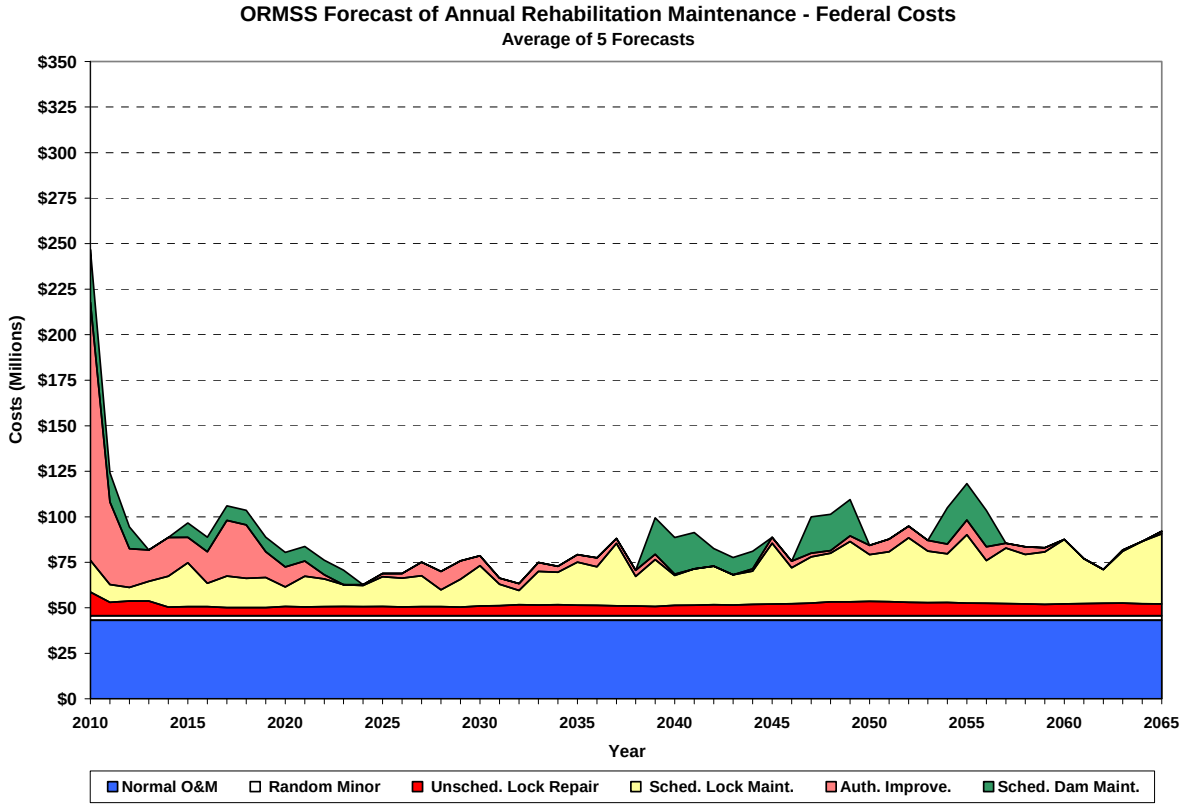
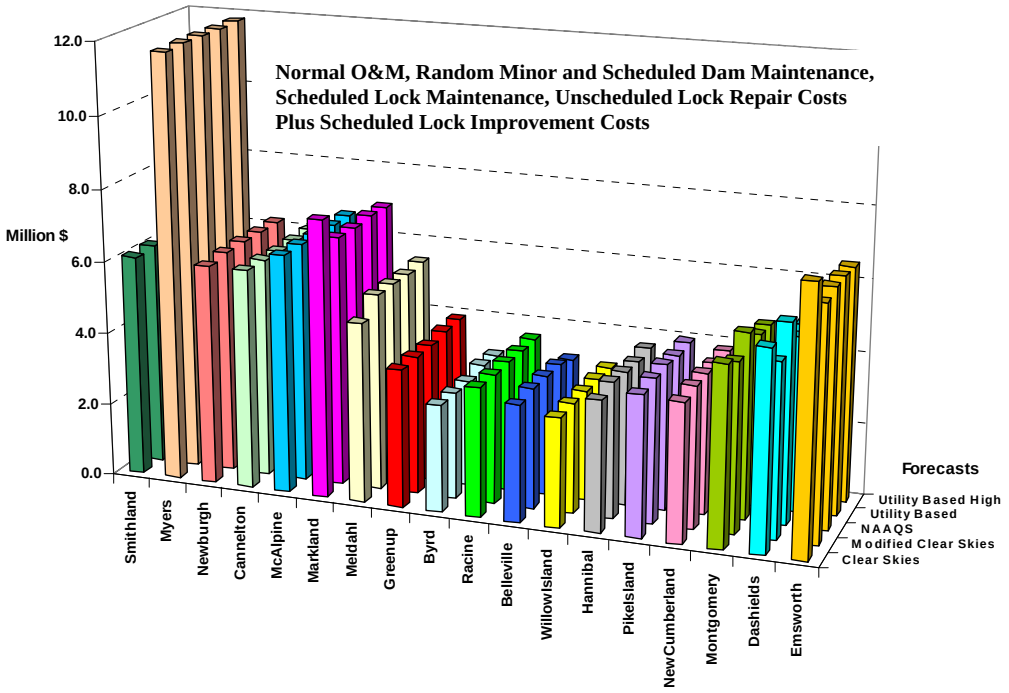


Figure 9-6 displays average annual Federal costs for the rehabilitation maintenance alternative by project and by traffic forecast. The bar graph combines normal O&M, random minor, scheduled dam costs, scheduled lock maintenance costs, unscheduled lock repair costs and lock improvement costs. The scheduled lock improvements are the authorized Myers and Greenup improvements, the economically justified component replacements and the recommended rehabilitations shown in **Table 9-6**. The unscheduled lock repair costs and scheduled lock maintenance costs are lower because of rehabilitation efficiencies.

Costs for early rehabilitation needs at Markland, Hannibal, Meldahl, Myers, Pike Island, Willow Island, Newburgh and Cannelton as well as maintenance costs at Emsworth, Dashields, and Montgomery are included in **Figure 9-6**. Also, costs at Myers include the authorized auxiliary chamber extension.

FIGURE 9-6
Rehabilitation Maintenance
Average Annual Project Costs
(2010-2070, 5 1/8%, FY03 $)



9.4.2.2 System Benefits

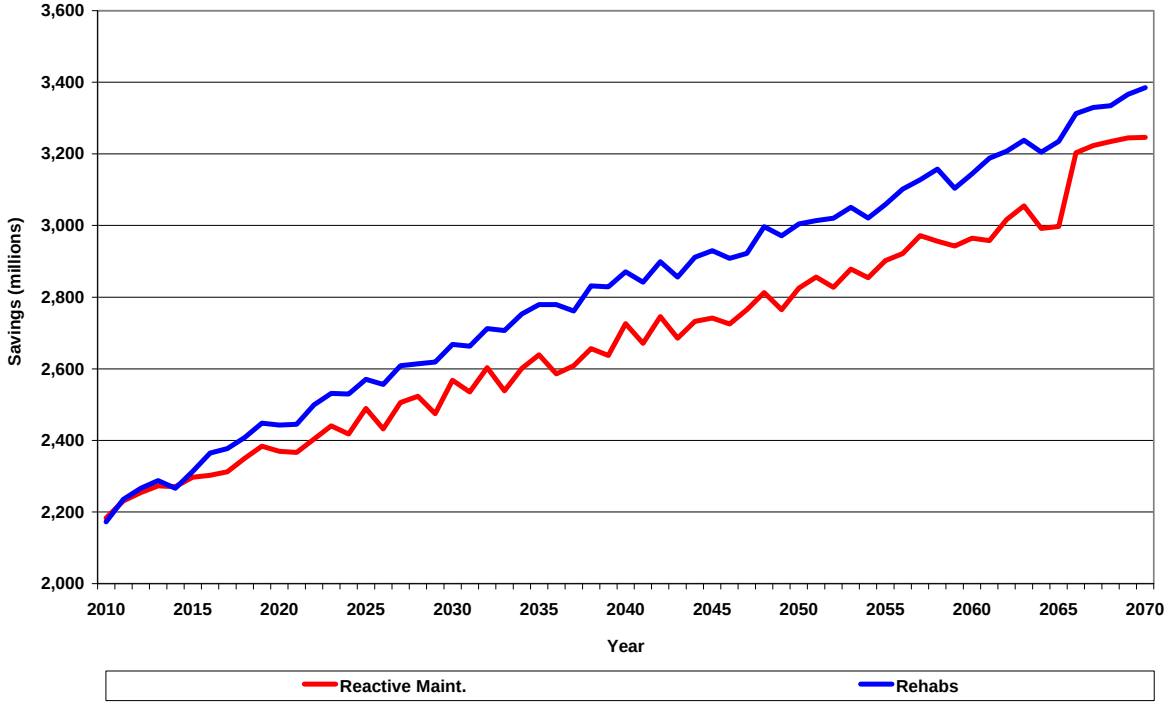
System benefits are the equilibrium transportation rate savings net of any transportation losses caused by congestion or delay due to scheduled improvement and unscheduled repair closures. **Figure 9-7** displays system transportation benefits averaged over all 5 traffic forecast scenarios for the reactive and rehabilitation maintenance

strategies. The gap represents incremental system benefits attributable to the more aggressive component replacement and rehabilitation maintenance strategy.

FIGURE 9-7

ORMSS Forecast of Annual Rehabilitation Maintenance Transportation Benefits

Average of 5 Forecasts



9.4.2.3 System Statistics

Bundled component replacement optimization was done at the project level in a system context. The simultaneous effect of bundling component replacements at each project and between each project is captured by locking the recommended replacements for all projects and re-equilibrating the transportation system. Given the results of bundled component replacement analysis, ORNIM was run to calculate the expected system component replacement costs under each of the five traffic forecast scenarios. **Table 9-12** summarizes average annual system benefits and costs from a rehabilitation maintenance strategy at each mainstem project over the five traffic forecast scenarios. Scheduled improvement costs for this alternative include Greenup and Myers, justified up-front component replacements and justified major rehabilitation work shown in **Table 9-6**. Unscheduled repair costs decrease further with the rehabilitation maintenance strategy. Average annual benefits range from $2.37 to $2.60 billion. Average annual costs range from $97.4 to $99.0 million.

Table 9-13 displays incremental benefits and costs of rehabilitation maintenance compared to reactive maintenance plans. Incremental costs are negative because rehabilitation maintenance is a more efficient maintenance strategy than reactive maintenance. In the long run, it is more economic to perform bundled component

replacements compared to reactive maintenance. The table also shows the incremental net benefits of planned rehabilitations. Incremental net benefits range from $115.7 to $183.2 million.

TABLE 9-12
Rehabilitation Maintenance*
Average Annual Costs and Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Rehabilitation Maintenance Benefits					
Equilibrium Waterway Savings	$2,386.2	$2,565.1	$2,570.7	$2,602.1	$2,659.1
Reduced Savings from Unscheduled Repair	($17.6)	($62.7)	($36.9)	($56.1)	($61.5)
Total System Benefits	**$2,368.6**	**$2,502.4**	**$2,533.8**	**$2,546.1**	**$2,597.7**
Rehabilitation Maintenance Costs					
Scheduled Lock Maintenance	$18.3	$17.4	$17.0	$17.6	$17.5
Scheduled Dam Maintenance	$6.9	$6.9	$6.9	$6.9	$6.9
Scheduled Lock Improvements*	$20.4	$16.7	$20.9	$16.7	$16.6
Unscheduled Lock Repair	$4.2	$7.4	$4.8	$7.3	$7.3
Normal O&M	$46.7	$46.7	$46.7	$46.7	$46.7
Random Minor	$2.4	$2.4	$2.4	$2.4	$2.4
Total System Costs	**$99.0**	**$97.6**	**$98.8**	**$97.7**	**$97.4**
Net Benefits	**$2,269.5**	**$2,404.8**	**$2,435.0**	**$2,448.4**	**$2,500.2**
BCR	**23.9**	**25.6**	**25.7**	**26.1**	**26.7**

** Scheduled Lock Improvements are 50% cost shared with the Trust Fund and include authorized 600' extension of the auxiliary chamber at Myers in 2010 and rehabilitation of the Greenup main chamber in 2010-11, justified component replacements plus justified rehabilitations.*

TABLE 9-13
Rehabilitation Maintenance
Average Annual Incremental Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Incremental Benefits over Reactive Maintenance	$115.7	$128.7	$181.9	$117.4	$137.5
Incremental Costs over Reactive Maintenance	($0.0)	($2.5)	($1.3)	($2.1)	($2.6)
Net Incremental Benefit	**$115.7**	**$131.2**	**$183.2**	**$119.5**	**$140.2**

9.4.3 New 600' Locks at EDM

Under new 600' locks at EDM, normal O&M is performed, along with scheduled cyclical maintenance for inspection. Scheduled lock improvements include the authorized improvements at Greenup and J.T. Myers, justified component replacements, justified rehabilitations and justified new 600' locks at EDM. Unscheduled lock repair costs are estimated from reliability modeling. Scheduled dam maintenance, based on engineering judgment, is included in project costs.

9.4.3.1 System Costs

ORNIM was run at all projects to estimate expected unscheduled repair/replace costs, component replacement costs, major rehabilitation costs and new 600' locks at EDM under each of the five different traffic forecast scenarios. The unscheduled repair costs, scheduled component replacement costs, major rehabilitation costs, and new 600' lock construction costs are added to other Federal maintenance costs to develop total system costs. **Figure 9-8** shows forecast Federal funding needs for a new 600' lock at EDM alternative. There is a spike in authorized improvement costs relative to the maintenance alternative cost graphics. Overall, this analysis shows that an average annual expenditure of $118.5 million is required to sustain navigation on the Ohio River from 2010-2070 with the new 600' locks at EDM alternative. New construction at EDM lowers future unscheduled lock repair and scheduled maintenance relative to reactive maintenance.

FIGURE 9-8

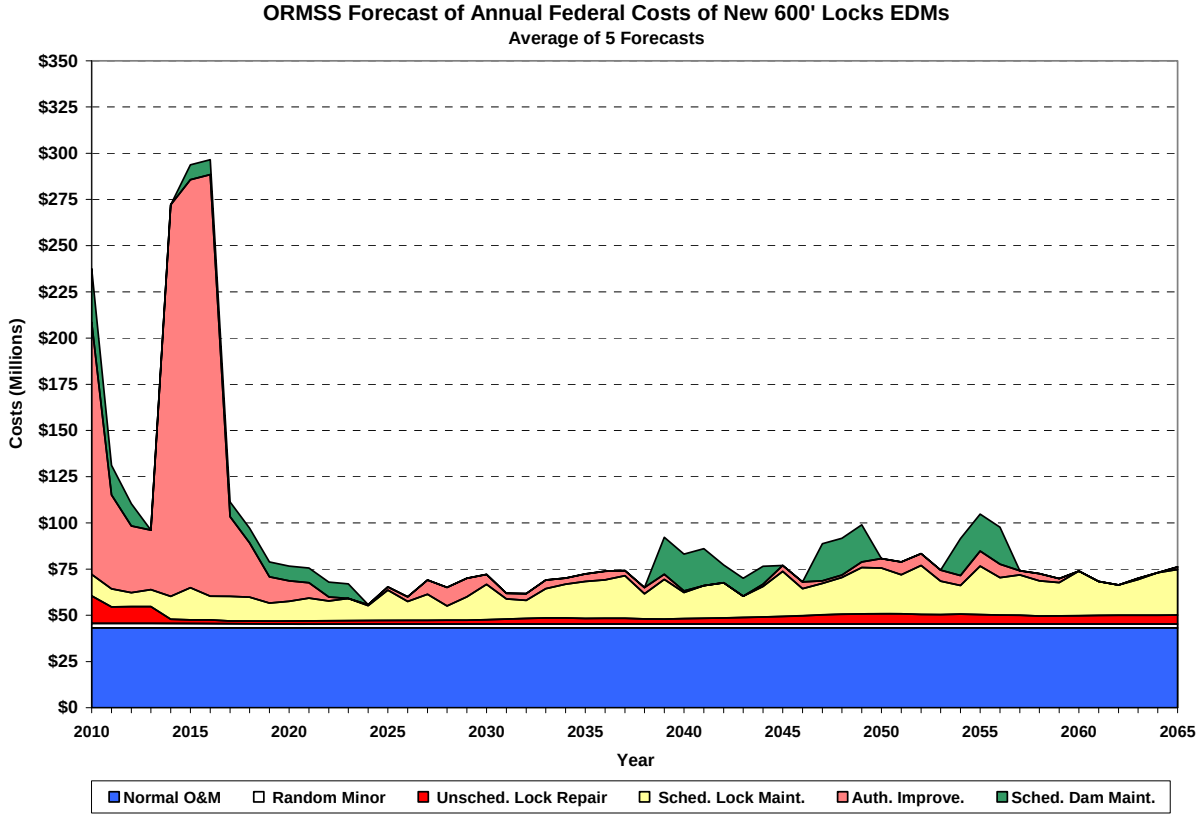
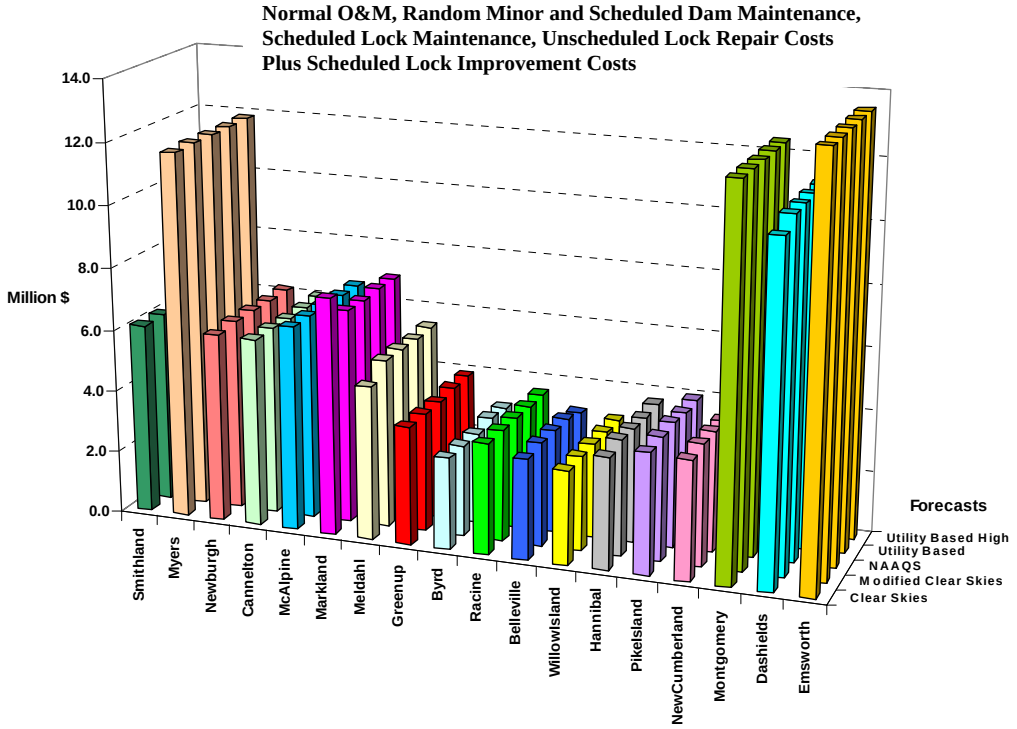


Figure 9-9 displays average annual Federal costs for the new 600' locks at EDM alternative by project and by traffic forecast. The bar graph combines normal O&M, random minor closure costs, scheduled dam costs, scheduled lock maintenance costs, unscheduled lock repair costs, and lock improvement costs. The scheduled lock improvements are the authorized J.T. Myers and Greenup improvements, economically justified component replacements and recommended rehabilitations plus the justified new 600' locks at EDM shown in **Table 9-7**. The unscheduled lock repair costs and the scheduled lock maintenance costs are lower because of the new construction.

Figure 9-9 shows new construction costs at EDM dominating annual system investment costs, with the authorized Myers auxiliary chamber extension standing out as well and the rehabilitation needs at Markland, Hannibal, Meldahl, Myers, Pike Island, Willow Island, Newburgh, and Cannelton.

FIGURE 9-9
600' Locks EDM
Average Annual Project Costs
(2010-2070, 5 1/8%, FY03 $)

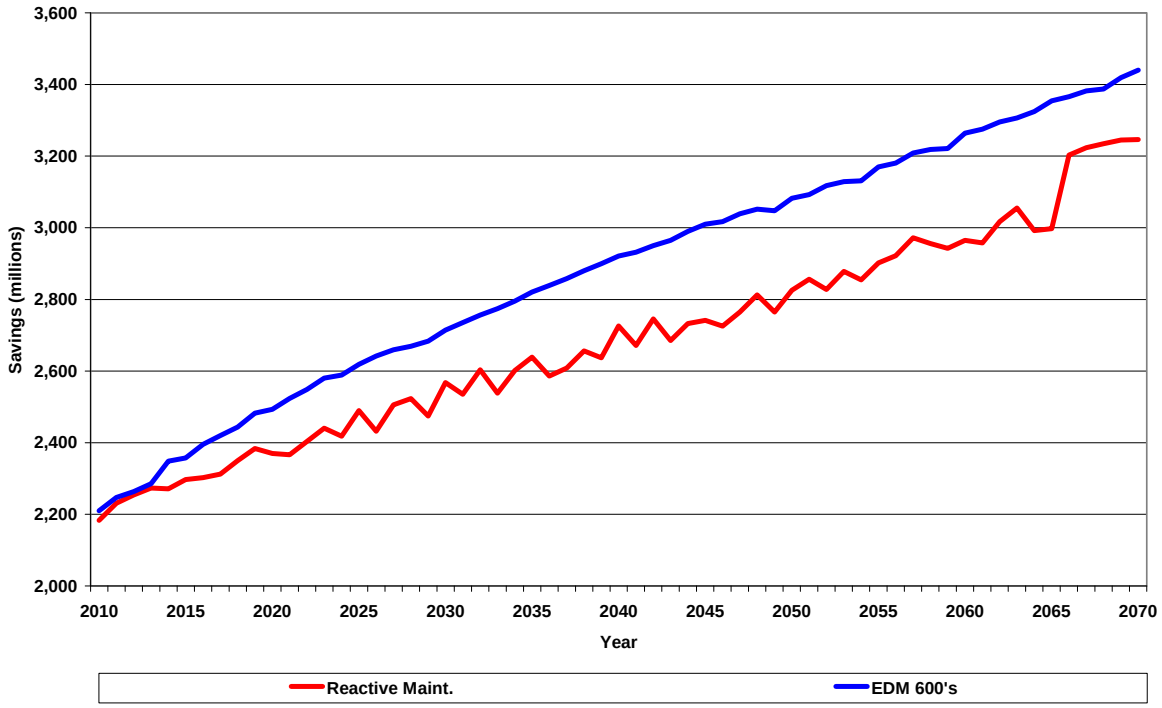


9.4.3.2 System Benefits

System benefits are the equilibrium transportation rate savings net of any transportation losses caused by congestion or delay due to scheduled improvement and unscheduled repair closures. **Figure 9-10** displays system transportation benefits averaged over all 5 traffic forecast scenarios for the reactive maintenance strategy and for the new 600' locks at EDM alternative. The gap represents incremental system benefits to the

more aggressive component replacement and rehabilitation maintenance strategies and the new locks at EDM.

FIGURE 9-10
ORMSS Forecast of New 600' Locks at EDM Transportation Benefits
Average of 5 Forecasts



9.4.3.3 System Statistics

Table 9-14 summarizes average annual system benefits and costs of constructing new 600' locks at EDM on top of rehabilitations, component replacements, and reactive maintenance elsewhere on the mainstem. Scheduled improvement costs for this alternative include Greenup and Myers, justified up-front component replacements, major rehabilitation work, and new 600' locks at EDM shown in **Table 9-7**. Average annual benefits range from $2.40 to $2.69 billion. Average annual costs range from $118.0 to $118.7 million.

Table 9-15 displays incremental benefits and costs of the 600' locks at EDM in conjunction with rehabilitations, component replacements, and reactive maintenance compared to the base-level WOPC (reactive maintenance only). Incremental costs are larger because of the new construction investment. The incremental net benefit of new 600' locks at EDM ranges from $128.8 to $235.0 million.

TABLE 9-14
New 600' Locks EDM*
Average Annual Costs and Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
New 600' Locks EDM Benefits					
Equilibrium Waterway Savings	$2,413.5	$2,631.5	$2,624.5	$2,656.5	$2,717.0
Reduced Savings from Unscheduled Repair	($12.9)	($20.7)	($19.1)	($20.8)	($23.6)
Total System Benefits	**$2,400.6**	**$2,610.7**	**$2,605.4**	**$2,635.7**	**$2,693.4**
New 600' Locks EDM Costs					
Scheduled Lock Maintenance	$15.2	$14.0	$13.9	$14.0	$14.0
Scheduled Dam Maintenance	$6.9	$6.9	$6.9	$6.9	$6.9
Scheduled Lock Improvements*	$43.0	$44.6	$44.7	$44.7	$44.5
Unscheduled Lock Repair	$4.0	$4.3	$4.2	$4.2	$4.2
Normal O&M	$46.7	$46.7	$46.7	$46.7	$46.7
Random Minor	$2.2	$2.2	$2.2	$2.2	$2.2
Total System Costs	**$118.0**	**$118.7**	**$118.6**	**$118.7**	**$118.5**
Net Benefits	**$2,282.6**	**$2,492.0**	**$2,486.8**	**$2,517.0**	**$2,574.9**
BCR	**20.3**	**22.0**	**22.0**	**22.2**	**22.7**

**Scheduled Lock Improvements are 50% cost shared with the Trust Fund and include aAuthorized 600' extension of the auxiliary chamber at Myers in 2010 and rehabilitation of the Greenup main chamber in 2010-11, justified component replacements, justified rehabilitations plus new 600' locks at EDM.*

TABLE 9-15
New 600' Locks EDM
Average Annual Incremental Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Incremental Benefits over Reactive Maintenance	$147.8	$237.0	$253.6	$207.0	$233.3
Incremental Costs over Reactive Maintenance	$19.0	$18.6	$18.6	$18.9	$18.4
Net Incremental Benefit	**$128.8**	**$218.4**	**$235.0**	**$188.1**	**$214.9**

9.4.4 New 1200' Locks at EDM

Under new 1200' locks at EDM, normal O&M is performed, along with scheduled cyclical maintenance for inspection. Scheduled lock improvements include the authorized improvements at Greenup and Myers, justified component replacements, justified rehabilitations, justified lock extensions, plus any justified new 1200' locks at EDM.

Unscheduled lock repair costs are estimated from reliability modeling. Scheduled dam maintenance, based on engineering judgment, is included in project costs.

9.4.4.1 System Costs

ORNIM was run at all projects to estimate expected unscheduled repair/replace costs, component replacement costs, major rehabilitation costs, and the cost of new 1200' locks at EDM under each of the five different traffic forecast scenarios. The unscheduled repair costs, scheduled component replacement costs, major rehabilitation costs, and new 1200' lock construction costs are added to other Federal maintenance costs to develop total system costs. **Figure 9-11** shows forecast for Federal funding needs under the new 1200' locks at EDM alternative. Notice the spike in authorized improvement costs relative to the maintenance alternative cost graphics. Overall, this analysis shows an average annual expenditure of $124.5 million is required to sustain navigation on the Ohio River from 2010-2070 with the new 1200' locks at EDM alternative. New construction at EDM lowers future unscheduled lock repair and scheduled maintenance relative to reactive maintenance.

FIGURE 9-11

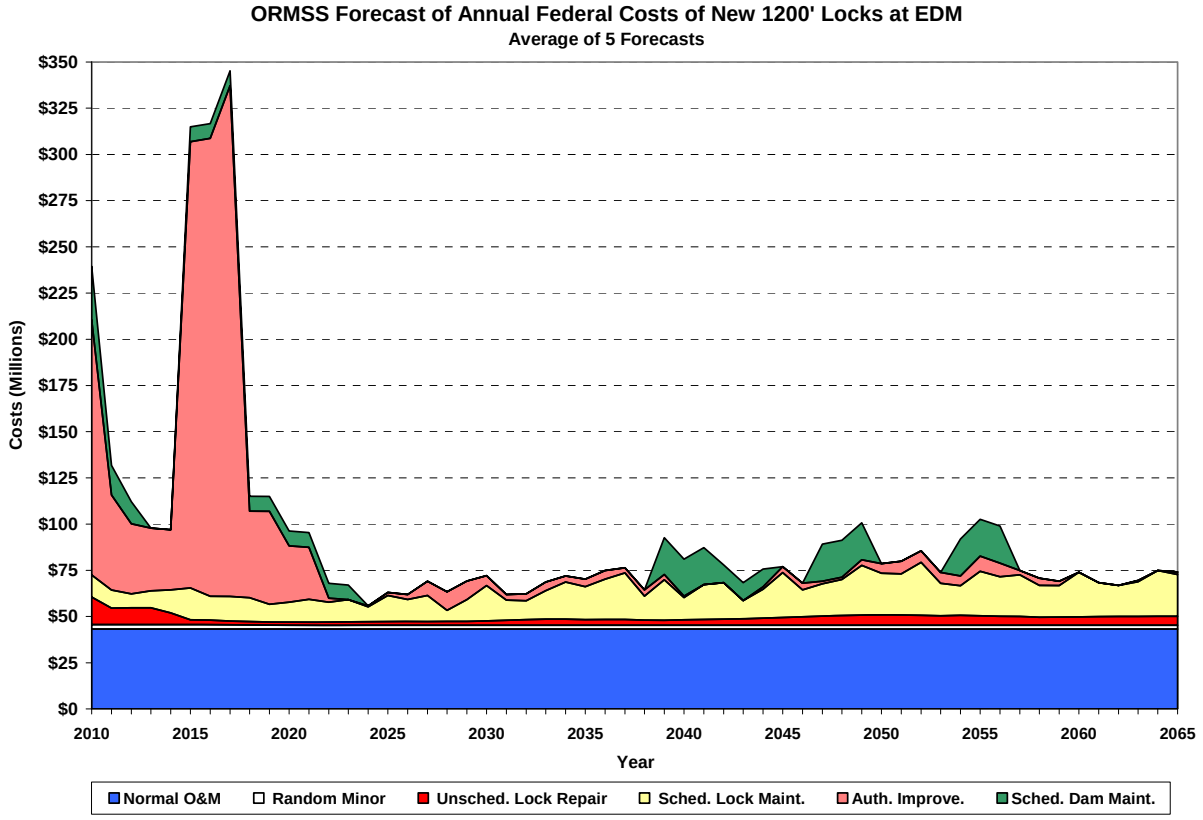
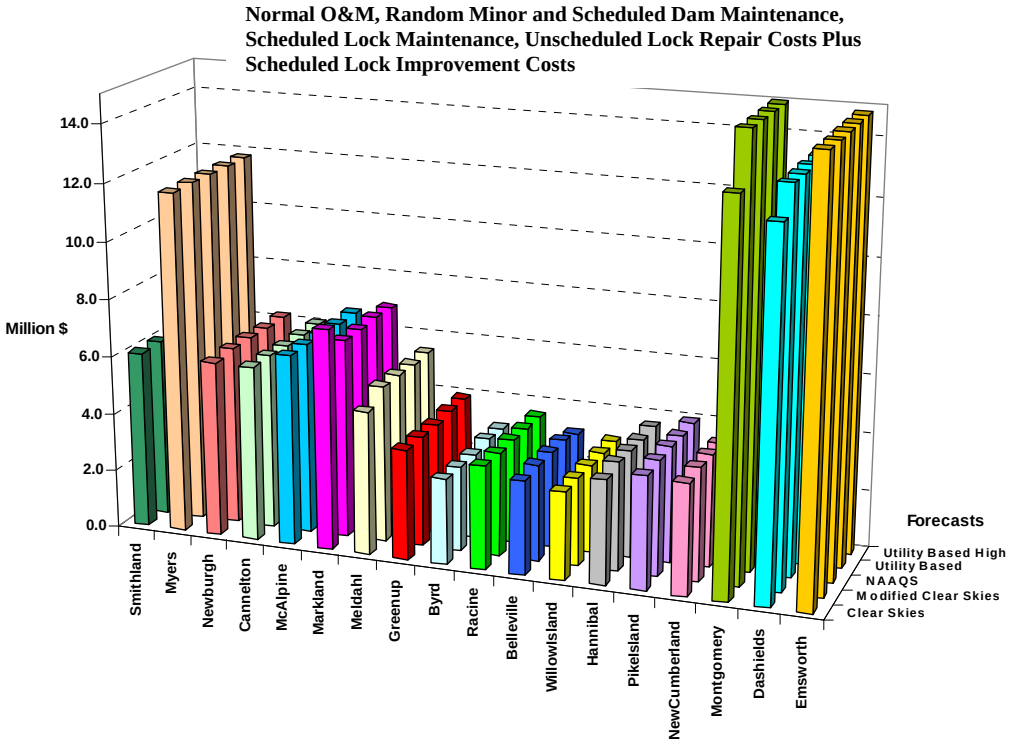


Figure 9-12 displays average annual Federal costs for the new 1200' locks at EDM alternative by project and by traffic forecast. The bar graph combines normal O&M costs, random minor closure costs, scheduled dam costs, scheduled lock maintenance costs, unscheduled lock repair costs, and lock improvement costs. The scheduled lock

improvements are the authorized Myers and Greenup improvements, the economically justified component replacements, recommended rehabilitations, plus the justified new 1200' locks at EDM shown in **Table 9-8**. The unscheduled lock repair costs and the scheduled lock maintenance costs are lower because of the new construction.

Figure 9-12 shows new construction costs at EDM dominating system investment costs, with the authorized Myers auxiliary chamber extension standing out as well and the rehabilitation needs at Markland, Hannibal, Meldahl, Myers, Pike Island, Willow Island, Newburgh, and Cannelton.

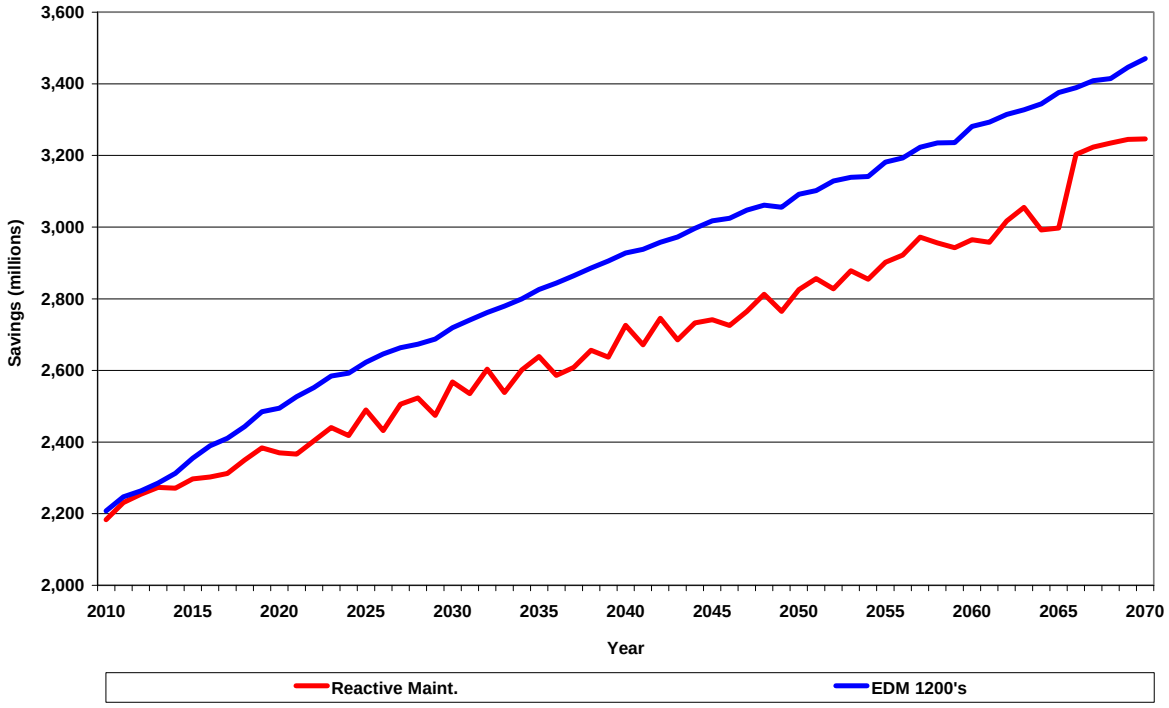
FIGURE 9-12
1200' Locks EDM
Average Annual Project Costs
(2010-2070, 5 1/8%, FY03 $)



9.4.4.2 System Benefits

System benefits are the equilibrium transportation rate savings net of any transportation losses caused by congestion or delay due to scheduled improvement and unscheduled repair closures. **Figure 9-13** displays system transportation benefits averaged over all 5 traffic forecast scenarios for the new 1200' locks at EDM alternative and reactive maintenance. The gap represents incremental system benefits attributable to the more aggressive maintenance and new construction associated with the new 1200' locks at EDM alternative.

FIGURE 9-13
ORMSS Forecast of New 1200' Locks at EDM Transportation Benefits
Average of 5 Forecasts



9.4.4.3 System Statistics

Table 9-16 summarizes average annual system benefits and costs of constructing new 1200' locks at EDM on top of rehabilitations, component replacements and reactive maintenance elsewhere on the mainstem. Scheduled improvement costs for this alternative include Greenup and Myers, justified up-front component replacements, major rehabilitation work, and new 1200' locks at EDM shown in **Table 9-8**. Average annual benefits range from $2.40 to $2.69 billion. Average annual costs range from $121.9 to $125.2 million.

Table 9-17 displays incremental benefits and costs of the 1200' locks at EDM in conjunction with rehabilitations, component replacements and reactive maintenance compared to the base-level WOPC (reactive maintenance only). Incremental costs are positive because of the investment required. The table also shows the incremental net benefits of the new 1200' locks at EDM. Incremental net benefits range from $120.5 to $234.9 million.

TABLE 9-16
New 1200' Locks EDM*
Average Annual Costs and Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
New 1200' Locks EDM Benefits					
Equilibrium Waterway Savings	$2,411.8	$2,633.7	$2,632.4	$2,656.6	$2,717.7
Reduced Savings from Unscheduled Repair	($15.6)	($22.6)	($20.5)	($22.7)	($25.6)
Total System Benefits	**$2,396.2**	**$2,611.1**	**$2,611.8**	**$2,633.9**	**$2,692.1**
New 1200' Locks EDM Costs					
Scheduled Lock Maintenance	$15.2	$13.9	$13.8	$13.9	$14.0
Scheduled Dam Maintenance	$6.9	$6.9	$6.9	$6.9	$6.9
Scheduled Lock Improvements*	$46.4	$50.9	$51.0	$50.9	$50.8
Unscheduled Lock Repair	$4.5	$4.5	$4.4	$4.4	$4.4
Normal O&M	$46.7	$46.7	$46.7	$46.7	$46.7
Random Minor	$2.2	$2.2	$2.2	$2.2	$2.2
Total System Costs	**$121.9**	**$125.2**	**$125.1**	**$125.1**	**$125.0**
Net Benefits	**$2,274.3**	**$2,485.9**	**$2,486.7**	**$2,508.8**	**$2,567.2**
BCR	**19.7**	**20.9**	**20.9**	**21.1**	**21.5**

** Scheduled Lock Improvements are 50% cost shared with the Trust Fund and include aAuthorized 600' extension of the auxiliary chamber at Myers in 2010 and rehabilitation of the Greenup main chamber in 2010-11, justified component replacements, justified rehabilitations plus new 1200' locks at EDM.*

TABLE 9-17
New 1200' Locks EDM
Incremental Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Incremental Benefits over Reactive Maintenance	$143.4	$237.4	$260.0	$205.2	$232.0
Incremental Costs over Reactive Maintenance	$22.9	$25.1	$25.1	$25.4	$24.9
Net Incremental Benefit	**$120.5**	**$212.3**	**$234.9**	**$179.8**	**$207.1**

9.4.5 Optimum Lock Size at EDM

ORNIM was run to optimize between 600' and 1200' chambers at EDM. With new 1200' or 600' locks at EDM, normal O&M is performed, along with scheduled cyclical maintenance for inspection. Scheduled lock improvements include the authorized improvements at Greenup and Myers, justified component replacements and rehabilitations, plus justified new 1200' or 600' locks at EDM. Unscheduled lock repair costs are estimated from reliability modeling. Scheduled dam maintenance, based on engineering judgment, is included in project costs.

Table 9-18 summarizes average annual system benefits and costs of the optimum lock size at EDM. Scheduled improvement costs for this alternative include Greenup and Myers, justified up-front component replacements, major rehabilitation work, and new locks at EDM as shown in **Table 9-9**. Average annual benefits range from $2.407 to $2.69 billion. Average annual costs range from $118.0 to $121.5 million.

TABLE 9-18
Optimum Lock Size at EDM*
Average Annual Costs and Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Optimum Lock Size at EDM Benefits					
Equilibrium Waterway Savings	$2,413.5	$2,631.5	$2,631.0	$2,656.5	$2,717.0
Reduced Savings from Unscheduled Repair	($12.9)	($20.7)	($19.4)	($20.8)	($23.6)
Total System Benefits	**$2,400.6**	**$2,610.7**	**$2,611.7**	**$2,635.7**	**$2,693.4**
Optimum Lock Size at EDM Costs					
Scheduled Lock Maintenance	$15.2	$14.0	$13.9	$14.0	$14.0
Scheduled Dam Maintenance	$6.9	$6.9	$6.9	$6.9	$6.9
Scheduled Lock Improvements*	$43.0	$44.6	$47.6	$44.7	$44.5
Unscheduled Lock Repair	$4.0	$4.3	$4.2	$4.2	$4.2
Normal O&M	$46.7	$46.7	$46.7	$46.7	$46.7
Random Minor	$2.2	$2.2	$2.2	$2.2	$2.2
Total System Costs	**$118.0**	**$118.7**	**$121.5**	**$118.7**	**$118.5**
Net Benefits	**$2,282.6**	**$2,492.0**	**$2,490.1**	**$2,517.0**	**$2,574.9**
BCR	**20.3**	**22.0**	**21.5**	**22.2**	**22.7**

** Scheduled Lock Improvements are 50% cost shared with the Trust Fund and include authorized 600' extension of the auxiliary chamber at Myers in 2010 and rehabilitation of the Greenup main chamber in 2010-11, justified component replacements, justified rehabilitations plus optimum of 1200'- 600' locks at EDM.*

Table 9-19 displays incremental benefits and costs of the optimally-sized locks at EDM in conjunction with rehabilitations, component replacements, and reactive maintenance compared to the base-level WOPC (reactive maintenance only). Incremental costs are positive because of the investment required. The table also shows the incremental net benefits of the new 1200' or 600' locks at EDM. Incremental net benefits range from $128.8 to $238.3 million.

TABLE 9-19
Optimum Lock Size at EDM
Average Annual Incremental Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Incremental Benefits over Reactive Maintenance	$147.8	$237.0	$259.8	$207.0	$233.3
Incremental Costs over Reactive Maintenance	$19.0	$18.6	$21.5	$18.9	$18.4
Net Incremental Benefit	**$128.8**	**$218.4**	**$238.3**	**$188.1**	**$214.9**

9.5 THE WITH-PROJECT CONDITION

The optimum lock size at EDM is a 600' chamber for four of five traffic forecast scenarios. Only in the NAQQS traffic forecast scenario is a 1200' new chamber recommended at Montgomery. Included in the optimized EDM alternative are chamber rehabilitations according to **Table 9-6**. **Table 9-20** shows the average annual benefits net of system costs for the WOPC and each investment alternative. The optimized EDM alternative maximizes net benefits across all traffic forecast scenarios and is thus selected as the with-project condition.

TABLE 9-20
Average Annual Net Benefits
(2010-2070, 5 1/8%, Million FY03 $)

Alternative	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
WOPC	$ 2,154	$ 2,274	$ 2,252	$ 2,329	$ 2,360
Advanced Maintenance	$ 2,265	$ 2,368	$ 2,424	$ 2,435	$ 2,484
Rehabilitaion Maintenance	$ 2,270	$ 2,405	$ 2,435	$ 2,448	$ 2,500
New 600' Locks EDM	$ 2,283	$ 2,492	$ 2,487	$ 2,517	$ 2,575
New 1200' Locks EDM	$ 2,274	$ 2,486	$ 2,487	$ 2,509	$ 2,567
Optimized EDM	**$ 2,283**	**$ 2,492**	**$ 2,490**	**$ 2,517**	**$ 2,575**

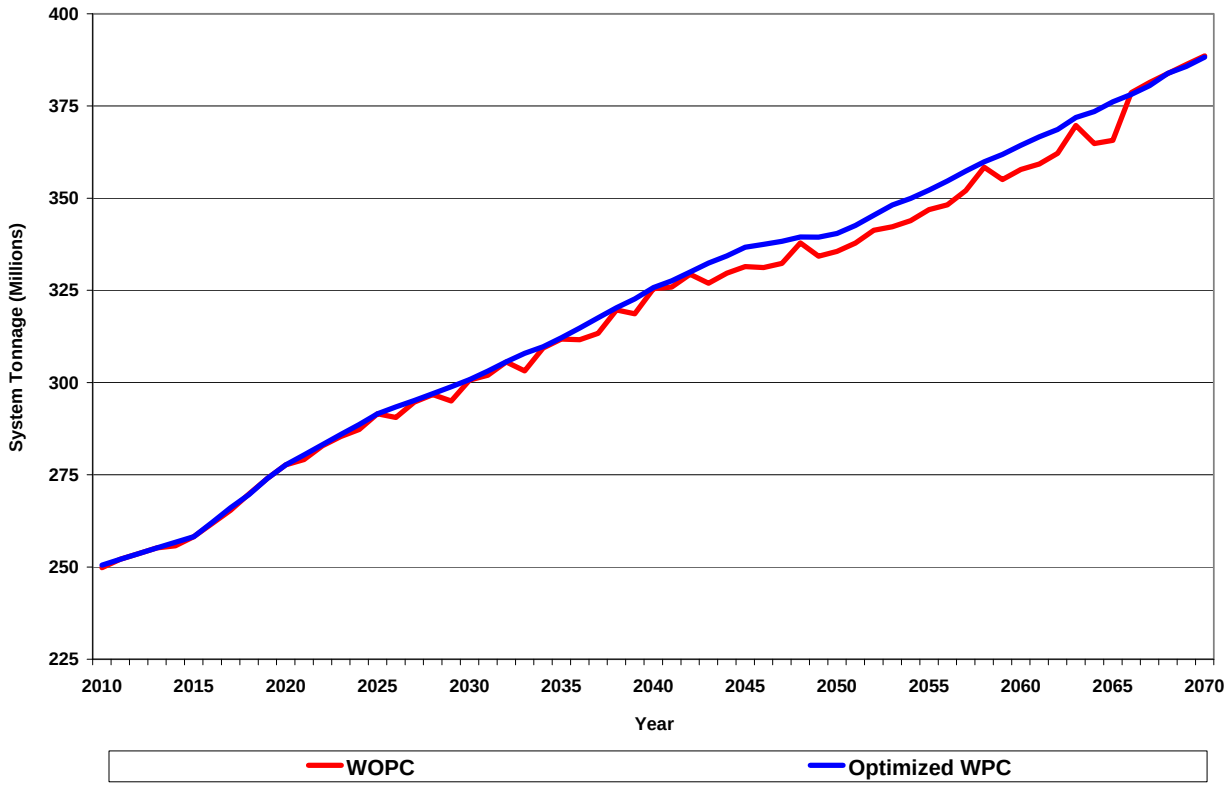
9.5.1 With-Project Condition System Statistics

The with-project condition (WPC) contains a combination of structural improvements and operational and maintenance strategies to optimize Ohio River mainstem navigation for the next 60 years. This sub-section compares WPC system statistics to WOPC system statistics.

9.5.1.1 Equilibrium System Tonnage

Figure 9-14 displays equilibrium system traffic accommodated in the WOPC and WPC. The gap represents incremental diverted traffic between the WOPC and WPC. Over the period of analysis, an average of 2.9 million tons of additional commercial traffic is diverted each year in the WOPC. This additional diverted traffic would challenge overland carrying capacity and increase congestion, traffic accidents, and pollutant emissions.

FIGURE 9-14
Equilibrium System Traffic
(Million Tons)

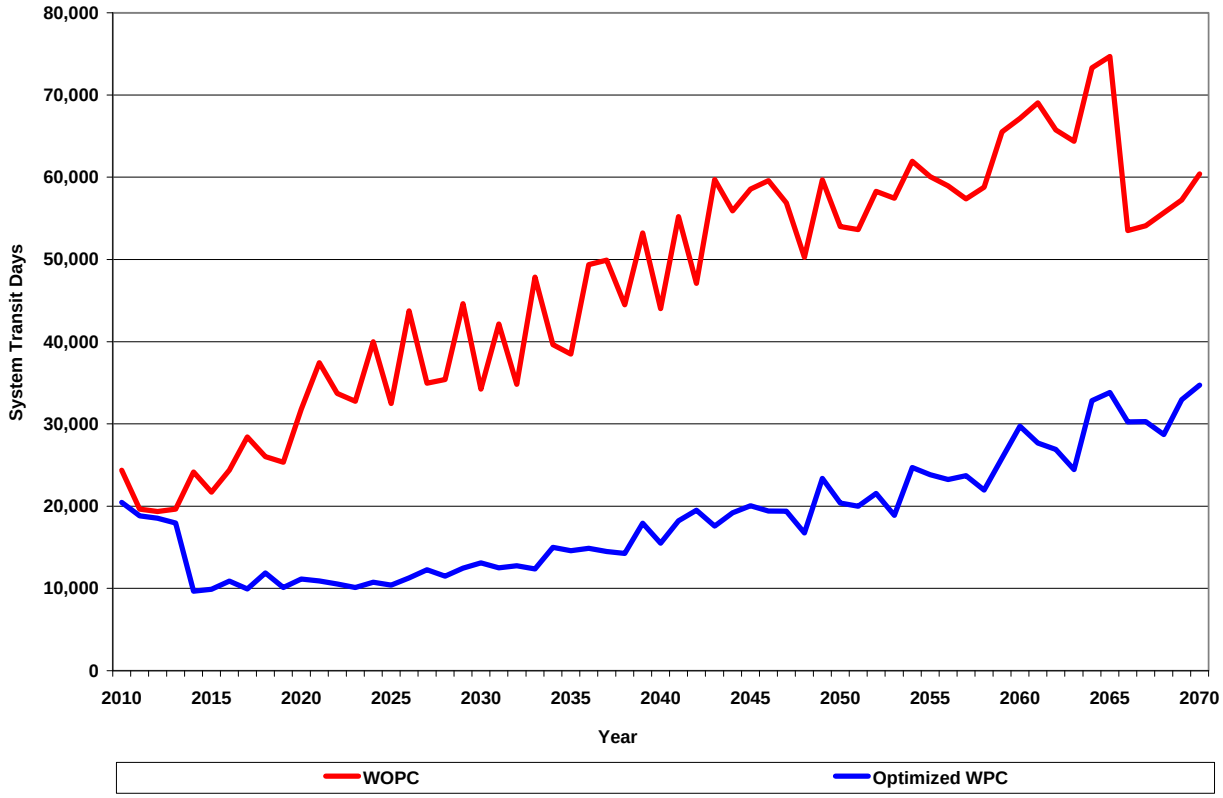


9.5.1.2 System Transit Days

Figure 9-15 compares system equilibrium traffic transit time (averaged over all five traffic scenarios) between the WOPC and WPC alternatives. With-project benefits are derived from a more efficient transportation system because of improved reliability and increased capacity. Capacity increases with fewer closures and the newer, larger chambers. System downtime decreases. The lower-river rehabs and upper-river new lock chambers reduce total system transit days relative to the WOPC.

The drop in transit days from 2013-2014 in the WPC is due to the new locks at EDM and the main chamber rehabs at Markland, Hannibal, Meldahl, Myers and Pike Island all coming on-line. The volatility in transit days seen in the WOPC curve results from the unreliability and more frequent scheduled closures found with the reactive maintenance strategy.

FIGURE 9-15
Transit Days to Accommodate Equilibrium Traffic
(WOPC vs. WPC)

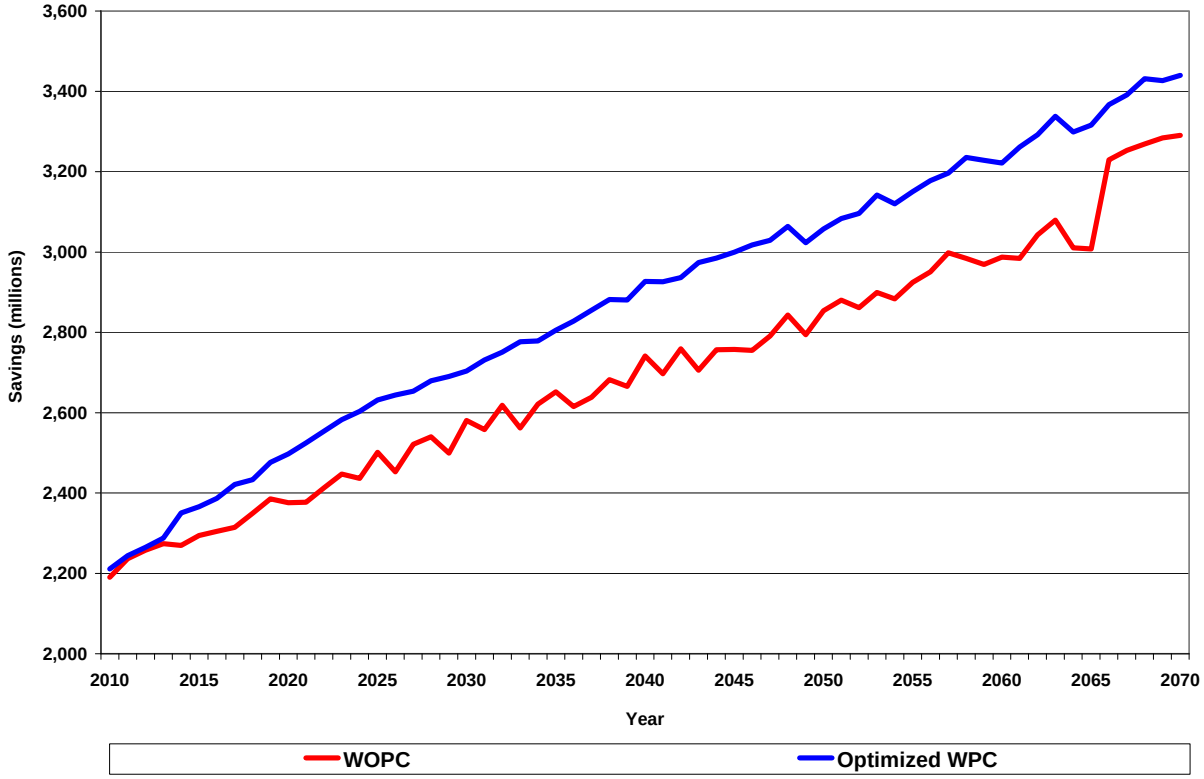


9.5.1.3 System Savings

Figure 9-16 displays system transportation savings averaged over all 5 traffic forecast scenarios for the optimized WPC and WOPC. Equilibrium transportation savings

represent system benefits in accordance with ER 1105-2-100. The gap represents incremental system benefits attributable to the more aggressive maintenance and new construction associated with the optimized WPC.

FIGURE 9-16
Equilibrium System Savings
(Million Dollars)



9.5.1.4 WPC Annual Incremental Benefits and Costs

Table 9-21 displays the average annual incremental benefits and costs, net benefits, and BCRs for the WPC under all 5 traffic forecast scenarios. Annual incremental benefits range from $147.8 to $259.9 million and annual incremental costs range from $18.4 to $21.5 million.

TABLE 9-21
WPC Average Annual Incremental Benefits and Costs
(2010-2070, 5 1/8%, Million FY03 $)

Ohio Mainstem System	Forecast Scenario				
	Clear Skies	Modified Clear Skies	NAAQS Growth	Utility Based	Utility Based High
Incremental Benefits over WOPC	$147.8	$237.0	$259.9	$207.0	$233.3
Incremental Costs over WOPC	$19.0	$18.6	$21.5	$18.9	$18.4
Net Incremental Benefit	**$128.8**	**$218.4**	**$238.4**	**$188.1**	**$214.9**
Incremental Benefit / Incremental Cost Ratio	**7.8**	**12.7**	**12.1**	**11.0**	**12.7**

SECTION 10
NAVIGATION SYSTEM INVESTMENT PLAN

10.1 GENERAL

The formulation of a navigation system investment plan (SIP) for the Ohio River involves a combination of different investment opportunities. Each investment alternative increases the efficiency of the current navigation system and benefits the nation's overall transportation infrastructure.

10.2 FINDINGS TO DATE

Long term navigation needs on the Ohio include new lock chambers at the small, antiquated upper Ohio projects and the need to increase reliability at other Ohio River projects. The new lock needs along with a more aggressive maintenance strategy will, in the long run; reduce the NED costs associated with the operation and maintenance of the heavily vested and economically mature Ohio River mainstem navigation system.

10.3 NEED TO MONITOR

The findings in this draft report are sensitive to variability in both traffic demand forecasts and lock component reliability and make clear the need for continued updates of the necessary data and computer models to monitor future investment needs for the Ohio River. The economically justified investments result from the benefits of directing scarce resources to a more aggressive maintenance strategy at some Ohio River projects and conducting timely new lock construction on the upper Ohio.

10.4 ECONOMICALLY JUSTIFIED INVESTMENTS

The following tables summarize the economically justified project-level investments of the draft ORMSS SIP. Dates shown indicate the optimum timing of the justified investment. RM indicates a reactive maintenance or fix-as-fail strategy is optimum for a specific component. Reactive maintenance and component replacement strategies are an integral part of the Ohio River mainstem navigation system investment plan. The last table in this section summarizes investment priority needs.

Table 10-1 shows a new 600’ x 110’ lock chamber to replace the existing 360’ x 56’ auxiliary chamber at Emsworth is economically justified immediately in the study period (2010). The table also shows main chamber component replacements to be traffic forecast sensitive. The draft ORMSS SIP recommends immediate feasibility level analysis for auxiliary lock chamber replacement at Emsworth and continued monitoring of traffic forecasts and main chamber component reliability to optimize future investments.

TABLE 10-1
Emsworth Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber *					
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	**2038**	**2016**	RM	**2050**
Land Wall	**2012**	RM	**2014**	RM	RM
Middle Wall	**2011**	RM	RM	RM	RM
Upper Guide Wall	RM	RM	RM	RM	RM
Lower Guide Wall	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	**2010**	**2010**	**2010**	**2010**	**2010**
Electrical Systems	New	New	New	New	New
	110 x 600	110 x 600	110 x 600	110 x 600	110 x 600

* Main Chamber is only used when the new 600' Aux is closed for maintenance. This is the reason for leaving the chamber in the reactive maintenance mode. If repairs are needed they will be made while the new lock is open.

Table 10-2 shows a new 600’ x 110’ lock chamber to replace the existing 360’ x 56’ auxiliary chamber at Dashields is economically justified immediately in the study period (2010). The table also shows main chamber component replacements to be traffic forecast sensitive. The draft ORMSS SIP recommends immediate feasibility level analysis for auxiliary lock chamber replacement at Dashields and continued monitoring of traffic forecasts and main chamber component reliability to optimize future investments.

TABLE 10-2
Dashields Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber *					
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	**2035**	RM	RM
Land Wall	**2013**	RM	**2010**	RM	RM
Middle Wall	RM	RM	RM	RM	RM
Upper Guide Wall	RM	RM	RM	RM	RM
Lower Guide Wall	RM	RM	RM	RM	RM
Auxiliary Chamber					
Electrical Systems	**2011**	**2010**	**2010**	**2010**	**2010**
Upper Guard Wall	New	New	New	New	New
Lower Guard Wall	110 x 600	110 x 600	110 x 600	110 x 600	110 x 600

Table 10-3 shows a new 600’ x 110’ lock chamber to replace the existing 360’ x 56’ auxiliary chamber at Montgomery is economically justified immediately in the study period (2010) in four of the five forecast scenarios. In the NAAQS growth forecast scenario, a 1200’ x 110’ replacement of the auxiliary chamber is optimum. The table also shows main chamber component replacements to be traffic forecast sensitive. The draft ORMSS SIP recommends immediate feasibility level analysis for auxiliary lock chamber replacement at Montgomery and continued monitoring of traffic forecasts and main chamber component reliability to optimize future investments.

TABLE 10-3
Montgomery Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber *					
Miter Gate Machinery (Upper and Lower)	RM	RM	**2015**	RM	RM
Hydraulic Systems	RM	RM	**2015**	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	**2017**	**2015**	**2051**	**2035**
Land Wall	**2015**	RM	**2011**	RM	RM
Middle Wall	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	**2010**	**2010**	**2010**	**2010**	**2010**
Electrical Systems	New	New	New	New	New
River Wall	110 x 600	110 x 600	110 x 1200	110 x 600	110 x 600

* Main Chamber is only used when the new 600' Aux is closed for maintenance. This is the reason for leaving the chamber in the reactive maintenance mode. If repairs are needed they will be made while the new lock is open.

Table 10-4 shows the need to replace auxiliary miter gates at New Cumberland ranges from 2033 to 2039 depending on the traffic forecast scenario. Since the cost of replacing both sets of miter gates exceeds the $10.6 million threshold when considering fabrication, delivery, assembly, painting, and installation, it is listed as a major rehab. The table also shows economically justified proactive component replacement of the electrical systems in two forecast scenarios. Due to the longer term need of auxiliary gate replacement at New Cumberland, the draft ORMSS SIP recommends continued monitoring of traffic forecasts and component reliability to optimize future investments.

TABLE 10-4
New Cumberland Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	**2015**	**2015**	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gate Upper	**2037**	**2034**	**2034**	**2037**	**2037**
Miter Gate Lower	**2038**	**2035**	**2034**	**2038**	**2038**
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

Table 10-5 suggests the need at Pike Island to rehab the main chamber miter gates and electrical systems in the 2015-2016 timeframe. Other component replacements show traffic forecast sensitivity. The draft ORMSS SIP recommends a near-term major rehabilitation study of the main chamber miter gates and electrical systems at Pike Island and continued monitoring of traffic forecasts and other component reliability to optimize future investments.

TABLE 10-5
Pike Island Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates Upper	**2016** Rehab	**2015** Rehab	**2015** Rehab	**2016** Rehab	**2015** Rehab
Miter Gates Lower					
Electrical Systems					
Miter Gate Machinery (Upper and Lower)	RM	RM	**2014**	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gate Upper	RM	**2052**	**2052**	**2057**	**2056**
Miter Gate Lower	**2058**	**2053**	**2053**	**2058**	**2056**
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

Table 10-6 shows the need to rehab the main chamber miter gates and miter gate machinery at Hannibal ranges from 2011 to 2012 depending on the traffic forecast scenario. The table also shows economically justified proactive auxiliary miter gate replacement way out in 2065 in one forecast scenario. Due to the immediate need of main chamber rehabilitation at Hannibal, the draft ORMSS SIP recommends immediate action on a major rehabilitation study and continued monitoring of traffic forecasts and component reliability to optimize future investments.

TABLE 10-6
Hannibal Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2012**	**2011**	**2011**	**2012**	**2011**
Miter Gate Machinery (Upper and Lower)	Rehab	Rehab	Rehab	Rehab	Rehab
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gate (Upper and Lower)	RM	**2065**	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

Table 10-7 shows the need to rehab the main chamber miter gates and electrical systems at Willow Island ranges from 2027 to 2028 depending on the traffic forecast. Such timing suggests a more intermediate need. The finding at Willow Island leads the draft ORMSS SIP to recommend continued monitoring of traffic forecasts and component reliability at Willow Island to optimize future investments.

TABLE 10-7
Willow Island Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2027**	**2027**	**2027**	**2027**	**2028**
Electrical Systems	Rehab	Rehab	Rehab	Rehab	Rehab
Hydraulic Systems	RM	RM	RM	RM	RM
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

Table 10-8 shows the need to rehab the main chamber miter gates, miter gate machinery, and electrical systems at Belleville in four of five traffic forecasts. The findings at Belleville lead to a draft ORMSS SIP recommendation of preparation for main chamber major rehabilitation project to begin study within the next 7 years and continued monitoring of traffic forecasts and component reliability to optimize future investments.

TABLE 10-8
Belleville Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2032**	**2017** Rehab	**2017** Rehab	**2017** Rehab	**2028** Rehab
Miter Gate Machinery (Upper and Lower)	RM				
Electrical Systems	**2010**				
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

Table 10-9 shows the need at Racine to rehab the main chamber miter gates, miter gate machinery, and electrical systems in 2019 -2020. The relatively robust finding at Racine leads to a draft ORMSS SIP recommendation of continued monitoring of traffic forecasts and component reliabilities at Racine, in the near term with the intent of starting a major rehabilitation analysis in the medium term to optimize investments.

TABLE 10-9
Racine Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2020** Rehab	**2019** Rehab	**2020** Rehab	**2019** Rehab	**2019** Rehab
Miter Gate Machinery (Upper and Lower)					
Electrical Systems					
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	**2050**	**2054**	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

Table 10-10 shows the need to rehab the main chamber miter gates and electrical systems at Byrd ranges from 2030 to 2045 depending on the traffic forecast scenario. Such a range suggests more uncertainty and because of the less robust finding at Byrd Locks the draft ORMSS SIP recommends continued monitoring of traffic forecasts and component reliability at Byrd to optimize future investments.

TABLE 10-10
Byrd Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2055**	**2044**	**2045**	**2030**	**2033**
Electrical Systems	**2024**	Rehab	Rehab	Rehab	Rehab
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Auxiliary Chamber					
Electrical Systems	RM	RM	RM	RM	RM

Table 10-11 shows the need at Meldahl to rehab the main chamber miter gates, miter gate machinery, and electrical systems ranges from 2010 to 2013 depending on the traffic forecast scenario. Also, main chamber hydraulic systems shows economic justification in two traffic scenarios. The auxiliary chamber gates show economic justification for proactive replacement in all traffic scenarios. Since the cost of replacing both sets of miter gates would exceed $10.6 million when fabrication, delivery, assembly, painting, and installation is considered, this also qualifies as a major rehab. Given the relatively robust findings at Meldahl, the draft ORMSS SIP recommends starting both a main chamber and auxiliary major rehabilitation analysis at Meldahl while continuing to monitor traffic forecasts and component reliability of the main hydraulic systems order to optimize future investments.

TABLE 10-11
Meldahl Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2013** Rehab	**2010** Rehab	**2010** Rehab	**2010** Rehab	**2010** Rehab
Miter Gate Machinery (Upper and Lower)					
Electrical Systems					
Hydraulic Systems	RM	RM	RM	**2020**	**2015**
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gates (Upper and Lower)	**2010**	**2010**	**2010**	**2012**	**2010**
Hydraulic Systems	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	**2058**

Table 10-12 shows immediate need at Markland to rehab the main chamber miter gates and culvert valves in three of the five traffic forecast scenarios. The table also shows a long term need (2052) to do similar rehab work on the auxiliary chamber in one forecast scenario. Markland findings also show justification for proactive component replacement to be traffic forecast sensitive. Given the relatively robust findings at Markland, the draft ORMSS SIP recommends an immediate main chamber major rehabilitation analysis at Markland that includes the economically justified main chamber component replacements while continuing to monitor traffic forecasts and component reliability of the auxiliary lock components to optimize future investments.

TABLE 10-12
Markland Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Base High
Main Chamber					
Miter Gates (Upper and Lower)	**2010**	**2010**	**2010**	**2010**	**2010**
Culvert Valves	**2013**	**2013**	Rehab	Rehab	Rehab
Miter Gate Machinery (Upper and Lower)	RM	**2023**	**2024**	**2015**	**2015**
Electrical Systems	**2016**	**2016**	**2013**	**2013**	**2013**
Hydraulic Systems	**2036**	**2022**	**2020**	**2016**	**2016**
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gates (Upper and Lower)	RM	RM	RM	RM	**2052**
Culvert Valves	RM	RM	RM	**2045**	Rehab
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

Table 10-13 shows economic justification at McAlpine for proactive replacement of main chamber culvert valves in 2010 and hydraulic systems in 2028-2030. Given this finding, the draft ORMSS SIP recommends replacement of the main chamber culvert valves at McAlpine for the near term and continued monitoring of traffic forecasts and main chamber component reliability to optimize future investments for all other components.

TABLE 10-13
McAlpine Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Hydraulic Systems	**2030**	**2030**	**2030**	**2030**	**2028**
Culvert Valves	**2010**	**2010**	**2010**	**2010**	**2010**
Culvert Valve Machinery	RM	RM	RM	RM	RM

Table 10-14 shows the need at Cannelton to rehab the main chamber miter gates, miter gate machinery, electrical and hydraulic systems, and culvert valves ranges from 2016 to 2017. Based on this finding at Cannelton, the draft ORMSS SIP recommends continued monitoring of traffic forecasts and component reliability of the main chamber until such time a main chamber major rehabilitation analysis is warranted.

TABLE 10-14
Cannelton Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2017** Rehab	**2017** Rehab	**2016** Rehab	**2017** Rehab	**2017** Rehab
Miter Gate Machinery (Upper and Lower)					
Electrical Systems					
Hydraulic Systems					
Culvert Valves					
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

Table 10-15 shows the need at Newburgh to rehab the main chamber miter gates, miter gate machinery, electrical and hydraulic systems, and culvert valves ranges from 2016 to 2025 depending on the traffic forecast scenario. Based on this finding at Newburgh, the draft ORMSS SIP recommends continued monitoring of traffic forecasts and component reliability of the main chamber until such time a main chamber major rehabilitation analysis is warranted.

TABLE 10-15
Newburgh Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2025** Rehab	**2016** Rehab	**2016** Rehab	**2016** Rehab	**2016** Rehab
Miter Gate Machinery (Upper and Lower)					
Electrical Systems					
Hydraulic Systems					
Culvert Valves					
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

Table 10-16 shows the need at Myers to rehab the main chamber miter gates, miter gate machinery, electrical and hydraulic systems, culvert valves and culvert valve machinery ranges from 2011 to 2014 depending on the traffic forecast scenario. Based on this finding at Myers, the draft ORMSS SIP recommends near term preparation of a main chamber major rehab analysis while continuing to monitor traffic forecasts and component reliability of the main chamber to ensure optimal investment timing.

TABLE 10-16
Myers Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	**2014** Rehab	**2011** Rehab	**2013** Rehab	**2013** Rehab	**2013** Rehab
Miter Gate Machinery (Upper and Lower)					
Electrical Systems					
Culvert Valves					
Culvert Valve Machinery					
Hydraulic Systems					

Table 10-17 suggests the need to replace or totally rehabilitate the culvert valves of both chambers at Smithland in the near term. The table also suggests a long term need to replace miter gates. The finding at Smithland means the draft ORMSS SIP will recommend continued monitoring of component reliability in the short run at Smithland until such time the need for a component replacement becomes clearer.

TABLE 10-17
Smithland Locks Investment Plan

Chamber / Component	Clear Skies	Modified Clear Skies	NAAQS	Utility Based	Utility Based High
Main Chamber					
Miter Gates (Upper and Lower)	RM	**2054**	**2052**	**2054**	**2048**
Culvert Valves	**2013**	**2013**	**2013**	**2013**	**2013**
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valve Machinery	RM	RM	RM	RM	RM
Auxiliary Chamber					
Miter Gates (Upper and Lower)	**2055**	**2050**	**2049**	**2050**	**2051**
Miter Gate Machinery (Upper and Lower)	RM	RM	RM	RM	RM
Hydraulic Systems	RM	RM	RM	RM	RM
Culvert Valves	**2010**	**2010**	**2010**	**2010**	**2010**
Culvert Valve Machinery	RM	RM	RM	RM	RM
Electrical Systems	RM	RM	RM	RM	RM

10.5 Summary of Priority Investment Needs

Table 10-18 summarizes priority investments necessary to economically and efficiently sustain Ohio River commercial navigation in the long run. The needs are defined as near-term, medium-term, and long-term. Follow-on feasibility level analysis will be required to authorize any investment decision.

TABLE 10-18
Priority Investment Needs

Investment	Year of Economic Justification
Near-Term (2010-2015)	
Emsworth New 600' Lock	2010
Dashields New 600' Lock	2010
Montgomery New 600' Lock	2010
Montgomery New 1200' Lock	2010
Markland Main Rehab	2010
Meldahl Main Rehab	2010-2013
Hannibal Main Rehab	2011-2012
Myers Main Rehab	2011-2014
Pike Island Main Rehab	2015-2016
Med-Term (2016-2025)	
Newburgh Main Rehab	2016-2025
Cannelton Main Rehab	2016-2017
Belleville Main Rehab	2017-2028
Racine Main Rehab	2019-2020
Long-Term (2026-2052)	
Willow Island Main Rehab	2027-2028
Byrd Main Rehab	2030-2045
Markland Aux Rehab	2052

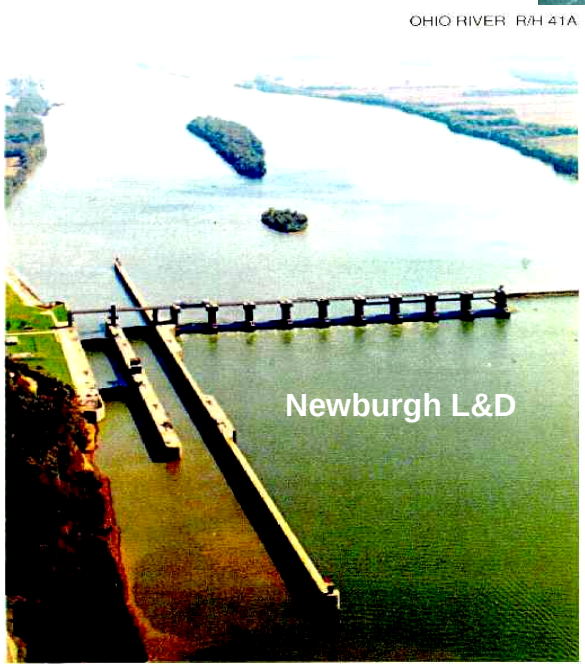
US Army Corps
of Engineers
Great Lakes and Ohio River Division
LOUISVILLE DISTRICT / HUNTINGTON DISTRICT / PITTSBURGH DISTRICT

Ohio River Mainstem Systems Study (ORMSS)

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Environmental Appendix: Volume 1 of 2
Cumulative Effects Assessment Report



July 2011

DEPARTMENT OF THE ARMY
U.S. ARMY ENGINEER DISTRICT, LOUISVILLE
CORPS OF ENGINEERS
P.O. BOX 59
LOUISVILLE, KENTUCKY 40201-0059

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Environmental Appendix: Cumulative Effects Assessment Report

July 2011

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Chapter 1

INTRODUCTION TO THE ORMSS CEA

1.1 CHAPTER OVERVIEW

The U. S. Army Corps of Engineers (Corps) is conducting a cumulative effects assessment (CEA) study as one part of an integrated System Investment Plan/Programmatic Environmental Impact Statement (SIP/PEIS) for long-term navigation needs and ecosystem sustainability needs on the mainstem of the Ohio River. This chapter provides an introduction to the CEA study. The section includes a brief description of the overall Ohio River study, the context for the environmental studies, the objectives and activities associated with the CEA study, and the contents of this report.

1.2 OHIO RIVER MAINSTEM SYSTEM STUDY

Waterway navigation facilitated by man-made structures has existed on the mainstem of the Ohio River for over 125 years. The 981-mile mainstem stretches from Pittsburgh, Pennsylvania, to Cairo, Illinois. In Pittsburgh, the Ohio River is formed at the confluence of the Allegheny and Monongahela Rivers; and at Cairo, the Ohio River flows into the Mississippi River. Mined natural resources such as coal and manufactured products such as petrochemicals are moved up and down the mainstem via towboats and various barge configurations. As such, waterway navigation has been and continues to be a vital link in the economic structure of the six contiguous states along the river (Pennsylvania, Ohio, West Virginia, Indiana, Kentucky, and Illinois). Waterway navigation on the Mississippi and on eight navigable tributary rivers expand the importance well beyond the six states. Further, such navigation is expected to remain a central part of commerce and economic growth in the region.

The design features, sizes, and locations of locks and dams on the Ohio River have evolved since the “wicket dams era” of a century ago. The Corps has been the lead federal agency since inception of the navigation system. At the current time, there are 19 “high-lift” locks and dams either on the river, under construction, or authorized. Each location is typically characterized by the presence of a main lock and a smaller auxiliary lock that is used during maintenance or rehabilitation periods for the main lock. Both locks may be used for recreational boats.

Several economic, engineering, and environmental issues are addressed in the current study, referred to as the Ohio River Mainstem Systems Study (ORMSS), to develop an investment plan for the navigation system to the year 2070. Economic issues are related to a range of projections of navigation traffic increases, and cost inefficiencies that occur due to barge queuing when main locks are subjected to maintenance or repair. Engineering issues relate to designs for increased sizes of auxiliary locks at several locations, and the development of risk functions that can be used to proactively schedule major repairs at existing facilities.

The SIP/PEIS includes several unique features that represent a more realistic approach for navigation system planning and management. First, it is widely recognized that "single number" projections of navigation traffic over several decades are problematic and fraught with uncertainties. The SIP/PEIS being developed includes five traffic forecasts through 2070. Further, the Ohio River Navigation Investment Model (ORNIM) is being used to develop numerous analyses of investment strategies based on combinations of assumptions related to navigation traffic levels, scheduling of routine lock and dam maintenance activities, and needs for major lock repairs or rehabilitation based on engineering risk analyses. As a result of anticipated uncertainties regarding navigation system needs and environmental consequences, it is recognized that the SIP/PEIS will require adjustment on a periodic basis. Such adjustments will be made in updated traffic projections, scheduling of investments, or maintenance priorities and will be documented through study reports and NEPA documents when appropriate for the changes under consideration. Finally, these features of the SIP/PEIS incorporate the concepts of adaptive management; i.e., monitor, evaluate, and adapt operational measures and practices.

1.3 CONTEXT FOR ENVIRONMENTAL STUDIES

Environmental issues have been addressed in a CEA study of the entire mainstem navigation system. This strategic-level impact study provides a holistic review of the past, current, and anticipated environmental impacts from multiple actions and programs of the Corps of Engineers; other federal, state, local governmental agencies; and private industries and agricultural activities. The CEA forms the technical basis for the Programmatic Environmental Impact Statement (PEIS) that has been prepared for the SIP/PEIS. The SIP/PEIS is an integrated report in that information required for an environmental impact statement pursuant to the National Environmental Policy Act (NEPA) are incorporated throughout the document rather than as a separate report.

Cumulative effects (CEs) are an emerging issue, in general, in impact studies; the definition that follows is in the Council on Environmental Quality (CEQ) National Environmental Policy Act (NEPA) Regulations (Council on Environmental Quality, 1978):

> "Cumulative impact" is the impact on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

This CEA study is in consonance with the above definition and with the policy of the U. S. Army Corps of Engineers relative to addressing the cumulative effects of water resources plans such as the SIP/PEIS. This policy is (EP 1165-2-1, U. S. Army Corps of Engineers, 1999):

> The cumulative effects of the plan and other similar activities should be analyzed. Each proposed water resource development activity is but a piece of a large-scale program. The combined beneficial and adverse economic, environmental and social impacts of individual projects, each of which may be relatively minor, can have a significant regional or national impact. At each level of the evaluation and review process it is necessary to assess the

> cumulative beneficial and adverse effects of individual project impacts. Significant effects should guide the decisions.

In addition to the CEA, two other issues are related to the context of environmental studies for the SIP/PEIS. The first involves the use of Environmental Sustainability (ES) as an "ultimate test" for determining the significance of cumulative effects. ES is identified in the Corps' recently published Environmental Operating Principles (EOPs). The second is associated with the usage of programmatic-level impact studies where water resources plans are being addressed. Both of these context issues are highlighted in this section.

1.3.1 Environmental Operating Principles

On March 26, 2002, General Robert Flowers, then Chief of Engineers of the Corps, announced seven EOPs for Corps planning and decision-making. Although all seven of the principles are applicable to the ORMSS, three are especially pertinent and have been incorporated in the CEA; they are (U. S. Army Corps of Engineers, 2002):

- Principle 1 -- Strive to achieve environmental sustainability. An environment maintained in a healthy, diverse, and sustainable condition is necessary to support life.
- Principle 2 -- Recognize the interdependence of life and the physical environment. Proactively consider environmental consequences of Corps programs and act accordingly in all appropriate circumstances.
- Principle 5 -- Seek ways and means to assess and mitigate cumulative impacts to the environment; bring systems approaches to the full life cycle of our processes and work.

The foundation principle is number 1, which relates to sustainable development and environmental sustainability. An early definition of sustainable development was that it is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). Stated differently, sustainable development involves the search for a path of economic progress that does not impair the welfare nor destroy the environmental and natural resources of future generations; thus intergenerational equity is a fundamental premise (Pearce, Markandya, and Barbier, 1989).

The above-three principles are addressed in a recent Engineering Circular (EC 1105-2-404) related to planning Civil Works projects consistent with ES considerations (U. S. Army Corps of Engineers, 2003). ES is defined as "a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations" (U. S. Army Corps of Engineers, 2002). While the EC indicates that it is applicable to feasibility and general reevaluation studies initiated after May 1, 2003, the concepts of ES were already being incorporated into the ORMSS. One relevant quotation from EC 1105-2-404 (U. S. Army Corps of Engineers, 2003) is:

> In accord with the environmental sustainability definition, "the Corps goal is to strive to achieve the appropriate balance between the economic and environmental benefits provided by a project. Currently, Corps projects can be developed to

achieve this goal through the formulation of plans that produce both national economic development benefits and national ecosystem restoration benefits. Where practical and supportable, the plan formulation should incorporate the principles of avoiding or minimizing significant adverse impacts within the guiding principle of limiting damage to the natural ecosystem. Through the incorporation of these principles, plans will likely avoid or minimize damages and be less intrusive. Thus, avoidance of disrupted natural processes is preferable, where practical, to creating new resources."

It is important to note that the EOPs, first announced by the Chief of Engineers in 2002, were incorporated in an Engineering Circular in May 2003, (EC 1105-2-404), and in Engineer Regulation (ER) 200-1-5 later in 2003 (U. S. Army Corps of Engineers, October, 2003).

1.3.2 Programmatic Environmental Impact Statements

Project-level environmental impact studies have been conducted for over 30 years in many countries. Since approximately 1990, there has been increasing attention directed toward strategic-level environmental impact studies in multiple countries. Strategic-level impact studies conducted in the United States are documented via the preparation of PEISs. The PEISs prepared in the United States are focused on environmental consequences of plans, programs, or policies of various governmental agencies. As noted above, a PEIS has been prepared for the SIP for the mainstem of the Ohio River. Further, in several other locations, the Corps has completed or is also involved in the preparation of PEISs for water resources plans or programs.

Strategic-level impact studies are typically characterized by larger geographical areas and longer future time frames than used at the specific project-level. Further, due to the paucity of consistent baseline data across the larger geographical area, and the possible complete absence of impact-related data on future projects and activities in the study area, the locational and quantitative specificity of impact predictions tends to be less than for project-level studies. However, despite these differences, strategic impact studies and associated PEISs provide the opportunity to more appropriately address cumulative effects from multiple actions and activities across space and time; to delineate geographical areas, habitat types, and plant and animal species which should be afforded more protection; and to require certain impact mitigation strategies and programs for enhancing ES. Further, the planning and implementation of adaptive management programs can be integrated into PEISs. Beyond these potential benefits, the opportunity exists for introducing environmental issues and concerns at the decision level which is often driven only by traditional engineering and economic analyses, and related non-environmental policy choices.

More specifically, the PEIS for the SIP being developed via the ORMSS addresses the direct, indirect, and cumulative effects of the plan itself. The SIP/PEIS is an official plan prepared by the Corps of Engineers which will guide or prescribe alternative means to maintain an efficient, economically viable, and environmentally compatible navigation system, and which will provide information upon which future Corps actions will be based. However, it should be noted that future environmental assessments (EAs) or EISs will be prepared, as appropriate, on specific actions included within the SIP/PEIS. Such future documentation is based upon the concept of tiering. Tiering is described in Section

1502.20 of the CEQ NEPA Regulations as follows (Council on Environmental Quality, 1978):

> Agencies are encouraged to tier their environmental impact statements to eliminate repetitive discussions of the same issues and to focus on the actual issues ripe for decision at each level of environmental review. Whenever a broad environmental impact statement has been prepared (such as a program or policy statement) and a subsequent statement or environmental assessment is then prepared on an action included within the entire program or policy (such as a site specific action) the subsequent statement or environmental assessment need only summarize the issues discussed in the broader statement and incorporate discussions from the broader statement by reference and shall concentrate on the issues specific to the subsequent action. The subsequent document shall state where the earlier document is available. Tiering may also be appropriate for different stages of actions.

Further, and as implied above, it will be necessary to periodically review the SIP/PEIS and PEIS in order to maintain current navigation and environmental information that can inform specific project-level decision-making. Such reviews can be aided by monitoring and policy information generated by an on-going adaptive management program. Depending upon the types of modifications to the SIP/PEIS, it may be necessary to issue one or more Supplemental PEISs at future dates.

1.4 GOALS AND ACTIVITIES OF THIS STUDY

The goal of the CEA is to assess the full direct, indirect, and contributed impacts of further modernization of the Ohio River mainstem navigation system on resources, ecosystems, and human communities along the mainstem. The analysis addresses the accumulation of meaningful impacts to environmental resources from maintenance and modernization of the navigation system in concert with impacts from other past, present, and reasonably foreseeable future actions (RFFAs) by the Corps of Engineers and others.

Multiple activities were associated with conducting this CEA study. For example, an eight-person group consisting of four persons from the Corps and four persons from an associated consulting firm (Woolpert, Inc.), periodically met to plan, discuss, review, and synthesize information. This group also periodically met with a 40-person Interagency Working Group (IWG) to discuss status reports and to seek input and participation in various study features. Further, 12 public scoping meetings were held to seek input on the scope and issues of concern related to the CEA.

Considerable effort was expended in the identification and procurement of pertinent information and reports. Identification was achieved through web-based searches of topics and agency reports. Traditional scientific searches of books and journals were also made. Numerous telephone and email communications were used to identify pertinent agency reports and data related to the Ohio River mainstem. As these various documents were procured, they were categorized by the topics to be addressed in this study. The documents were then reviewed for specific relevance and the pertinent information was extracted for subsequent use in this CEA.

A unique feature of this CEA was specific data gathering via field surveys (e.g., bathymetry and bottom substrate characteristics for use in a navigation traffic-fish effects model named NAVPAT). Further, specific research efforts were conducted for mussel resources, wintering habitat requirements for fishes, and upstream and downstream migration of fish species through existing locks and dams. The results of these surveys and research efforts have been incorporated herein.

A major activity involved the integrated analysis of the assembled information and data related to past, present, and potential future cumulative effects on key resources, ecosystems, and human uses and communities within and along the Ohio River mainstem. The key resources include water and sediment quality, mussels, fish, riparian/floodplain areas, recreation, and health and safety. An ecosystem perspective was used for riparian/floodplain resources, with this category also including wetlands, islands, and soils and geology. Consideration of potential effects on protected species is incorporated within appropriate chapters rather than as a separate chapter. Human uses and communities relate to navigation traffic, health and safety, river-based recreation, socioeconomics, and cultural resources. Individual chapters have been prepared on these resources, ecosystems, and human uses and communities. Internal and external reviews were incorporated in the preparation of each chapter.

1.5 CONTENTS OF THIS REPORT

This CEA report is organized into 13 chapters and five exhibits. Utilized references are listed, as appropriate, at the end of each chapter or exhibit. Following this introductory chapter, Chapter 2 summarizes the overall project approach, methodology, and findings for each resource type or Valued Environmental Component (VEC). Chapters 3 through 12 focus on the CEs from past, present, and future actions on ten identified VECs. Chapters 3 through 6 address the VECs related to aquatic and riparian ecological resources. For example, Chapters 3 through 5 relate to three subcomponents within aquatic ecological resources (water quality and sediment quality, fish, and mussel resources, respectively). Chapter 6 focuses on the riparian/floodplain resources VEC; including three functional categories involving hydrology and sediment dynamics, biogeochemistry and nutrient cycling, and habitat and food web maintenance. Threatened and endangered species are addressed, as appropriate, within Chapters 4, 5, and 6.

Chapters 8 and 9 are associated with human uses of aquatic and riparian ecological resources, with Chapter 8 addressing the health and safety VEC, including fish consumption advisories resulting from contaminant uptakes from the water and sediment phases. Chapter 9 highlights the river-based recreation VEC, with such recreation including boating, fishing, and multiple uses of the riparian zone. Because a primary focus of ORMSS is related to navigation investment actions, Chapter 10 addresses historical navigation traffic and projected trends under several scenarios. Chapters 7, 11, and 12 are broadly related to human uses of the Ohio River mainstem and its environs, with Chapter 7 addressing the air quality resources VEC. Chapters 11 and 12 encompass the socioeconomic and cultural resources VECs, respectively.

Chapter 13 discusses Adaptive Management and Monitoring approaches that may be applicable to integrated, long term strategies for management of Ohio River resources. The five exhibits include Exhibit A, Procedure and Special Methods, which delineates the key features of the process and special methods used to identify, analyze, and synthesize

information related to this study. Additional exhibits include a report on the public scoping process and an analysis and projection of land use patterns.

1.6 REFERENCES

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Chapter 2

CEA SUMMARY CHAPTER

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2.2 INTRODUCTION

This chapter summarizes the findings of a Cumulative Effects Assessment (CEA) conducted to address environmental issues related to development of the System Investment Plan/Programmatic Environmental Impact Statement (SIP/PEIS) for the Ohio River Mainstem Systems Study (ORMSS). The CEA was developed as a strategic-level impact study which provides a holistic synthesis of past, current, and anticipated environmental impacts from multiple actions and programs of the Corps of Engineers; other Federal, state, and local governmental agencies; and others (e.g., private industries and agricultural activities). In addition to synthesizing the impacts of multiple actions, such strategic level studies consider time and space dimensions and delineate geographical areas, habitat types, and plant and animals species which should be afforded special protection while also identifying certain impact mitigation strategies and programs for

enhancing Environmental Sustainability (ES). Further, the planning and implementation of adaptive management programs can be integrated into such studies.

As stated in Chapter 1 **INTRODUCTION TO THE ORMSS CEA,** cumulative effects (CEs) are becoming increasingly important in environmental impact studies. The CEA for ORMSS adhered to CEQ's NEPA's definition:

> "Cumulative impact" is the impact on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time (Council on Environmental Quality, 1978).

The ORMSS CEA is also in consonance with Corps' policies and approaches, including those outlined in the Environmental Operating Principles (EOPs) (USACE 2002), which are discussed in more detail in Chapter 1 of the CEA.

The specific goal of the CEA was to assess the full direct, indirect, and contributed impacts of further modernization of the Ohio River mainstem navigation system on the resources, ecosystems, and human communities along the mainstem. The study, however, went beyond this goal to consider Environmental Sustainability (ES), defined in the EOPs as "a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations." Regarding ES, the CEA 1) explored ES as an "ultimate test" for determining the significance of cumulative effects and 2) identified types of actions necessary to achieve ES.

2.3 CEQ METHODOLOGY AS APPLIED TO THE ORMSS CEA

This section summarizes an 11-step procedure, promulgated by the CEQ, for planning and conducting impact studies of cumulative effects. Within this framework, four special methods were developed and applied to conduct the ORMSS CEA. These methods, adapted to the 11 steps, were:

- a continuous scoping process designed to determine the scope of the CEA and significant issues to be addressed
- the development of matrices that relate the potential impacts of reasonably foreseeable future actions (RFFAs) to initially12 Valued Environmental Components (VECs) and their subcomponents
- an analysis approach for determining the past, present, and future ES conditions of the VECs and subcomponents, and
- a method that relates to delineating actions required to attain ES. Such actions also are referred to as "ES needs".

Further details on these methods are included in CEA Report, Exhibit A – Procedure and Special Methods. **Table 2-1** presents the 11-step CEQ general framework, followed by a detailed stepwise explanation of how the four methods were applied to conduct the

ORMSS CEA. The four methods are shown in **bold** when first introduced in the narrative for the 11-step framework.

TABLE 2-1
The CEQ Framework

EIA Components	CEA Steps
Scoping	1) Identify the significant cumulative effects issues associated with the proposed action and define the assessment goals. 2) Establish the geographic scope for the analysis. 3) Establish the time frame for the analysis. 4) Identify other actions affecting the resources, ecosystems, and human communities of concern.
Describing the Affected Environment	5) Characterize the resources, ecosystems, and human communities identified in scoping in terms of their response to changes and capacity to withstand stresses. 6) Characterize the stresses affecting these resources, ecosystems, and human communities and their relation to regulatory thresholds. 7) Develop a baseline condition for the resources, ecosystems, and human communities.
Determining the Environmental Consequences	8) Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities. 9) Determine the magnitude and significance of cumulative effects. 10) Modify or add alternatives to avoid, minimize, or mitigate significant cumulative effects. 11) Monitor the cumulative effects of the selected alternative and adapt management.
SOURCE: Council on Environmental Quality, 1997.	

While the steps listed in the table should be viewed as components of a cohesive process, they are organized under the basic components of environmental impact assessment. Steps 1 to 4 relate to scoping, Steps 5 through 7 to describing the affected environment, and Steps 8 through 11 to determining the environmental consequences.

- CEQ Step 1 – <u>Identify the significant cumulative effects issues associated with the proposed action and define the assessment goals.</u> This step identified typical impacts associated with the construction and operation of navigation system locks and dams, and their repair, rehabilitation and periodic maintenance activities. Public scoping meetings were held along with several meetings of a 40-person Interagency Working Group (IWG) that met throughout the development of the CEA. The membership of the IWG consisted of representatives from several federal and state agencies responsible for environmental and natural resources management, and three non-governmental organizations. The IWG participated throughout the CEA study and consequently, provided **continuous scoping**. The initial scoping in Step 1 provided the basis for the identification of 12 VECs of concern. The 12 original VECs were aquatic ecological resources (including water and sediment quality, mussels, and fish as subcomponents), riparian and floodplain resources (including floodplain hydrology, terrestrial habitat, wetlands, islands, and soils and geology as subcomponents), threatened and endangered species

(including fish, mussels, mammals, birds, and plants), air quality, recreational uses of the river, noise, aesthetics, human health and safety, cultural resources, transportation and traffic, land use, and socioeconomic resources (including environmental justice).

- Step 2 – Establish the geographic scope for the analysis. The geographic scope for the majority of the identified CE issues and related VECs consisted of the mainstem of the Ohio River along with its 500-year floodplain. When data were available on actions, resources, and impacts, the geographic scope often focused on the mainstem and the contiguous counties in the six states along the mainstem.

- Step 3 – Establish the time frame for the analysis. The selected time frame was typically from 1920 to 2070 for most VECs. The earlier date coincides with the initiation of locks and wicket dams on the Ohio River mainstem. The latter date encompasses the economic study period for the current SIP/PEIS. One exception for this time frame was the inclusion of information on much earlier cultural sites for the cultural resources VEC.

- Step 4 – Identify other actions affecting the resources, ecosystems, and human communities of concern. As noted in the cumulative effects definition in the introduction to this chapter, "other actions" include past, present, and Reasonably Foreseeable Future Actions (RFFAs). To more fully assess these actions and their potential effects, a series of 22 RFFA matrices were developed. The 22 matrices encompassed the 12 VECs and their subcomponents as delineated in Step 1. The RFFAs, which also included similar past and present actions, were defined as:

  > Actions identified by analysis of formal plans and proposals by public and private entities that have primary (direct) or secondary (indirect) impacts on VECs associated with the Ohio River. RFFAs also include potential actions that are beyond mere speculation when incorporated in plans or documents by credible private or public entities. RFFAs may also include events forecasted by trends, probable occurrences, policies, regulations, or other credible data that may have bearing on the VECs (adapted from CEQ 1997).

  Through the combined efforts of the project planning team and the IWG, a total of 87 RFFAs were identified and considered in the CEA; the types were divided into six categories: 1) navigation investment actions, 2) other Corps actions, 3) "but for" actions (actions that would not occur "but for" the existence of the navigation system), 4) actions by others, 5) natural disasters, and 6) regulatory environment. Each listed RFFA was characterized in terms of its anticipated time period of occurrence, probability of occurrence, and location on the river. The anticipated effects of each RFFA on each VEC or subcomponent were described and recorded. Finally, the importance (high, medium, or low) of each RFFA relative to CEs on each VEC or subcomponent was described and recorded.

  Many sources were consulted to identify and describe the RFFAs including ORSANCO data, EPA air quality data, census data, scientific literature, Corps studies and documentation for the Myers and Greenup projects and the Environmental Restoration Program (ERP), as well as navigation projections and other studies by the Corps' Economics Group.

- Step 5 – Characterize the resources, ecosystems, and human communities identified in scoping in terms of their response to change and capacity to withstand stresses. This step was based upon an analysis of environmental sustainability (AES) for the pertinent VECs or subcomponents. The AES approach was comprised of four parts: 1) identification of "common effects" on the VEC or its subcomponent from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix (Step 4 above); 2) selection of indicators of environmental sustainability (ES) for the VEC or its subcomponent, and their tiered grouping, as appropriate; 3) description of the "connections" between the common effects (and related High and Medium importance RFFAs) and the indicator groups; and 4) assignment of a "bottom line" determination of the ES of the VEC or subcomponent, based on considering the past, present and future conditions. The ES categories included "not sustainable", "marginally sustainable", and "sustainable". Specific ES conditions were developed for each VEC or subcomponent.

- Steps 6 and 7 – Characterize the stresses affecting these resources, ecosystems, and human communities and their relation to regulatory thresholds; and define their baseline conditions. These two steps were addressed jointly for each VEC or subcomponent. The approach consisted of identifying historical and current laws, regulations, ordinances, and programs that contain regulatory thresholds and/or policies related to the VEC or subcomponent. Then, historical reference point and trends information, along with current conditions, were summarized for the ES indicators for the VEC or subcomponent. Numerous information sources were reviewed for Steps 6 and 7. Further, the institutional information and environmental conditions and compliance with regulatory thresholds served as the basis for the categorization of the past and present ES for the VEC or subcomponent.

- Step 8 – Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities. This step was largely accomplished through the development of the RFFA matrices as described in Step 4. Further, peer-reviewed literature, various governmental studies and reports, and impact-study related and resource-management related books were used to more thoroughly document numerous relationships. Attention was also given to various interactions between VECs and subcomponents (e.g., what are the implications of changes in water quality on the populations of mussels in the river?).

- Step 9 – Determine the magnitude and significance of cumulative effects. Due to limited data on specific impacts from various actions, and to the system-wide focus of the CEA study, it was not possible to quantitatively determine the magnitude of the cumulative effects on the VECs and subcomponents. Rather, a qualitative determination was made based on the AES approach described in Step 5. The significance of the cumulative effects was ascertained via compliance or noncompliance with regulatory thresholds, and the consideration of the connections between common effects and indicators of ES. The assigned categories of ES for the past, present and future represent the composite significance determination for the CEs on each VEC or subcomponent.

- Step 10 – Modify or add alternatives to avoid, minimize, or mitigate significant cumulative effects. This step was addressed via the identification of generic mitigation measures for many of the analyzed actions, with particular attention given to navigation investment actions by the Corps. In addition, various regulatory programs that can facilitate or are expected to emphasize generic mitigation measures for numerous actions also were identified and incorporated into the analysis. Further, the fourth special method used in this CEA delineated a process to identify various mitigation and other ES needs for two of the most significant Ohio River resources – the aquatic ecological and riparian/floodplain resources.

- Step 11 – Monitor the CEs of the selected alternative and adapt management. This step was addressed systematically for each VEC and subcomponent. The key criteria used to "trigger" Step 11 were the past, present, and future ES categories for the VECs and subcomponents. If the VEC or subcomponent was currently categorized as "sustainable", and this is expected to continue into the future, only targeted additional monitoring over that currently being done is recommended, and no specific adaptive management strategy will be developed. For VECs or subcomponents that are currently categorized as "not sustainable", or "marginally sustainable", specific collaborate monitoring will be recommended along with an appropriate adaptive management strategy.

Although the CEQ guidance provides distinct steps, the steps were adapted to create a relatively seamless process to attain the ORMSS' CEA goal of providing a comprehensive and integrated understanding of the numerous actions and issues that have shaped and will continue to shape the environment of the Ohio River mainstem.

2.4 SPECIAL CEA-RELATED STUDIES

As the CEA study progressed, it was realized that additional research studies, surveys and databases would be necessary to support well grounded CEs assessments, make ES determinations, and identify ES needs that might be further studied in an adaptive management program. The results of these surveys, research efforts and special reports were incorporated into the main chapters of the CEA or as appendices. Following is a list of these special studies and their placement in the CEA:

Research studies included:

- A study of various engineering and hydraulic factors related to Ohio River locks and dams, along with fish swimming velocities of 44 target species. The objective of this study was to assess upstream fish-passage opportunities through Ohio River mainstem dams by relating historical hydraulic conditions at the dams to swimming capabilities of select native and non-native fishes to determine if the dams are restricting upstream movements of fishes. Additionally, abundance and distribution of target species were examined in relation to upstream fish-passage opportunities. The study suggests that upstream fish passage opportunities generally occur during open-river conditions, when dam gates are lifted clear of the water and are no longer controlling water levels at the dams. The general spatial pattern of

open-river indicated that the potential for fish passage is low to high at dams in the Louisville District, low to moderate at Huntington District dams, and low at Pittsburgh District dams. In general, open-river conditions were more frequent during higher flows of winter and spring and generally nonexistent during lower-flows of summer and fall. (Additional information is included in the CEA Chapter 4 – Fish, and in Aquatic Studies Exhibit A – Fish Passage (USGS).

- A study of winter habitat types used by fishes in the Smithland and Belleville navigation pools, and comparison of the results between the downstream and upstream pools. The objective of this study was to examine how abiotic characteristics (e.g., channel morphology, latitude, depth, etc.) regulate winter habitat use of critical fish species in the Ohio River. The two-year research project focused on a lower pool (Smithland – RM 846 to 918) and an upper pool (Belleville – RM 162 to 204) of the Ohio River. The study found distinct differences between the pools relative to species richness and winter habitat use. Connectivity between tributary habitats and mainstem habitats appeared to be important to winter success of fishes. Island backwaters appeared to be particularly important for fishes during winter, providing flow breaks and shelter from barge activity. Further insights of the study are included in the CEA Chapter 4 – Fish, and in Aquatic Studies Exhibit B – Winter Habitat (Southern Illinois University).

- A review and analysis of the Corps' statutory authorities, policies, regulations and guidance for mitigation of historical environmental damages from Corps projects and actions by others, and for mitigation of proposed Corps projects, plans, and/or programs. The results are summarized in CEA Exhibit A – Procedure and Special Methods.

Databases developed included:

- An in-depth compilation of basic literature and historical data on mussel species in the navigation pools of the Ohio River mainstem. The database, available on a CD, includes mussel species by Ohio River pool, known fish hosts for mussels by pool, and information on establishment of zebra mussels in the Ohio River, as well as common names for mussels and fishes. The database was used in development of CEA Chapter 5 – Mussels and presented in Aquatic Studies Exhibit I – Mussels Database (OSU).

- The collection of data on bottom substrates and bathymetry for navigation pools in the Ohio River mainstem for the Navigation Predictive Analysis Technique (NAVPAT) model. The goal of NAVPAT is to provide quantitative results, which can assess tow induced changes in aquatic habitat quality for a specific area of a river cross-section or an entire reach of river. NAVPAT incorporates 15 life stages of fishes to link tow movements to possible biological effects. Further details are provided in CEA Chapter 4 – Fish and in the NAVPAT Report.

Other special studies included:

- Under the Endangered Species Act (ESA), a Section 7 Biological Assessment (BA) related to continued navigation system operational practices and effects on threatened or endangered plant and animal species within or near the Ohio River mainstem. The primary objective of the BA is to facilitate consultation with the USFWS in compliance with the Endangered Species Act. It presents detailed information to assess effects to 18 listed Threatened and Endangered (T&E) species from operation and maintenance activities on the Ohio River and its commercially navigable tributaries, including two mammal, two bird, one fish, one crustacean, nine mussel and three plant species. The Section 7 BA is not part of the CEA Report, but is included in the Environmental Appendix of the SIP/PEIS.

Four additional studies undertaken for ORMSS related to fish movement and passage in the Ohio River were conducted by the West Virginia Department of Natural Resources in coordination with the Ohio River Fish Management Team (ORFMT). Another related fish study listed below was conducted by Tennessee Technological University, Cookeville, Tennessee.

- The Fish Passage Direct Observations Study surveyed fish community structures at lock chambers and in tailwaters and studied hydrologic conditions that promote fish passage and short-term movement patterns of targeted species at the Winfield Locks and Dam on the Kanawha River.

- The Fish Tagging and Recovery Study examined fish movement in the Ohio River along with hydrologic conditions that stimulated movement based on fish tagging and tag return data.

- Studies of recreational angling efforts were conducted at eight tailwaters along the Ohio River mainstem and compared current angling activities with results from similar previous studies.

- The Glochdial Infestation Study collected fish from ten areas to determine rates of glochial (juvenile mussel) infestation of host fish and ascertain potential impacts of restricted fish passage on host/mussel relationships.

- The Lipid and Fatty Acid Survey analyzed fatty acid profiles of migratory fish from six pools to determine if genetic variations occurred among different populations.

The results of these five studies are summarized in the discussion on fish passage in Chapter 4 of the CEA and in Aquatic Studies, Exhibit D.

2.5 ORGANIZATION OF VALUED ENVIRONMENTAL COMPONENTS (VECs) AND CEA CHAPTERS

The continuous scoping process applied to the CEA led to the reorganization of the original 12 VECs into 10 substantive VEC chapters. Noise and Aesthetics, originally listed as separate VECs were incorporated into the Health & Safety and Recreation

chapters, respectively. Land Use, also formerly a separate VEC, was considered in a detailed supplemental appendix to the Socioeconomics chapter. Information on threatened and endangered (T&E) species was integrated into relevant sections on species and biotic communities, with special emphasis on the endangered mussels of the Ohio mainstem.

Reorganization of the VECs led to development of 10 chapters for the CEA, as follows: Key resources include **1) water and sediment quality, 2) mussels, 3) fish, 4) air quality**. An ecosystem perspective was used for **5) riparian/floodplain resources**, with this category also including wetlands, islands, riparian forests, and soils and geology. Human uses and communities are related to navigation **6) transportation and traffic**, **7) health and safety**, **8) river-based recreation**, 9**) socioeconomics** and **10) cultural resources**. Work plans developed early in the CEA process provided a framework for assembling and analyzing pertinent information for each VEC chapter. Typical contents of the VEC chapters included:

- Definition of VEC and its Subcomponents
- Objectives and Scope of the VEC Study
- Issues from Scoping
- Indicators of Environmental Sustainability
- Laws, Regulations, Ordinances, and Programs
- Past to Current Baseline Conditions for the VEC and its Subcomponents
- Special Information Related to the Ohio River
- Interactions with Other VECs
- Relevant Actions Affecting the VEC and its Subcomponents
- Cumulative Effects and Environmental Sustainability
- Summary and Conclusions
- References

Of the ten VEC chapters prepared, the review process identified six that were of higher priority: Water and Sediment Quality, Fish, Mussels, Riparian/Floodplain Resources, Health and Safety, and Recreation.

2.6 PROJECT DEVELOPMENT ORGANIZATION

Three groups worked together from the early stage of the CEA to its final development and review: a Central Planning Team (CPT), an Oversight Board (OB), and

the previously mentioned IWG. Information on the roles and composition of these groups is included in **Table 2-2** and presented in further detail in Exhibit A.

TABLE 2-2
Key Groups in Developing the ORMSS CEA

Component	Key Functions	Composition/ Meeting Frequency
Central Planning Team (CPT)	Provided leadership to the entire CEA process; including educational features related to CEA; interactions with the OB and IWG; development of VECs, RFFAs, methods, and AES; and syntheses and internal review of information.	Consisted of 7 members – 3 persons from the Corps and 4 persons from a consulting firm; representing several disciplines; met every 2 - 3 months throughout project
Steering Committee --- Oversight Board (OB)	Provided policy advice and overall approvals for scheduling and budgetary matters for the entire ORMSS.	14-person group comprised of Corps management–level professionals from the pertinent Division and 4 Districts
Interagency Working Group --- (IWG)	Provided scientific and/or policy information to the CPT; aided in identifying research needs; participated in the completion of RFFA matrices, the identification of indicators for AES, and the delineation of ES needs; and reviewed various study documents.	Approximately 40 members from Federal and state agencies and NGOs. Organizations represented included U.S. Fish & Wildlife Ser., U.S.EPA, ORSANCO, State Departments of Natural Resources, Nature Conservancy and Ohio River Foundation.

2.7 ELEMENTS COMMON TO ALL VEC ANALYSES

Each VEC chapter contains detailed information related to the CEA processes of scoping and describing the affected environment. As this information was collected and analyzed, it was used to determine each VEC's past, present, and future environmental sustainability (ES). Further, this information and input from members of the IWG were used to outline actions needed to move toward higher levels of ES for some VECs. As discussed in the previous section on organization**,** the VEC chapters had a common framework, enabling the preparation of cross-reference tables to summarize some elements common to analyses of all VECs. Such cross-referencing is useful in illustrating the far-ranging connections between and among VECs.

Legal measures and government programs are common to all VECs. **Table 2-3** lists more than 60 laws, regulations and programs applicable to the overall CEA and uses shading to illustrate their primary or secondary relevance to each VEC. At least 10 such laws, regulations and programs are cross-cutting, with shadings applied to six or more VECs. NEPA is the most far-ranging measure listed, affecting every VEC. In general, the denser shading pattern for the columns for aquatic ecological resources (water & sediment quality, fish and mussels), riparian resources, and health and safety illustrate the interrelatedness of these VECs. Relationships among the remaining VECs also occur, but distinct patterns are less apparent.

TABLE 2-3
Cross-Reference of Laws, Regulations and Programs Applicable to VECs in the ORMSS CEA

Laws, Regulations and Programs	WQ & SQ	Fish	Mussels	Riparian Resources	Health & Safety	Recreation	Air	Transportation & Traffic	Cultural Resources	Socioeconomics
Abandoned Shipwreck Act										
Archaeological & Historic Preservation Act										
Archaeological Resources Protection Act										
Civil Rights Act, Title VI										
Clean Air Act										
Clean Water Act										
COE Permitting Statutes (listed below)										
Sec. 10 (obstructions in nav. waters)[1]										
Sec. 404 (dredged & fill materials)[2]										
Emergency Planning & Community Right-to-Know Act (a.k.a. SARA Title II										

[1] Section 10 is a provision of the River and Harbor Act.
[2] Section 404 is a provision of the Clean Water Act.

Laws, Regulations and Programs	WQ & SQ	Fish	Mussels	Riparian Resources	Health & Safety	Recreation	Air	Transportation & Traffic	Cultural Resources	Socioeconomics
Emergency Wetlands Resources Act										
Endangered Species Act										
Executive Orders:										
11988 (floodplain mgmt.)										
11990 (wetland protection)										
12898 (environmental justice)										
13112 (invasive species)										
13274 (transportation project review)										
13287 ("Preserve America")										
13186 (protection of migratory birds)										
Farm Security & Rural Investment Act 2002 Farm Bill)										
Farmland Protection Policy Act										
Federal Water Project Recreation Act										
Fish & Wildlife Act										
Fish & Wildlife Conservation & Water Resources Development Act										
Fish & Wildlife Coordination Act										
Flood Control Act of 1944										
Hazardous Materials Transportation Act										
Historic Sites Building & Antiquities Act										
Inland Waterways Revenue Acts										
Kentucky Mussel Refuges Act										
Migratory Bird Conservation Act										
Migratory Bird Treaty Act										
National Environmental Policy Act (NEPA)										
National Flood Insurance Acts										
National CSO Control Policy										
National Historic Preservation Act										
National Invasive Species Act										
National Trails System Act										
National Wildlife Refuge System Admin. Act & National Wildlife Refuge System Improvement Act										

Laws, Regulations and Programs	WQ & SQ	Fish	Mussels	Riparian Resources	Health & Safety	Recreation	Air	Transportation & Traffic	Cultural Resources	Socioeconomics
Native American Grave Protection & Repatriation Act (NAGPRA)										
Noise Control Act										
North American Wetlands Conservation Act										
Occupational Safety & Health Act										
Oil Pollution Act										
ORSANCO monitoring										
Phase 1 & 2 NPDES Program (stormwater)										
Pollution Prevention Act										
Quiet Communities Act										
Reclamation Recreation Mgmt. Act										
Recreational boating safety regulations and programs										
Refuge Recreation Act										
Rivers and Harbors Act										
Sec. 7 (promulgation of nav. regs)										
Sec. 107 (small navigation projects)										
Safe Drinking Water Act										
Site remediation statutes, including CERCLA, RCRA & SARA										
Spill response										
State cultural resources regulations										
State fishing regulations										
State water quality certification										
Toxic Substances Control Act										
TMDL program										
Transportation Equity Act (TEA-21)										
Water Resources Development Acts (WRDA)										

Key to shading: **Indicates primary relevance to a VEC.**
Indicates secondary relevance to a VEC.
No shading indicates non-applicable.

Reasonably foreseeable future actions (RFFAs) are a second CEA element common to all VECs. **Table 2-4** cross references the RFFAs for ORMSS and their positive or

negative effects by VEC. As with **Table 2-3,** the emergence of a darker shading pattern on the left side of **Table 2-4** illustrates the interrelatedness of the six VECs assigned higher priority.

The third important common element was the identification of specific indicators of ES for each VEC. Such indicators provide benchmarks for measuring CEs on a given resource. Consequently, well chosen indicators can be used to make connections between multiple actions and the condition of a VEC and to facilitate analyses of past, present, and future ES.

TABLE 2-4
RFFAs Ranked High and Medium and their Effects by VEC

RFFA	WQ & SQ	Fish	Mussels	Riparian Resources	Health & Safety	Recreation	Air	Transportation & Traffic	Cultural Resources	Socioeconomics
Navigation Investment Actions										
Lock Extensions/New Locks/Replacement or Rehabilitation		-	-	-	+	+	-	+	-	H/M+
L&D operation and maintenance	-	-	-		+	+		+	-	
Non-structural navigation improvements		+			+	+	+	+		
Dam replacement and rehabilitation		-	-	-	+	+		H/M+	-	
Other Corps Actions										
Channel dredging/dredged material disposal	-	-	-			-			-	
Navigation aids - Construction and O&M					+					
Flood damage reduction projects										
levees/floodwalls		-		-	+	-			-	+
dry dams, other projects off mainstem	-	-		-	+	+		+		
channel modifications		-	-	-	+					
nonstructural measures (e.g. relocation)		+	+	+		+				
Emergency streambank stabilization (Sec. 14)		-	-		+					
Modification of Corps structures for environmental improvements (Sec. 1135)		+	+	+		+			-	
Environmental restoration of aquatic ecosystems (Sec. 206)		+	+	+		+				
Recreation facilities - Construction and O&M					+	+		-		+
ERP Projects - 5 categories	+	+	+	+		+				H/M+
Port development (Sec. 107) and maintenance dredging	-	-	-	-	-	-	-	+	-	H/M
Pool maintenance		-	-	-	-	+				-
"But for" Actions										
Commercial Navigation										
barge queuing		-	-		-		-	-		-
fleeting areas/barge storage	-	-	-		-	-	-		-	H/M-
terminals	-	-	-	-	-	-	-	+	-	H/M
multi-modal sites	-	-	-	-	-	-	-	+	-	H/M

RFFA	WQ & SQ	Fish	Mussels	Riparian Resources	Health & Safety	Recreation	Air	Transportation & Traffic	Cultural Resources	Socioeconomics
increased traffic	-	-	-	-	-	-	-	+		
dispersed barge traffic		-	-	-	-	-				
barge/tow tech/"green" design			+		+					
accidents/spills	-	-	-		-	-				
Coast Guard Nav. Aids - Constr'n.,O&M					+	+				
Instream sand and gravel mining	-	-	-	-	-		-		-	
Floodplain sand and gravel mining	-		-	-			-		-	
Limestone aggregates mining			-	-			-		-	
Coal utilities	-	-	-	-	-		-	+	-	
Other coal industries	-	H/ M-	-	-	-		-	+	-	
Hydropower on dams		-	-	-	-	-				
Water intakes			-							
Industrial users, excluding coal-related	-	-	-		-		-	+		
Recreation facilities - Construction and O&M			-		+	+		-		+
Actions by Others										
Public lands acquisition and management		+	+	+		+				
Floodplain development										
residential		-	-	-	-		-		-	
commercial		-	-	-	-	-	-		-	
industrial	-	-	-	-	-	-	-		-	H/M
Private recreational sites, including camp-grounds, docks, and seasonal trailer parks				-		+			-	
Crossings										
bridges		-	-	-	-				-	H/M
utility		-	-		-				-	
industrial		-	-		-				-	
Riverbed crossings		-	-		-					
Marina development & operation	-	-	-		-	+		-	-	H/M
Water -based recreation										
boating					-	+		-		+
fishing		-			-	+		-		+
PWCs					-	+		-		
hunting					-	+				
wildlife watching						+				+
sight-seeing						+				+
Silviculture			-			+			-	
Agriculture	-	-	-	-	-				-	+
WWTP discharges										
municipal		-	-		-	+				
industrial	-	-	-		-	+				
onsite systems		-	-		-	-				
Stormwater discharges	-	-	-		-	-				-
Brownfields redevelopment		+			+	+				
Trail/bikeway development						+				
Casinos									-	

RFFA	WQ & SQ	Fish	Mussels	Riparian Resources	Health & Safety	Recreation	Air	Transportation & Traffic	Cultural Resources	Socioeconomics
Hazardous waste sites		-	-		-	-				
Natural Climatic Events										
floods		+		+	-	-		-		-
droughts		+			-	-		-		-
severe storms		+			-	-			-	-
earthquakes					-				-	
Regulatory Environment										
Phase I & 2 NPDES program	+	+	+		+					+
TMDLs	+	+	+		+					
Site remediation		+	H/M +		+					
More stringent quality standards for environmental media	+	+	+		+	+	+			
Pollutant source control	+		+		+		+			
Wetland mitigation banking		+				+			-	
Carbon sequestration		+	+		+					
Farmland preservation		+	+			+				
Effluent trading	+				+					
Control of agricultural discharges	+		+		-	+				
Pollution Prevention			+							
Emissions trading					+		+			
COE permitting programs		+						-		H/M+
Small navigation projects		-	-	-	-	-				
Boating safety regulations					+	+				
ORSANCO monitoring program	+	+	+		+	+		+		+
Spill response	+	+	+		+	+				+
Information and FOIA										
Environmental Awareness Education	+		+	+	+					
ESA (Endangered Species Act)		+	+							
Environmental sustainability practices		+	+	+	+	+				

Key to shading/symbols:

Indicates high importance ranking
Indicates high-medium ranking H/M
Indicates medium importance ranking
Effect on resource is primarily positive +
Effect on resource is primarily negative -
No symbol for mixed + and - impacts

No shading indicates the RFFA is of low importance ranking or was not ranked.

Table 2-5 lists the indicators developed for the six higher priority VECs. Indicators were selected independently for each VEC, but they frequently overlapped between or among allied VECs. For example, indicators for water & sediment quality, fish, mussels and riparian/floodplain resources have similarities related to potential pollution, habitat

alterations, and biodiversity. These similarities underscore the intricacies and interdependence of environmental resources and the importance of assessing resources cumulatively in large systems such as the Ohio River.

TABLE 2-5
Indicators of Environmental Sustainability by VEC

Indicators for Water & Sediment Quality

- measures of key water quality parameters, including dissolved oxygen, pH, fecal coliforms, turbidity, total suspended solids and nutrients
- level of conformance with state and federal water quality standards, including attainment of permissible use designations
- TMDL (total maximum daily load) implementation
- effectiveness of specific point source control and nonpoint source control programs
- ability to sustain diverse, healthy populations of aquatic organisms, and
- effectiveness of spill response, monitoring programs and related precautionary measures

Indicators for Fish

- composition of fish communities, including numbers of intolerant and nonnative species, abundance and diversity
- amount of habitat with stable substrates, adequate depths, suitable currents, and sufficient food supplies
- reproductive viability as measured by amount of spawning habitat, genetic connectivity, and numbers of gravid females and larval individuals
- percent of population with abnormalities such as parasites, tumors, ulcers, and fin erosion
- water quality measurements such as levels of dissolved oxygen, and pH and
- level of disturbance from biotic stressors, such as invasive species and from abiotic stressors, such as river traffic

Indicators for Mussels

- amount of habitat with stable substrates, suitable depths, and currents and connectivity to other mussel populations
- measures of water quality parameters important to mussel populations
- extent of food supplies to help ensure good growth rates and reproduction
- availability of fish hosts to ensure reproductive success and maintain species diversity
- extent of disturbance from biotic stressors, such as invasive Asian clams and zebra mussels and from abiotic stressors, such as river traffic

Indicators for Riparian/Floodplain Resources

- adequacy of hydrologic connections between riparian areas and adjacent water bodies and uplands
- capacity for water storage in floodplain
- quality of soil structures
- adequacy of water table and groundwater recharge
- sustainability of sediment dynamics
- capacity of riparian areas to intercept pollution
- integrity of riparian habitats and
- measures of biodiversity

Indicators for Health & Safety

- number and magnitude of spills of oil, fuel, and other hazardous or toxic materials
- potential sources of contamination associated with past or present activities
- number of accidents associated with commercial or recreational boating

- number and types of public advisories related to boating, swimming and fish consumption
- noise levels from construction activity, commercial transportation and other sources

Indicators for Recreation

- types of recreation and associated opportunities
- availability of recreational-related facilities (e.g. boat launch ramps, marinas)
- quality of experience related to river conditions (e.g. density of watercraft, safety concerns)
- number and types of public advisories related to boating, swimming and fish consumption

2.8 APPROACH TO ANALYZING ENVIRONMENTAL SUSTAINABILITY

The ES categories of the various VECs included in the CEA were derived by combining the best professional judgment of the Central Planning Team and IWG members with the CEs of multiple actions (i.e., RFFAs) as manifested through information available on indicators selected for each VEC. Although ES categories are somewhat qualitative, they are based on thorough analyses of past and present conditions as well as future conditions related to trends, plans, laws, regulatory programs and other sources of information that are beyond mere speculation.

Categories of ES were determined for the past, present and future of each VEC. Specific ES categories were developed for each VEC and are found in the corresponding CEA chapters. The general template for the ES categories follows:

- Not sustainable (NS) – The composite conditions of the selected indicators do not reflect conditions that can sustain the resource long-term.

- Marginally sustainable (MS) – The composite conditions for the selected indicators are such that the resource can be sustained for the majority of river miles in or along the Ohio mainstem, but conditions of the indicators are somewhat tenuous both in location and likelihood of occurrence.

- Sustainable (S) – The composite conditions of the selected indicators reflect sustainability for essentially all the river miles in or along the Ohio mainstem. Further, conditions of the indicators meet or exceed regulatory thresholds and pertinent governmental programs are in place to support the resource.

2.9 ES CONCLUSIONS BY VEC

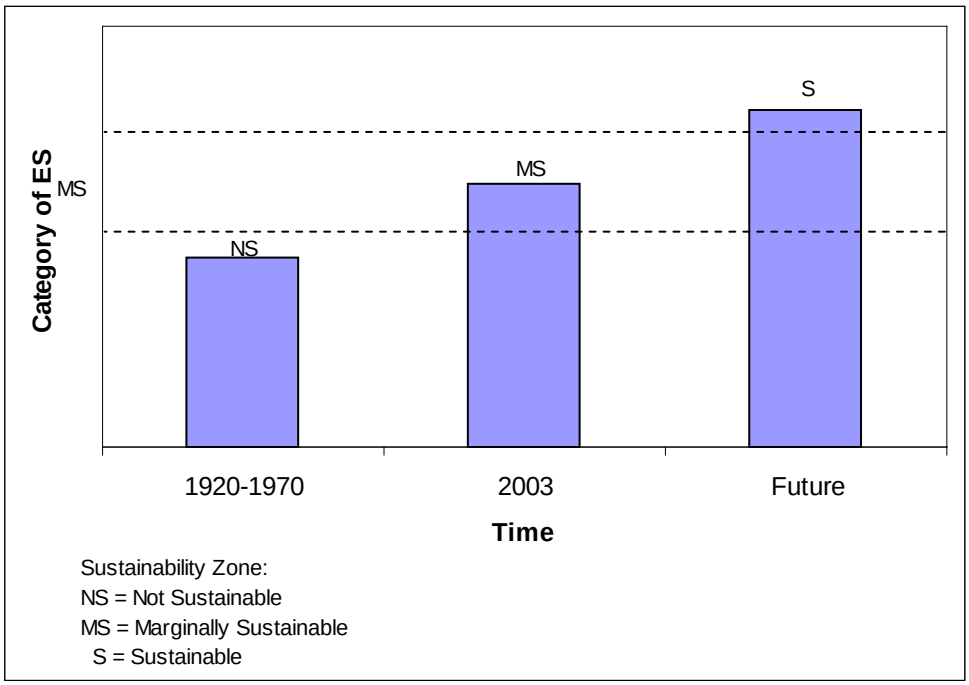
Applying this methodology to each VEC in the CEA resulted in past, present, and future characterizations of ES that were included in bar graphs accompanied by synopses of conditions. Because of implementation of important legislation or the quality of information available, more than one ES category may be used to categorize past conditions.

The following sections present the ES graphs (**Figures 2-1 through 2-11)** and their respective synopses which form the basis for additional conclusions related to interactions among VECs, overall CEs, and sustainability of the Ohio River mainstem.

Water Quality and Sediment Quality

Prior to 1920, and continuing up to about 1970, the water quality of the mainstem was in a degraded state characterized by low DO concentrations, low pH levels in the upper river, high bacterial contamination, high nitrogen concentrations, and remobilization of potentially toxic chemicals that had become associated with river sediments. Essentially no pollution reduction programs, control programs, or regulatory programs were in place during this period. Further, declines in the diversity and health of fish communities in the mainstem had occurred. Accordingly, the ES of water quality was classified as "not sustainable". Primary contributors to these conditions were the largely untreated and uncontrolled point and nonpoint pollutant discharges from growing municipalities and various types of industries and land uses along the river.

FIGURE 2-1
ES of Water Quality



Due to the programs of ORSANCO, and requirements of the Federal Water Pollution Control Act (FWPCA) (and the amended Clean Water Act (CWA)), water quality of the Ohio River has shown steady improvement in recent decades. For example, Dissolved Oxygen (DO) concentrations are typically above the 5.0 mg/L standard, pH levels are between the 6.0 to 9.0 standard, and nitrogen concentrations meet current water quality criteria. However, continuing concerns include bacterial contamination primarily associated with NPS pollution downstream from major urban areas, legacy "contaminated sediments" in the upper river, and fish consumption advisories throughout the mainstem. In contrast, the results of algae (plankton) and aquatic macroinvertebrate surveys in recent decades have demonstrated steady improvements in these resources, which parallel water

quality improvements. Regarding the attainment of permissible use designations, as of 2003, 779 of 981 miles (~80%) of the mainstem were "fully supporting" aquatic life, and 949 miles (~97%) were "fully supporting" public water supply use. None of the mainstem was "fully supporting" fish consumption due to consumption advisories along its total length. For contact recreation, 269 miles (~27%) were "fully supporting", with major impairment continuing from combined sewer systems in urban areas. Overall, implementation of NPDES permit programs for municipalities, industries, and stormwater has led to the reduction of discharges into the mainstem. Initiatives for increasing the use of Best Management Practices (BMPs) have also been established. Further, the diversity and health of fish communities along the mainstem has considerably improved. Accordingly, as of 2004, although there are many positive signs, the ES of the water quality VEC is classified as "marginally sustainable".

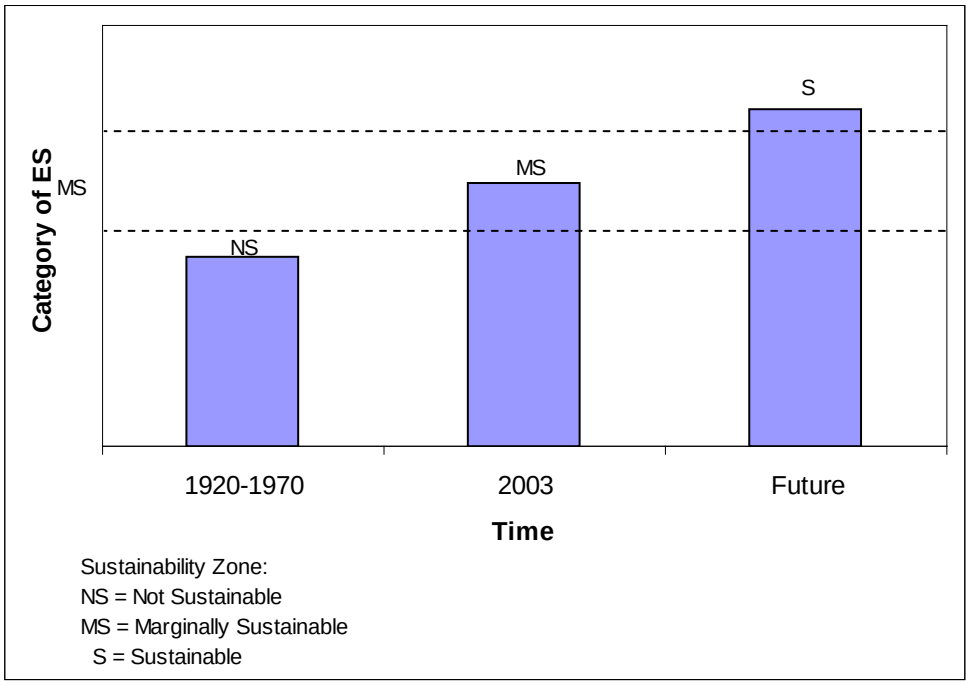
Regarding the future, it is expected that water quality of the Ohio River mainstem will further improve with continuation of source control and other pollution reduction programs, and other remediation efforts. Therefore, it is anticipated that the ES of water quality will achieve a "sustainable" condition. However, vigilant efforts are still needed to continue effective water quality and aquatic ecological monitoring and management efforts. In this regard, it may be desirable to plan and implement source monitoring programs for selected RFFAs (actions) considered of high importance relative to cumulative effects. Further, special surveys for legacy-contaminated sediments are needed along with site-targeted efforts to reduce bacterial pollution from CSOs. Actions expected to be beneficial to water quality in the future include implementation of nonstructural navigation improvements and technological improvements related to communications and more environmentally-advanced barge design. Activities that support commercial navigation (e.g., port development and maintenance dredging) will continue to be scrutinized by regulatory agencies and nongovernmental organizations (NGOs) and may be more strictly regulated. Some redevelopment activity may revive underused urban space or industrial brownfields areas, with possible long-term water quality benefits related to clean up. Much development activity, however, will involve conversion of existing floodplain lands that now afford habitat protection, open space and ecosystems values. Once converted, such lands are unlikely to revert to their former more natural states. Increasing emphasis on pollution prevention, erosion control BMPs, and implementation of the Phase 1 and 2 NPDES programs could counteract some adverse impacts, particularly in more urban areas. In general, several regulatory initiatives in recent years should measurably improve water and sediment quality, but it is not possible to predict the magnitudes of their beneficial effects.

Fish

Prior to1920 and continuing well into the mid-20th century, fish communities became degraded, as reflected in the decline of many native species and the increase in pollution tolerant species. This decline was particularly pronounced in the upper and middle river, where human populations grew rapidly during the first half of the 20th century, concurrent with increased inputs of domestic sewage, industrial effluent, and acid mine drainage. Numerous other actions contributed to degradation of fish communities, including land clearing and sedimentation beginning in the 19th century, impoundment of the river by navigation dams that disrupted migrations of several important river fishes, in-stream sand and gravel dredging, development of new ports, terminals and marinas, introduction of the

common carp, and increasing quantities of stormwater runoff from urbanizing areas. Because these actions contributed to habitat loss, changes in species composition and abundances, and serious declines in necessary water quality conditions, the ES for this period is classified as "not sustainable". Further, until 1948, when a limited precursor of the CWA was passed and the ORSANCO interstate compact was signed, pertinent laws were limited. Accordingly, based on scientific data indicating changes in fish communities as well as the recognition of multiple actions and factors causing such changes, it was concluded that the composite conditions for the selected indicators of ES for fish communities did not reflect conditions that would sustain diverse, healthy fish populations throughout the river.

FIGURE 2-2
ES of Fish Communities



From the mid-20th century until the present time, improvements in the sustainability of the fish resource have been observed throughout the mainstem. Such improvements have resulted primarily from initiatives by ORSANCO, efforts of the six Ohio River states, and the requirements of the FWPCA and the amended CWA. As municipal wastewater and industrial effluents to the river have decreased and other pollution control measures have increased pH and DO while reducing toxins, fish communities of the Ohio River have shown steady improvement, marked by the recovery of many native species. The common carp is no longer as dominant as in earlier years. Concurrent with improvements in water quality, however, has been the continued inundation of fish habitat not only from navigation structures constructed before 1950, but also from continuing construction and operation of additional high-lift dams. The modern navigation system, combined with land use and flood control practices in the watershed, has caused the inundation and siltation of extensive areas of gravel substrates preferred by many migratory fishes. Various studies on human impacts on Ohio River fishes, including studies on winter habitat and fish passage, underscore the need for additional research and development of resource management practices to gain a more comprehensive understanding of ES of mainstem

fish. Accordingly, the ES of the fish resource at present is classified as "marginally sustainable." Two major uncertainties emerged during the last decade that may affect the fish resource into the future: 1) the invasion of four Asian carp species and 2) the invasion and unknown population dynamics of zebra mussels, which seriously impact native mussels, an important food resource for many fish species.

Regarding the long-term future, the CEA has identified 60 RFFAs ranked as having high or medium importance. These include actions that change habitat, change disturbance regimes, change hydrological patterns, affect ecological functions, and are related to population changes. During recent decades, regulatory requirements and pollution control programs have been implemented that will benefit the fish resource, if continued into the future. Additional tools and studies that also should increase understanding of the ES of fish in the mainstem include the NAVPAT habitat assessment model, the new Ohio River Fish Index (ORFIn), and supplemental fish studies related to §316(a & b) of the CWA. It is also expected that the Ohio River Fish Management Team and USFWS Ohio River Valley Environmental Team will continue to be involved in fish resource monitoring and management. Given recent improvements in the resource, development of new assessment tools, and the level of stakeholder interest, it is expected that fish communities of the Ohio River mainstem will attain a "sustainable" condition and may further improve with long-term elimination of combined sewer overflows and better nonpoint pollution control. The habitat effects of impoundment of the river are expected to persist into the future, but adaptive management may produce measures that counteract such effects and benefit habitat and enhance interpool connectivity. A possible threat to the resource is the invasion of Asian carps. Vigilance by ORSANCO and other resource agencies will be required to assess populations of Asian carps while potential measures to control these species are evaluated for the Ohio and other major river systems in the U.S.

Mussels

To summarize the historical and current status of mussel populations in the Ohio River mainstem, the following observations can be made:

- Over the last century the number of mussel species has declined from about 80 to the currently reported 54 species. Evidence suggests that the number reached a low in the vicinity of about 25 to 35 species in the 1950s and 1960s. Numerous factors contributed to the decline, including, but not limited to, water pollution from municipalities, industries, and acid mine drainage; instream extractions of sand and gravel; construction and operation of high-lift locks and dams; and disruptions to mussel beds due to barge fleeting areas, queuing, and disposal of dredged materials. Recent increases in the numbers of species can be attributed to water quality improvements and protection efforts related to mussel beds. However, despite these advances, research continues on the unique characteristics of the life cycles of numerous mussel species, and their susceptibility or resiliency regarding natural stresses from dynamic river flows and water quality, and from human-induced stresses associated with economic development activities. The greatest factor affecting mussels in the mainstem Ohio River is habitat alteration resulting from impoundment by the high lift dams.

- The lower portion of the river was not as severely affected by water quality degradation as the upper river. As a result, the lower river typically had and continues to support more diverse mussel populations and generally higher densities than the upper river. However, concerns currently exist relative to fluctuating populations of invasive zebra mussels and potential appearance of black carp. Thus there is a need for additional research on the interactive relationships between the invasive species and native mussels and their associated life cycle, including fish hosts.

- Five mussel species (fanshell, pink mucket, orangefoot pimpleback, clubshell, and fat pocketbook) are currently Federally listed as endangered for the mainstem, and recovery plans have been developed for each. Candidate species include the sheepnose mussel, rayed bean, and spectacle case; the latter species has not been found recently in the Ohio mainstem.

- As more information is assembled on the locations and characteristics of mussel beds in the mainstem, planning and implementation of targeted and long-term mussel monitoring programs can be more effectively accomplished. Further, the results can be used in an adaptive management program focused on enhancing and maintaining the ES of the mussel resource.

Based upon the above-described affected environment conditions, the consideration of multiple actions and their effects, the discussion of the connections with the three tiers of indicators, and the ES categories, the ES of mussels of the mainstem of the Ohio River can be characterized and depicted as follows:

In the time period from 1920, and continuing up to the mid-point of the last half of the 20th century, the ES of freshwater mussels in the mainstem was in a continuing decline and thus classified as “not sustainable”. The decline in mussel species and densities, and the areal extent of mussel beds, was particularly noted in the upper and middle river segments, with the lower river experiencing a similar, but lesser decline. Numerous actions contributed to the decline, including, but not limited to, acid mine drainage in the upper river, high-lift locks and dams disrupting mussel and fish-host migration, numerous discharges of untreated to partially treated municipal and industrial wastewaters, in-stream sand and gravel mining, dredging for new ports and terminals, periodic maintenance dredging for the navigation system, mussel harvesting for button manufacturing and the cultured pearl industry, and multiple land use changes resulting in increased nonpoint source pollution. These actions and others contributed to losses in quality mussel habitat throughout the river, declines in necessary water quality conditions, and disruptions in various components of the mussel life cycle. The greatest factor continuing to affect mussel resources in the Ohio River is presence of high-lift dams with attendant modification of clean-swept gravel, cobble, and sand substrates now covered and/or replaced by finer-grained material. Additional contributing factors to this decline included the limited information on life cycle requirements of several mussel species and poor understanding of the influence of biological and physical-chemical conditions on timing reproduction. Further, there was limited recognition of the biological importance of mussels, and limited existence of environmental and resource protection laws up to 1948 (FWPCA) and 1973 (when the ESA was passed). Accordingly, as a result of the scientific data indicating declines in various mussel populations in the mainstem, as well as the

recognition of multiple actions and factors causing such declines, it was concluded that the composite conditions for the selected indicators of ES for mussels did not reflect conditions that would sustain diverse, healthy populations of freshwater mussels throughout the river.

In the time period from 1975 up to 2003, some improvements in sustainability of the mussel resource in the mainstem have been noted, although improvements are typically localized and exhibit frequent fluctuations. Conversely, there has also been a general reduction in number of mussel beds since about 1975. Improvements that have occurred resulted from: 1) reduced acid mine drainage in the upper river, 2) enhanced treatment requirements for municipal and industrial wastewater treatment plant discharges, 3) consideration of mussel bed locations in river-related permitting programs (e.g., Section 404 and Section 10 permits) and navigation system operational features (location of queuing and barge fleeting/storage areas, and placement of dredged material), and 4) protection provided through designation of several mussel species as threatened or endangered under the ESA and similar state protective mechanisms.

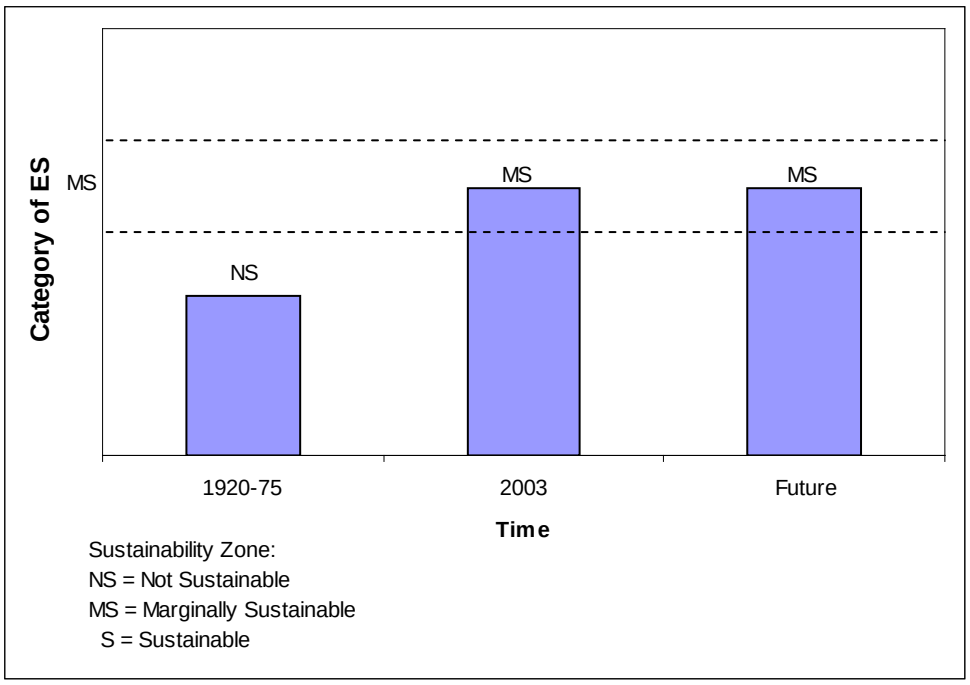
Recent fish migration research indicates evidence of some inter-pool movement (see Chapter 4, FISH); however, it is not clear if sufficient host fish are able to move successfully from a mussel assemblage in one pool to suitable mussel habitat in another pool, especially when carrying mussel glochidia. The designation of "marginally sustainable" is appropriate considering that composite conditions for the selected Ecological Sustainability indicators are such that diverse mussel populations are occurring only along some segments and in some pools of the river and that conditions of the indicators are somewhat tenuous both in location and likelihood of occurrence. The conditions also reflect a continuing level of uncertainty regarding appropriate quantitative measures of the Ecological Sustainability of freshwater mussels.

Six previously designated endangered species have not been recently found in the mainstem; however, five others are continuing in the river due, in part, to natural recovery. In contrast to the improvements, concerns still exist regarding the occurrence of nonindigenous species such as zebra mussels and possible future establishment of black carp. The most recent decade has been characterized by expanding databases to include results of scientific studies of freshwater mussels in the Ohio River. These databases, although incomplete, have been used in recent environmental planning and permit programs and are providing the bases for on-going research efforts into the life cycle of various mussel species. As a result of relatively recent scientific data (since 1990) indicating recruitment and general improvement in some mussel populations in navigation pools in the lower, middle, and some upper portions of the river; the recognition of improvements in water quality and general habitat conditions resulting from various features of the CWA and ESA, and evidence of inter-pool movement, albeit somewhat limited (see Chapter 4), it is concluded that the current ES classification is "marginally sustainable,"

Regarding the future, this study has identified 56 types of RFFAs ranked as having high importance relative to CEs on native mussels, and 14 additional types ranked as having medium importance. These 70 RFFAs include actions that directly or indirectly contribute to mussel habitat degradation and instability, affect reproductive success and community connectivity, or are beneficial to mussels (numerous regulatory and

educational actions are included in this latter group). As additional regulatory requirements and pollution control programs are implemented, habitat conditions should be more conducive to reproductive success and community connectivity than at present. Of particular importance is the need to integrate considerations of mussel beds and the life cycle features of mussels into permitting and other locational decisions within or along the mainstem. As further mussel monitoring and research is conducted, these data should be added to databases to provide further information for both protecting and promoting mussels. Further, consideration should be given to implementation of an integrated adaptive management program for the Ohio River freshwater mussels.

FIGURE 2-3
ES of Mussel Resources



This assessment of future marginal sustainability acknowledges that many unknowns remain and that recovery of the Ohio River mainstem native mussel populations will be a long-term process involving many years of collaborative efforts and monitoring. Evidence of recruitment and population stability is necessary to validate viability. To illustrate the many uncertainties, the following tasks to effect recovery have been selected from a more extensive list from Watters (1994) and supplemented by the ORMSS IWG:

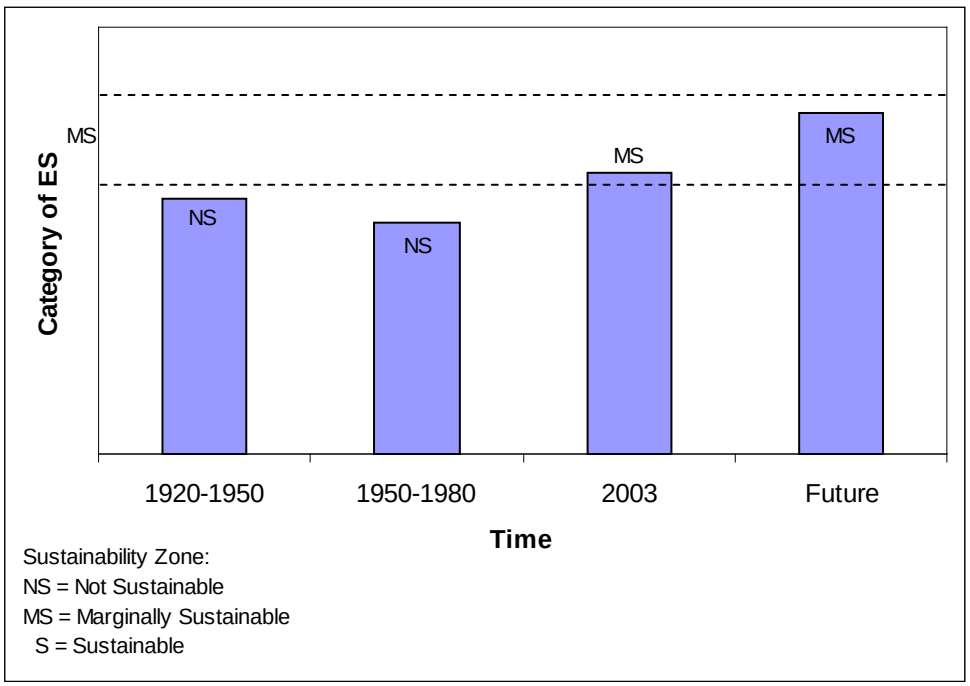
- Identify other resource values associated with mussel populations, including fish hosts, key food organisms, and habitat elements.
- Protect and manage mussel populations and their habitat on a site-specific basis to avoid future net loss of available habitat or populations.
- Characterize the habitat that best supports species of concern, including historically important sites.
- Restore habitats and reintroduce mussel species to suitable areas.
- Conduct searches for additional populations.

- Enforce all laws and regulations pertaining to collection of specimens and protection of habitat.
- Enhance knowledge of life histories for species of concern, including life histories of host fishes.
- Identify the potential effects and responses to zebra mussel and Asian carp species invasions and their control measures.
- Evaluate the efficacy of removing zebra mussels from vessels to prevent re-infesting areas.
- Increase public and agency awareness of existing laws that protect mussels.
- Use media opportunities to reach the general public and encourage involvement in the recovery process.
- Restore and protect direct connections to tributary populations.
- Restore mobility of fish hosts through dams at appropriate times of the year needed for mussel reproduction.

Riparian/Floodplain Resources

In the time period prior to 1920, and continuing up to about 1950, the riparian/floodplain resource (RFR) can be classified as "not sustainable" due to relatively rapid losses of riparian habitats and their functions, the lack of knowledge of the importance of these resources to both terrestrial and aquatic ecosystems, and the essential absence of any institutional programs to manage or control riparian areas. Further, the lack of awareness of environmental services performed by RFR coupled with ongoing floodplain development, especially in the upper and middle river, led to loss and fragmentation of valuable RFR along the Ohio mainstem before such resources could be well-documented.

FIGURE 2-4
ES of Riparian/Floodplain Resources



In the time period from 1950 to 2000, worsened "not sustainable" conditions occurred in the first several decades as a result of still more disruptions and losses of riparian areas. However, recent decades have included an increasing awareness of riparian services, including regulation of wetlands, a highly productive riparian component. The establishment of the Ohio River Islands National Wildlife Refuge has focused attention on the disappearance of another riparian habitat type, islands, and has heightened visibility of the riparian resources of the Ohio mainstem embayments. These initiatives suggest the current status of RFR may be moving toward "marginally sustainable." Accompanying these initiatives is an increasing recognition that institutional programs must be established to protect RFR.

Regarding the future, the growing awareness of environmental services performed by RFR, as well as increasing demand for river corridor enhancement and protection for passive recreation may help move RFR toward a more sustainable future. However, it is less certain if environmental regulations and institutional programs will be in place to support RFR sustainability and stem fragmentation and loss of RFR from development along the Ohio River mainstem. Accordingly, the future ES of RFR is classified as "marginally sustainable."

An important issue is the need for institutional programs for riparian area management. Examples of such program features include, but are not limited to:

- requiring impact identification and mitigation via NEPA,
- designation of special management areas on public lands,
- regulation of activities on privately-owned riparian areas,
- utilization of incentives such as cost-sharing, low-cost loans, or tax reductions to encourage the use of BMPs on riparian areas, and
- the purchase of privately owned riparian lands, either in fee or by easement, for public management.

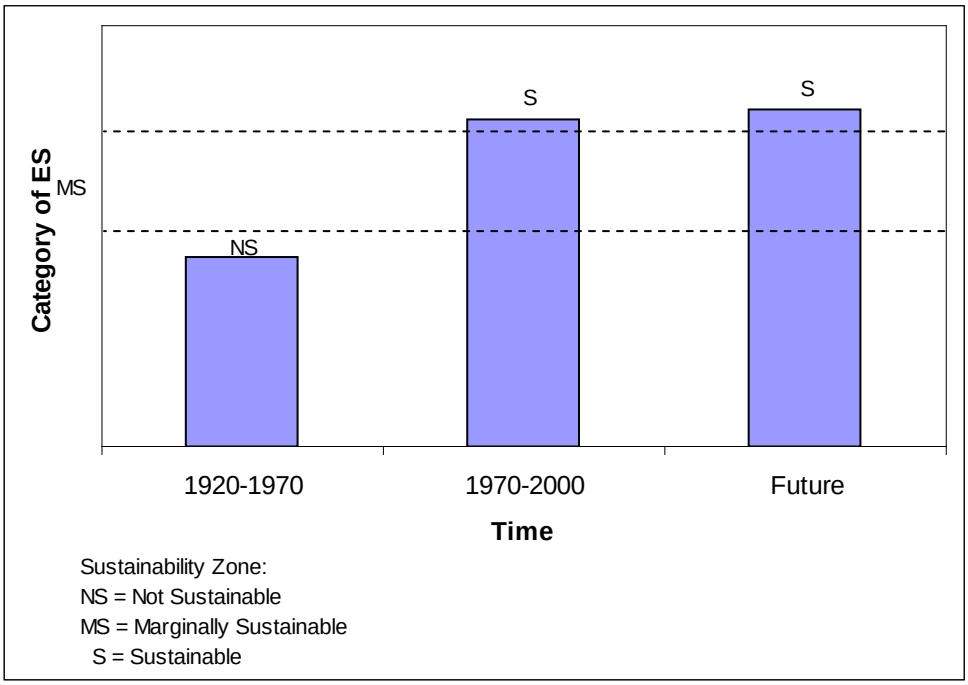
Air Quality

In the time period prior to 1920, and continuing up to about 1970, the air quality of the Ohio River Valley was in a degraded state and thus classified as "not sustainable" due to largely untreated and uncontrolled point and nonpoint pollutant discharges from coal fired power plants, other types of industries and vehicular sources.

Due to the requirements of the Federal Clean Air Act of 1970 (CAA) and subsequent amendments, the air quality in the region has shown a steady improvement in recent decades; thus it is currently in a "sustainable" category.

Regarding the future, it is expected that air quality in the Ohio River Valley will further improve as a result of the continuation of source control and other pollution reduction programs; therefore, it will be maintained in a "sustainable" condition. However, this characterization should not bring complacency; rather, vigilant efforts are still needed to continue effective air quality monitoring and management efforts. Such efforts are reflected in the recent implementation of more stringent standards for ozone and particulate matter and ongoing efforts to establish effective limits for mercury and to continue analysis of the need to control other types of emissions.

Figure 2-5
ES of Air Quality



Health and Safety

In the time period prior to 1920 and continuing into the 1960-70s, health and safety (H&S) issues on the Ohio River represented a broad spectrum of risk factors. Construction and workplace conditions were generally more dangerous than at present; spills and discharges from commercial navigation, river oriented industries, and untreated municipal effluents contributed to a variety of public health risks; and little or no information was available to advise the public of ambient risk levels associated with river oriented activity.

While individual risk factors no doubt varied significantly from time to time, most H&S related issues for the period are categorized in **Figure 2-6** as 'marginally sustainable.' However, activities that involved more direct exposure to water quality risk factors are categorized as 'not sustainable' in **Figure 2-7**.

Improvements to water quality, reduced risks of spills and faster response, improved workplace safety standards, and effective safety standards for recreational boating have all combined to make the Ohio River a safer place to work, live, and play. These improved present day conditions result in a 'sustainable' classification in **Figure 2-6.** Improved conditions have also contributed to reduced risk factors associated with contact recreation and fish consumption. However, problems associated with continued exceedances of biological standards, the persistence of some contaminants associated with fish consumption, and mixed signals regarding fish consumption standards result in a present time classification of 'marginally sustainable' for these activities.

FIGURE 2-6
Health & Safety for Workplace and Boating Accidents

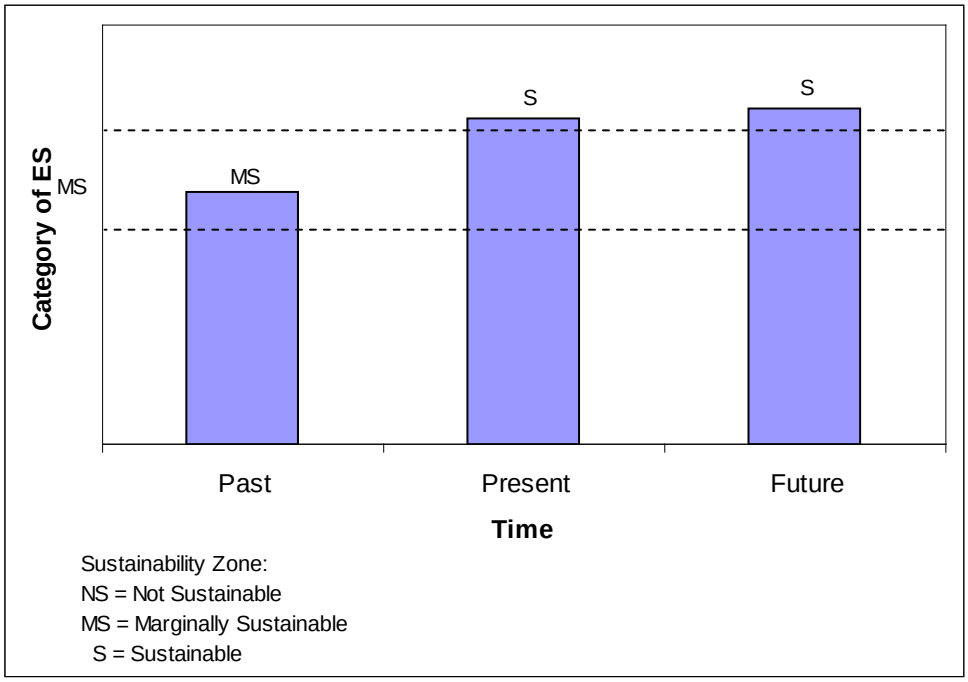
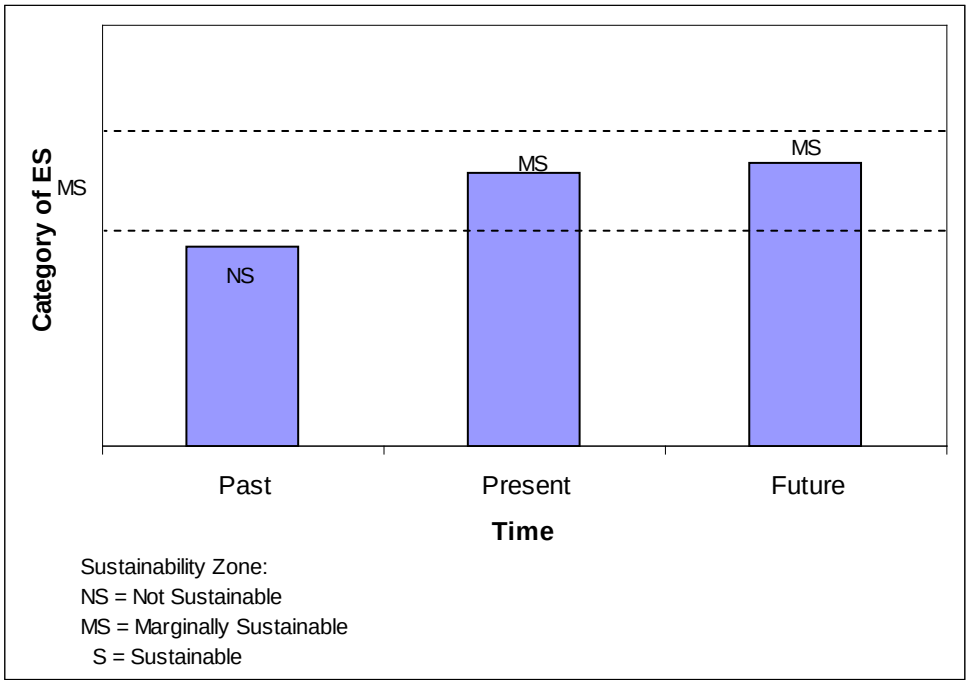


FIGURE 2-7
Health & Safety for Contact Recreation and Fish Consumption



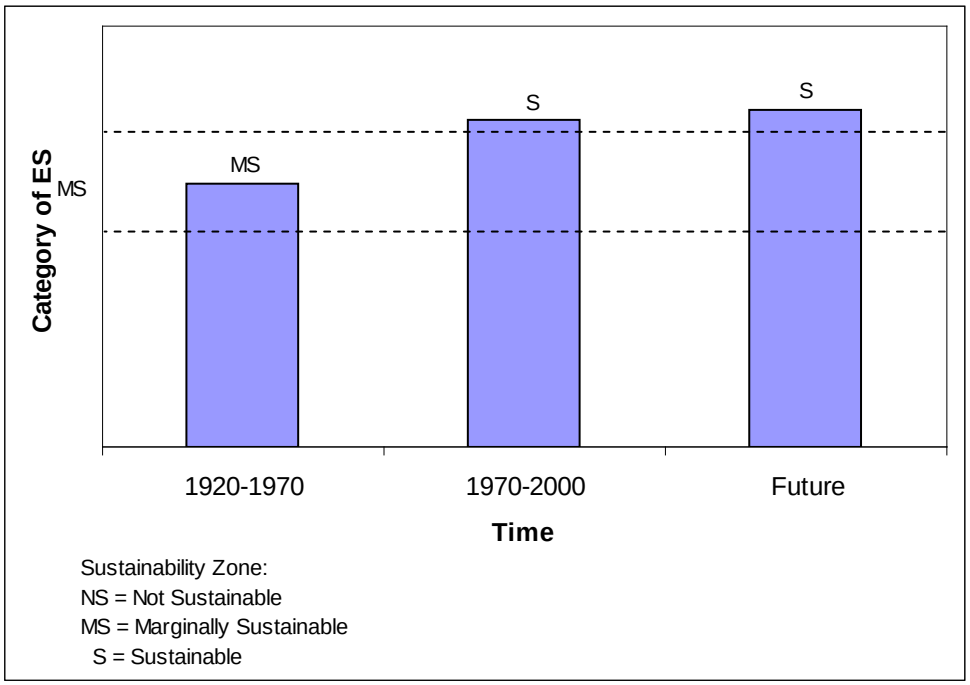
With respect to the future, most H&S issues are expected to remain in the 'sustainable' rankings. It is important to note, however, that continued growth of commercial navigation, recreational activity, river oriented industries, and other uses of the river will require continued improvements in management and regulation of H&S issues just to maintain the status quo.

While improvement of risk factors associated with contact recreation and fish consumption is expected to continue, these factors are kept in the 'marginally sustainable' category as a conservative estimate of potential trends. Some efforts required for continued improvement, such as rehabilitation of sanitary sewer systems to eliminate CSOs and SSOs or reduction of mercury emissions from coal combustion, will require significant investments and long periods of time to achieve results.

Recreation

• In the time period prior to 1920, and continuing up to about 1950, recreation on the Ohio River occurred in a degraded environment due to largely untreated and uncontrolled pollution discharges from growing municipalities, mining activity, and various types of industries and land uses along the river. Although the river continued to be used for recreation during this period, the overall ES was "marginally sustainable" and may have been "not sustainable" for the worst years of pollution. However, recreation information from the worst decades of pollution is limited as that time period coincided with the Great Depression, World War II, and the post-war period shortly thereafter, when leisure time and financial resources were limited.

Figure 2-8
ES of Recreational Resources



• At the present time, recreation on the Ohio River is currently in a "sustainable" condition due in large measure to water quality improvements related to ORSANCO programs and requirements of the FWPCA (and the amended CWA). Water quality improvements, combined with increased economic prosperity, have increased the demand for and stimulated the development of marinas, ramps and other recreation facilities along the river. The recent era of more integrated riverfront planning also has addressed

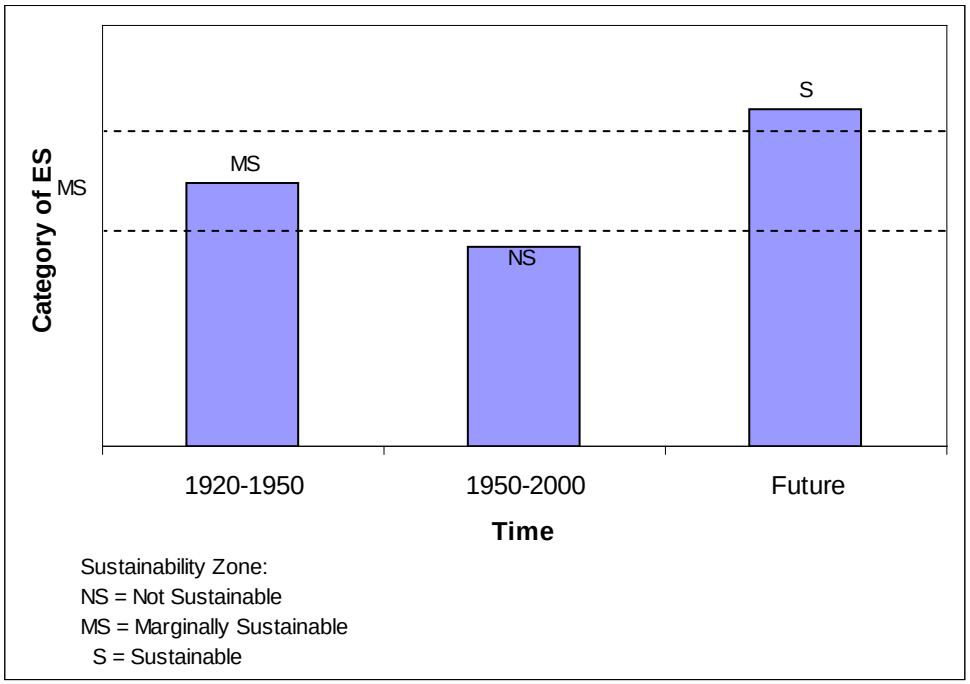
recreation needs and has increased opportunities for an expanded spectrum of recreational choices.

- Regarding the future, it is expected that community planning and development of recreation facilities, further water quality improvements, especially in stormwater and CSO management, and habitat protection and restoration efforts will continue to enhance recreation experiences. Socioeconomic projections for a stable or slowly growing population and continued improving standard of living would be expected to result in continued growth of demand for recreational opportunity. Consequently, the future ES is classified as "sustainable." Although the perception exists that increased participation could lead to overcrowding and competition for limited resources, it does not currently seem to be an overriding influence affecting people's decisions to participate in river-related activities.

Transportation and Traffic

In the time period prior to 1920, and continuing up to about 1950, the waterway transportation and traffic system can be classified as "marginally sustainable". This classification is a result of system capacities that tended to exceed demands; however, the system was not particularly cost-effective or efficient, nor was it focused on minimizing externalities.

FIGURE 2-9
ES of Transportation and Traffic System



In the time period from 1950 to 2000, "non-sustainable" conditions were often experienced as a result of the construction of new infrastructure, demands that exceeded system capacities at numerous locations, and the use of auxiliary locks during repair and maintenance periods. In fact, due to the aging infrastructure, it can be anticipated that the

"non-sustainable" conditions will continue into the future, and even further decline, in the absence of the system investment plan and its implementation.

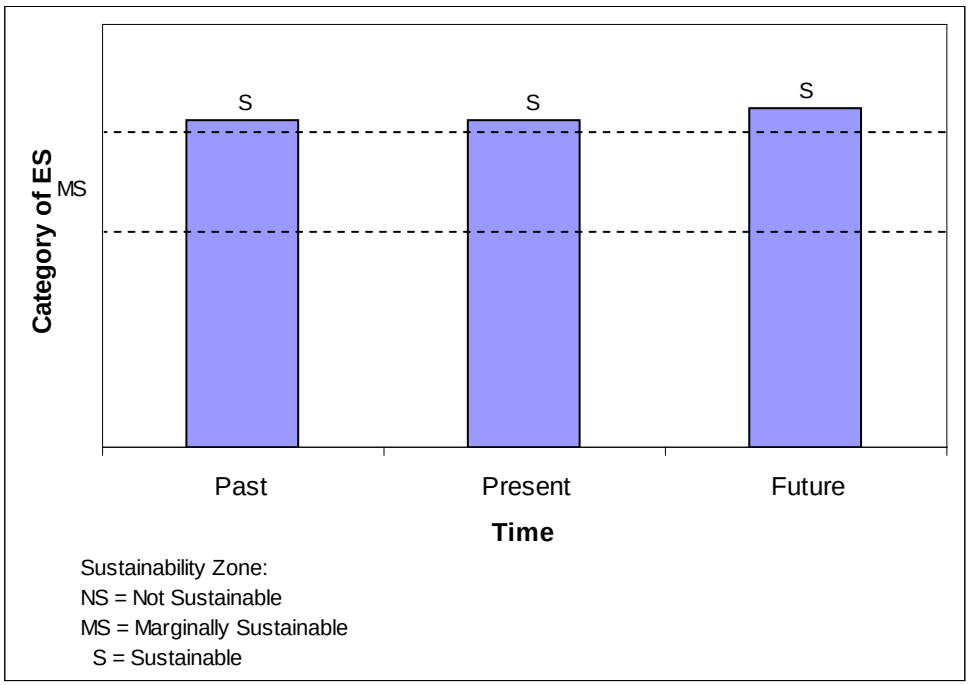
Regarding the future, it is anticipated that the sustainability of the transportation and traffic system will improve as a result of navigation investment actions. Even if recreational uses of the river markedly increases, there is adequate capacity to handle these boats when both chambers are operating.

Socioeconomic Resources

Historic, present and future trends for socioeconomic resources in the Ohio River study area illustrate a pattern of increasing sustainability, related to population growth and conversion of natural resources and landscapes.

The past was characterized by rapid conversion of natural resources and landscapes to meet the industry and infrastructure demands of a rapidly expanding population. Although socioeconomic resources were generally sustainable, volatile patterns of explosive growth and recession cycles occurred such that the ES was somewhat less stable than in recent decades.

Figure 2-10
ES of Socioeconomic Resources



At present, the region offers a reasonably healthy mix of agriculture, varied industries, and commercial, financial, education, and health care services and is supported by a fully developed economic infrastructure. This economic infrastructure includes rail, highway, river and air transportation, modern communication capabilities, and affordable and reliable utilities, including coal fired electricity generation that depends directly on the river navigation system. The social system is equally well established, with a generally

healthy, educated and technically skilled population supported by an established network of urban, suburban, and rural communities.

In recent decades, improved water quality has contributed to increased redevelopment interest for many riverfront neighborhoods. Growing interest in environmental amenities within residential/commercial settings contributes to the design of community oriented restoration projects that combine floodplain functionality, aquatic and riparian habitat enhancement, open space, recreational activities, stormwater detention, and related functions within multi-purpose or integrated aquatic restoration projects.

Regarding the future, the projected slow population growth and attendant slow growth of the economy allows for a gradual expansion from the existing infrastructure and an opportunity for relative economic stability in contrast to the 'boom and bust' patterns of the past century. The projected growth patterns may present opportunities to proceed with gradual and better planned processes of development and redevelopment serving the needs and interests of a stable and established population. This steady pattern for development should score higher for sustainability than the more volatile pattern of the past.

Further, ongoing investments in social and economic infrastructure should have a generally positive impact on Socioeconomic Resource values. For the Ohio River valley, most primary infrastructure investments have already been accomplished, including a complete system of interstate and other primary highway networks, railroads, river bridges, airports, locks and dams, levees and floodwalls. Expansion plans for infrastructure continue on the basis of projected demand or existing capacity expansion needs, but a relatively stable population for the foreseeable future should contribute to reduced growth rate in demand for additional primary infrastructure. Future improvements to this system would focus primarily on maintenance, refinement, or replacement of the existing inventory.

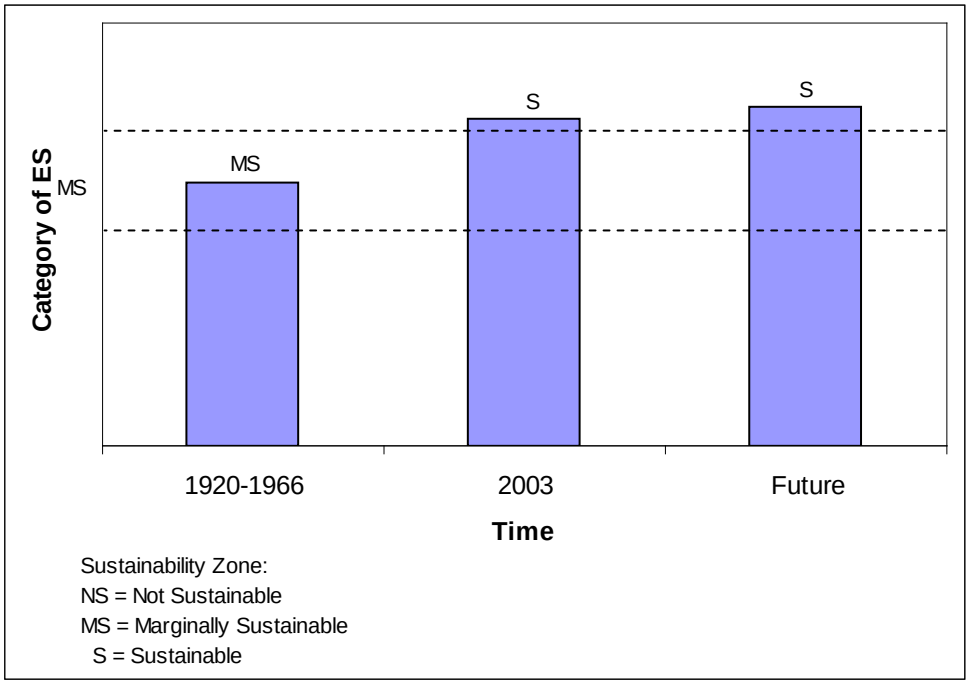
Both lock extension/replacement and ongoing maintenance/repair of existing locks would contribute to positive socioeconomics impacts. Within the context of the larger economy of the Ohio River valley, these actions would contribute fairly small, but cumulative impacts. Long term growth of navigation traffic will require more tugs and barges in operation, more terminals and related port facilities, more maintenance dredging for expanded terminals, and expanded areas of fleeting operations. These expansions would convert existing floodplain lands (e.g., farmland, riparian woods, and wetlands) that now afford habitat protection, open space, and ecosystems values to other uses. Once converted, such lands are unlikely to revert to their former more natural states. Expansion of navigation infrastructure would also compete for space with expansion of riverfront industries, coal fired utilities, mining and other commercial operations. Mixed-use urban waterfront developments, marinas, and other recreation-oriented developments would also compete for waterfront space. Waterfront development policies that support the conversion of brownfields, unused or underdeveloped terminals, or other underutilized industrial sites could help to minimize conversion impacts to existing agricultural uses or riparian habitats.

Cultural Resources

In the period from 1920 and continuing until passage of the National Historic Preservation Act of 1966 (NHPA) and other preservation acts later in the 20th century, limited measures were in place to preserve and protect cultural resources; most resources remained unsurveyed. Widespread razing of potentially historic structures during this time is viewed by some State Historic Preservation Offices (SHPO) professionals as having contributed to a decline such that cultural resources may overall have been at the "marginally sustainable" level.

The implementation of cultural resources legislation, including creation of the National Register of Historic Places and establishment of SHPOs, has heightened awareness of the need to preserve historic structures in communities along the Ohio River. Simultaneously, NHPA provisions that require consideration of cultural resources where federal involvement occurs have led to the discovery and preservation of previously unknown cultural resources. Accordingly, the ES classification for the current time is "sustainable."

Figure 2-11
ES of Cultural Resources



Regarding the future, federal and state regulations concerning cultural resources are expected to remain in place and help maintain a "sustainable" condition. During each year of this study, additional resources have become eligible for possible placement on the NRHP, although some SHPO professionals have observed that numbers of NRHP candidate properties may be limited due to societal trends toward disposability, tear down, and sprawl. Additional riverfront development, including recreational areas may result in covering or damage to cultural resources near the land surface.

Positive trends related to cultural resources include

- the development of predictive models to determine probability for cultural resources occurrences,
- recent emphasis on context integration of historic districts, and
- an increasing number of river festivals and other events through which residents of the Ohio River valley are rediscovering the rich cultural heritage of the river.

2.10 INTERACTIONS WITH OTHER VECS

CEA not only considers past, present, and future conditions and trends for individual VECs, but also the interactions which may occur among VECs. Assessment of VEC interactions is prescribed in Step 8 of the CEQ Guidelines: Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities.

VEC interactions for the Ohio River mainstem were visualized by constructing a crosswalk of all potential interactions which were then ranked as high, medium, or low/no interactions, as shown in **Table 2-6.** Interactions rankings were based on information presented in individual VEC chapters of the CEA, as well as on best professional judgment of the project team members.

TABLE 2-6
Interactions among VECS in the ORMSS CEA

VEC Interactions*	WQ & SQ	Fish	Mussels	Riparian/Floodplain Resources	Air	Health & Safety	Recreation	Transportation	Socioeconomics
Cultural Resources				M	M		H	H	H
Socioeconomics	H	M	M	M	H	H	H	H	
Transportation	M	M	H	M	H	H	H		
Recreation	H	H	M	H	M	H			
Health & Safety	H	M			H				
Air	M			M					
Riparian/Floodplain Resources	H	H	M						
Mussels	H	H							
Fish	H								

***Key to shading:**

High

Medium	
Low or no interaction	

2.11 ES OVERVIEW OF ALL VECS

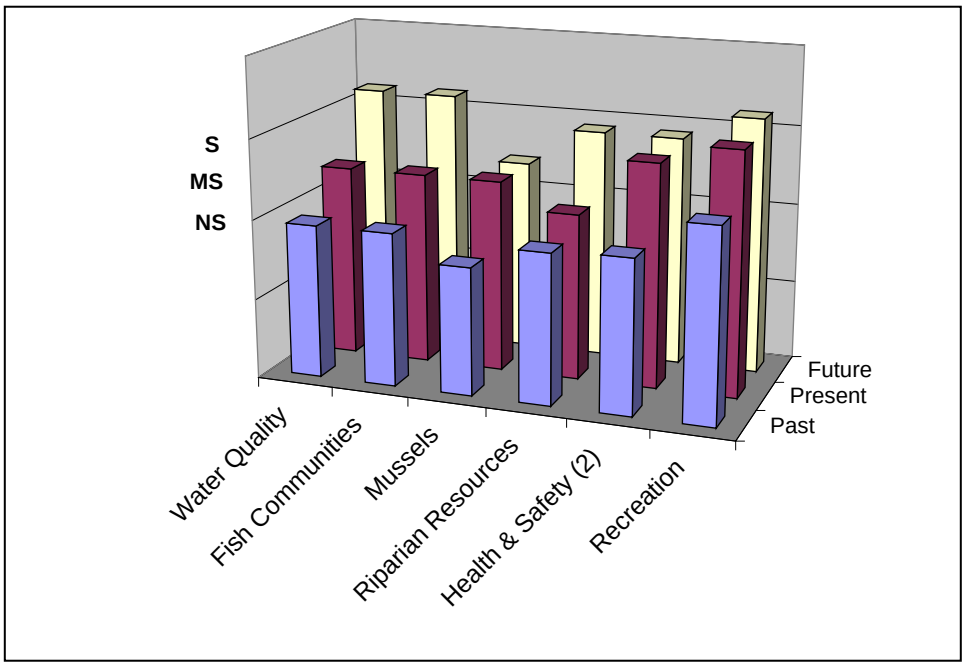
Of 45 VEC interactions cross-referenced in the table, 23 display a high level of interaction, 14 display medium interaction, and 8 potential interactions either have no or low interaction. The four VECS with the highest interaction levels are water & sediment quality (6 Hs), recreation (7 Hs), transportation (6 Hs), and socioeconomics (6 Hs). Other important VECs have fewer interactions in part because they are confined to only one environmental medium. Fish and mussels, for example, are confined to water and, accordingly, have very limited interaction with VECs such as air and cultural resources.

Combining ES classifications for individual VECs with interactions among VECs reveals an overview for all ten VECS discussed in the ORMSS CEA. In this context, ES values of certain VECs become important "drivers" that influence ES values of other VECs in the overall system. Most notably, dramatic improvements in ES of the Water Quality VEC, subsequent to implementation of ORSANCO programs and the Clean Water Act, have driven other components of the aquatic ecosystem of the Ohio River toward increased ES. The ES of fish has measurably improved, while ES of riparian resources and mussels have benefited to a lesser extent. Cleaner water and improved aquatic resources in turn have enhanced recreational boating and fishing on the mainstem and stimulated growth of related support facilities such as marinas. Cleaner water nationwide also has contributed to a trend toward increased development and use of trails, greenways and other recreational facilities along rivers, including the Ohio mainstem. Such recreation facilities often stimulate riverfront development, including restaurants and entertainment districts, which add to local economic growth, but concomitantly contribute to loss of riparian/floodplain resources and cultural resources.

H&S represents a VEC with improved ES in recent decades (due to improved water quality and more stringent workplace regulations), but with the potential for its ES to be driven downward by complex interactions with other VECs. Possible growth of commercial navigation, recreational activity, river-oriented industries, and other river users will require vigilance in management and regulation of H&S issues just to maintain the status quo.

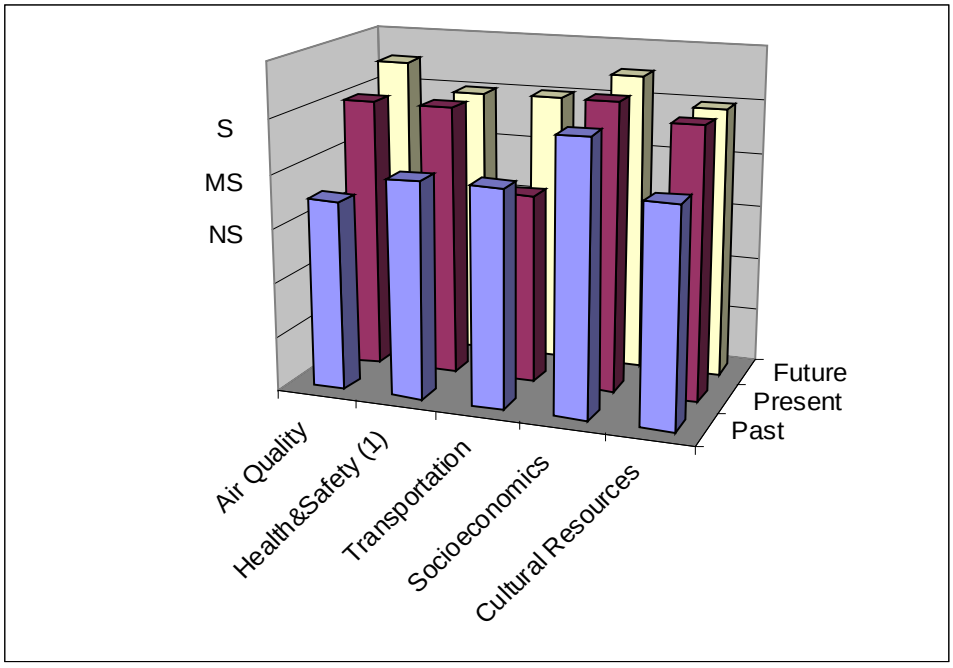
ES values of RFR and mussels are particularly confounding in part because of somewhat limited knowledge of these VECs. Regarding RFR, lack of knowledge until recently was correlated with the relatively low value assigned to these resources. Although interest in RFR has increased, these resources present a challenging complex of biogeochemical, hydrological and ecological processes. Similarly, Ohio River mussels are challenging to study, despite the fact that information on Ohio River mussels has been collected since the 1800s. Scientists studying mussels are hampered not only by lack of knowledge of reproductive cycles and habitats needs, but also by increased water depths due to impoundment of the river. The relatively precarious ES values for RFR and mussels are emphasized in the concerns and opportunities presented in the following section. **Figures 2-12 and 2-13** depict past, present, and future ES levels for all VECs.

FIGURE 2-12
ES Trends for VEC Group 1



Sustainability Scale: NS, values in the "not sustainable" range; MS, values in the "marginally sustainable" range; S, values in the "sustainable" range

FIGURE 2-13
ES Trends for VEC Group 2



Sustainability Scale: NS, values in the "not sustainable" range; MS, values in the "marginally sustainable" range; S, values in the "sustainable" range

2.12 CONCERNS AND OPPORTUNITIES RELATED TO ES OF VECS

The conclusions section on ES of each VEC identified topics of concern for potential inclusion in an adaptive management strategy (**Table 2-7)**. The "Related Indicators" column in the table illustrates the relationship among VECs. For example, indicators for topics of concern for Recreation overlap with those for H&S.

TABLE 2-7
Key Topics for Further Consideration in an Adaptive Management Program

VEC **Topic of Concern**	**Related Indicators**
Water Quality & Sediment Quality	
1) Legacy contaminated sediments	Measures of key water quality parameters, including dissolved oxygen, pH, fecal coliforms, turbidity, total suspended solids and nutrients
2) Bacterial contamination from CSOs	Effectiveness of specific point source control and nonpoint source control programs
3) Continued development in riparian areas	Integrity of riparian habitats – Riparian indicator
Fish	
Asian carp species moving upriver	1) Composition of fish communities, including numbers of intolerant and nonnative species, abundance and diversity 2) Level of disturbance from biotic stressors, such as invasive species and from abiotic stressors, such as river traffic
Mussels	
1) Enhance knowledge of life histories for species of concern, including life histories of host fishes.	Availability of fish hosts to ensure reproductive success and maintain species diversity
2) Importance of incorporating protection of mussel habitat into site-specific permits	1) Amount of habitat with stable substrates, suitable depths, and currents and connectivity to other mussel populations 2) Measures of water quality parameters important to mussel populations
3) Characterize the habitat that best supports species of concern, including historically important sites.	1) Amount of habitat with stable substrates, suitable depths, and currents and connectivity to other mussel populations 2) Extent of food supplies to help ensure good growth rates and reproduction
4) Restore habitats and reintroduce species of concern to suitable areas.	1) Availability of fish hosts to ensure reproductive success and maintain species diversity 2) Amount of habitat with stable substrates, suitable depths, and currents and connectivity to other mussel populations 3) Extent of food supplies to help ensure good growth rates and reproduction

VEC Topic of Concern	Related Indicators
5) Conduct searches for additional populations of species of concern.	1) Availability of fish hosts to ensure reproductive success and maintain species diversity 2) Amount of habitat with stable substrates, suitable depths, and currents and connectivity to other mussel populations 3) Extent of food supplies to help ensure good growth rates and reproduction
6) Enforce all laws and regulations pertaining to collection of specimens and protection of habitat.	Potentially related to all mussel indicators
7) Identify the potential effects and responses to zebra mussel and Asian carp invasions and their control measures.	Extent of disturbance from biotic stressors, such as invasive zebra mussels and from abiotic stressors, such as river traffic
8) Increase public and agency awareness of existing laws that protect mussels.	Potentially related to all mussel indicators
9) Use media opportunities to reach the general public and encourage involvement in the recovery process.	Potentially related to all mussel indicators
Riparian/Floodplain Resources	
1) Continued fragmentation and loss of riparian resources	Integrity of riparian habitats
2) Need for institutional coordination for riparian area management, including: a. Requiring impact identification and mitigation by NEPA b. Designation of special management areas on public lands c. Regulation of activities on privately-owned riparian areas d. Utilization of incentives to encourage use of BMPs, and e. Purchase of privately owned lands for public management	Related to all riparian indicators: 1) adequacy of hydrologic connections between riparian areas and adjacent water bodies and uplands 2) capacity for water storage in floodplain 3) quality of soil structures 4) adequacy of water table and groundwater recharge 5) sustainability of sediment dynamics 6) capacity of riparian areas to intercept pollution 7) integrity of riparian habitats and 8) measures of biodiversity
Air	
Establishment of more effective limits for mercury emissions	Potential sources of contamination associated with past or present activities – Health & Safety indicator
Health & Safety	
1) Growing potential conflicts among recreation, commercial and navigation river users	1) Number of accidents associated with commercial or recreational boating 2) Quality of experience related to river conditions (e.g. density of watercraft, safety concerns) - Recreation indicator
2) Need to eliminate CSOs and SSOs	1) Potential sources of contamination associated with past or present activities 2) Effectiveness of specific point source control and nonpoint source control programs - Water Quality indicator

VEC Topic of Concern	Related Indicators
3) Reduction of mercury emissions from coal-fired power plants	Potential sources of contamination associated with past or present activities
4) Clarification of fish consumption advisories	Number and types of public advisories related to boating, swimming and fish consumption
Recreation	
1) Need to eliminate CSOs and SSOs	1) Quality of experience related to river conditions (e.g. density of watercraft, safety concerns) 2) Number and types of public advisories related to boating, swimming and fish consumption 3) Potential sources of contamination associated with past or present activities – Health & Safety indicator
2) Perception that increased participation could result in overcrowding and competition for limited resources	1) Types of recreation and associated opportunities 2) Availability of recreational-related facilities (e.g. boat launch ramps, marinas) 3) Quality of experience related to river conditions (e.g. density of watercraft, safety concerns)
Transportation &Traffic	
1) Competition over time between navigation and recreation vessels for use of locks	Average queuing times for barge traffic at locks over time
2) Amounts and types of fuels used by tows	Amounts and types of fuels used by tows vs. alternative fuels
Socioeconomics	
Need to balance long-term growth of navigation with infrastructure that supports it.	1) Barge tonnage passing through locks over time - Transportation indicator 2) Numbers of terminals and intermodal transfer facilities over time - Transportation indicator 3) Average queuing times for barge traffic at locks over time - Transportation indicator
Cultural Resources	
1) Limited eligibility of cultural resources for placement on National Register of Historic Places because of societal trends toward disposability, tear-down and sprawl.	Number of properties/sites within the study area listed or eligible for listing in the National Register of Historic Places or listed in any special state listings
2) Riverfront development, including recreation facilities, causing covering or damage to cultural resources near land surface.	1) Effectiveness of Federal regulations and SHPOs in preserving cultural resources within the study area 2) Level of efforts necessary to minimize impacts and recover artifacts and information during unavoidable past and future actions.

Opportunities to enhance ES of VECs through regulatory efforts, educational programs and societal trends also were identified through the assessment of ES and offer positive signs for ES of several VECs, as shown in **Table 2-8**. The continuation or success of such efforts and trends, however, are not assured and need to be monitored through an adaptive management program. The concepts of adaptive management and recommendations related to aquatic and riparian resources were discussed by two small working groups convened during the ORMSS process. Further information on these working groups and their recommendations are presented in CEA Chapter 13, Adaptive Management.

TABLE 2- 8
Potential Opportunities and Positive initiatives to Enhance ES of VECs

Water Quality

- Environmental impacts related to barge operation may be alleviated to some extent though implementation of nonstructural navigation improvements and technological improvements in communications and more environmentally-advanced barge design.
- Activities that support commercial navigation (e.g., port development and maintenance dredging) will continue to be scrutinized by both regulatory agencies and NGOs and may be more strictly regulated. Land disposal of in-stream dredged materials, for example, may become more common.
- Some development activity may revive or renovate underused urban space or industrial brownfields areas, with possible long-term water quality benefits related to surface and groundwater clean up.
- Increasing emphasis on pollution prevention, erosion control BMPs, and implementation of the Phase 1 and 2 NPDES programs could counteract some adverse impacts, particularly in more urban areas.
- In general, several regulatory initiatives in recent years, including TMDL development, the national CSO policy, and Phase 1 and 2 programs should measurably improve water and sediment quality, but, at this time, it is not possible to predict the magnitudes of their beneficial effects.

Fish

- Additional data on Ohio mainstem fish communities should become available through:
  1) new Section 316(a & b) studies required by the Clean Water Act,
  2) development of NAVPAT habitat assessment models, and
  3) further application and evaluation of ORFIn.
  4) incorporation of fish passage features in association with new lock construction and major rehabilitations should contribute to restoration of fish communities.

Mussels

- Implementation of additional regulatory requirements and pollution control programs should improve habitat conditions and contribute to reproductive success and community connectivity.
- Further mussel monitoring and research should enhance the databases and provide additional information for both protecting and promoting mussels.

- Fish passage improvements should help in recovery of mussel resources.

Riparian/Floodplain Resources

- Both a growing awareness of the services of riparian/floodplain services and increased demand for passive recreation along riparian corridors should be beneficial.

Recreation

- Community planning and development of recreation facilities, water quality improvements (including stormwater and CSO management), habitat protection and restoration efforts, will continue to enhance recreation experiences.

Socioeconomics

- Demographic trends indicate potential opportunities to proceed with more gradual and better planned development/redevelopment serving a more stable, established population in contrast to the earlier rapid conversion of resources to meet the demands of a rapidly expanding population.
- Waterfront development policies that support conversion of brownfields and unused or underdeveloped terminals could minimize conversion impacts to existing agricultural lands and riparian habitats.

2.13 CONCLUDING COMMENTS

In accordance with CEQ guidance for assessing cumulative effects, the CEA developed for ORMSS assessed the full direct, indirect, and contributed impacts of further modernization of the Ohio River mainstem navigation system on ten valued environmental components: water quality, fish, mussels, riparian/floodplain resources, air, health & safety, recreation, transportation & traffic, socioeconomics, and cultural resources. Four special methods consistent with the CEQ framework (described in detail in Exhibit A) were developed and applied to systematically conduct the assessment for each VEC.

The CEA went beyond its initial goal and holistically assessed the ES of each VEC as an “ultimate test” for determining the significance of cumulative effects. The resulting ES synopses and actions identified to achieve environmental sustainability of individual and interacting VECs form an important foundation for a long-term adaptive management program for the Ohio River.

Chapter 3

WATER QUALITY AND SEDIMENT QUALITY

3.1 TABLE OF CONTENTS

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Biological Indicators of Water Quality of the Ohio River

Attainment of Ohio River Designated Uses

Interactions with Other VECs

Relevant Actions Affecting Water & Sediment Quality

Cumulative Effects and Environmental Sustainability

Summary and Conclusions

References

3.2 DEFINITION OF WATER QUALITY

This chapter considers how cumulative effects of human use of the Ohio River have influenced water quality and what water quality impacts may be anticipated in the foreseeable future. In the Ohio River Mainstem Systems Study (ORMSS), water quality refers to the integration of physical, chemical and biological parameters of the aquatic environment and their evaluation in relation to human health and aquatic ecological resources. Water quality standards are used to assess the levels at which a particular waterbody is being protected; specific water quality parameters evaluated in the ORMSS are discussed in the section titled Indicators of Environmental Sustainability. The importance of algae, macroinvertebrates, and fish as biological indicators of Ohio River water quality also is considered in this chapter. The effects of water quality on other

important environmental components are integrated in the section titled Interactions with Other VECs.

3.3 OBJECTIVES AND SCOPE OF THE WATER QUALITY STUDY

3.3.1 Objectives

This chapter assesses the system-wide cumulative impacts on water quality of all likely major navigation improvements along the mainstem of the Ohio River during the planning period from 2000 to 2070. Impacts directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFAs) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFAs. These future actions include the major navigation improvements identified in this study; other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies; actions by non-governmental entities, and predictions of general economic expansion and development as well as regulatory changes.

The results of the Cumulative Effects Assessment (CEA) will lead to further consideration of:

1) the significance of impacts of the RFFAs on affected resources
2) the degree to which proposed navigation improvements contribute to those impacts, and
3) what constitutes sustainable water quality for the Ohio River mainstem.

3.3.2 Geographic Scope

The geographic focus for water quality impacts includes the Ohio River mainstem, which is most directly impacted by operation and maintenance of the navigation system, and also includes lands along either bank of the Ohio River lying "between the bluffs." This "floodplain zone" is defined as the meander channel of the Ohio River and includes the 100 and 500 year floodplains as well as terraces of level land lying above these flood zones. Floodplain lands are considered in this assessment because water quality is affected by siltation and contaminants associated with construction, industry, agriculture and other land-based activities and because interactions of the river and its floodplain are important factors in the river's ecology..

3.3.3 Time Frame

The established time frame for this project is 1920 to 2070. The earlier date approximates initiation of the Corps' lock and dam construction activities on the Ohio River while the latter date approximates the end of the 60-year planning horizon encompassed by the ORMSS. Discussion of impacts on water quality, however, requires consideration of water quality conditions before 1920. Understanding pre-1920 conditions is important in determining how the lock and dam (L&D) construction and operation contributed to subsequent changes in water quality.

3.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. A more detailed discussion of the scoping meetings is presented in Chapter 2 of this report.

The meetings were attended by 185 persons and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted.

Water quality was a major focus of the meetings. Comments that directly and indirectly addressed water and sediment quality are presented in **Table 3-1**.

TABLE 3-1
Comments from Public Scoping Meetings

Direct Comments on Water Quality	Relevance to Water Quality	Total
Methods to be used for assessing water quality	Need to accurately document baseline conditions	2
Need to consider 404 application approvals and resultant actions as direct USACE actions	Discharging of dredged and fill materials into the river	1
Increased spills and accidents potentially affecting aquatic life and impairing water quality	Lowering of WQ & damage to aquatic life	1
Cumulative effect of discharges on river may offset water quality improvements	Failure to attain WQ standards and potential damage to aquatic resources	4
Challenges to water quality presented by CSOs and SSOs	Failure to attain WQ standards and potential damage to aquatic resources	2
High levels of mercury, arsenic, fecal coliform bacteria and agri-chemicals in surface water	Failure to attain WQ standards and potential damage to aquatic resources	1
Need for more stringent discharge permitting procedures or moratorium on permits	Failure to attain WQ standards and potential damage to aquatic resources	2
Possibility of implementing mechanical aeration in mainstem pools	Need for sufficient oxygen levels for aquatic life	1
Importance of continued water quality improvements as a high priority	Need for WQ improvements to benefit aquatic life	1
Overall effects of navigation structures and activities on groundwater levels	Potential lowering of groundwater levels	1
Need to protect public groundwater supplies	Potential contamination and lowering of public groundwater levels	1
Need to improve sediment and erosion control from public and private developments	Potential turbidity and sedimentation lowering WQ & damaging aquatic life	1

Need for long-term plan to address silt removal and prevent future sedimentation	Potential turbidity and sedimentation lowering WQ & damaging aquatic life	1
Impaired water quality and bioaccumulation in fish tissue of harmful substances stirred up by dredging	Uptake of toxic substances in the food web	2
Other Comments with Implications for Water Quality	**Relevance to Water Quality**	**Total**
Need for ongoing coordination and cooperation with concerned agencies and groups	Importance of working together to achieve WQ goals	3
Other Comments with Implications for Water Quality	**Relevance to Water Quality**	**Total**
Development of ongoing program to reevaluate cumulative effects every 5 years	Need for continual WQ assessment	1
Importance of including commercial dredging and associated permitting process in CEA	Dredging causes turbidity and can damage habitats	2
Importance of coordination of resources agencies in determining baseline conditions	Need for a common under-standing of baseline conditions	2
Loss of shoreline trees and river property caused by barge activity	Potential erosion and sedimentation and increased water temperatures in localized areas	7
Effects of Greenup L/D improvements on barge queuing	Increased turbidity and sedimentation related to queuing	1
Importance of coordination between Corps and Ohio River public water suppliers	Need to ensure safe public water supplies	1
Prolonged bureaucratic procedures in obtaining discharge permits	Obstacle in achieving WQ standards	1
Bank undercutting and failure caused by increased barge traffic, queuing and wave action	Potential erosion and sedimentation lowering WQ	7
Bank erosion caused by USACE-controlled pool fluctuations	Potential erosion and sedimentation lowering WQ	3
Loss of significant farmland to urban development along river corridor	Increased polluted runoff from impervious surfaces	3
Loss of green space and wildlife habitat with development of marina facilities	Increased runoff & potential pollution from marinas	5
Development of floodplains and wetlands resulting in increased runoff and habitat loss	Increased runoff and loss of wetland filtering capacity	4
Need to develop comprehensive plans for development along river	Importance of nonpoint pollution and cumulative effects	3
Loss of unique, sensitive species due to water quality problems and habitat modifications	Reductions in aquatic life	2

Comments from public scoping meetings were reviewed as the list of RFFAs was developed for this assessment. In some manner, almost all comments in **Table 3-1** are encompassed by the RFFA list. Later in this chapter, the cumulative effects of RFFAs affecting water and sediment quality are grouped and discussed according to their impacts, which may: 1) cause turbidity and sedimentation, 2) contribute to point source pollution, 3) contribute to nonpoint source pollution or 4) contribute to pollution reduction. The comments presented in **Table 3-1** are connected to these potential impacts. For example, the first comment, which concerns Corps 404 permits, is directly related to discharge of dredged and fill materials into the river and potential turbidity and sedimentation. Similarly, most public comments can be linked to one or more of the four impacts mentioned above. These impacts are discussed in more detail in the Cumulative Effects (CE) section of this chapter.

Further, because of the interdisciplinary nature of CEA, public comments frequently are related to more than one VEC. Several comments applicable to water quality,

therefore, also apply to mussels, fish, and/or riparian resources and will appear in the public comments tables in those chapters.

3.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

Indicators of Environmental Sustainability (ES), which vary by VEC, generally provide benchmarks for measuring cumulative effects on a given resource or VEC. ES indicators for water and sediment quality include:

- measures of key water quality parameters, including dissolved oxygen, pH, fecal coliforms, turbidity, total suspended solids and nutrients
- level of conformance with state and federal water quality standards, including attainment of permissible use designations
- TMDL (total maximum daily load) implementation
- effectiveness of specific point source control and nonpoint source control programs
- ability to sustain diverse, healthy populations of aquatic organisms, and
- effectiveness of spill response, monitoring programs, and related precautionary measures.

Key water quality parameters discussed in further detail in the section titled "Past to Current Baseline Conditions" include dissolved oxygen, fecal coliform bacteria, turbidity, total suspended solids, nitrogen, and phosphorus. These indicators were selected because of their importance in characterizing water quality relative to aquatic ecological resources and public health and the availability of long-term data. Information on specific water quality indicators is followed by a brief discussion of the "Ohio River's Use Designations."

3.6 LAWS, REGULATIONS, ORDINANCES AND PROGRAMS

An important regulatory event for the Ohio River's water quality and other aquatic ecological resources was the signing of an interstate compact in 1948 that created the Ohio River Valley Water Sanitation Commission (ORSANCO). The principal mission of ORSANCO was to abate existing pollution and control future pollution of waters in the Ohio River basin (ORSANCO 1998).

Because less than one percent of sewered communities along the Ohio River treated their wastewater in 1948, one of ORSANCO's first actions was to adopt and promote standards for sewage treatment. Another milestone occurred in 1970 when ORSANCO adopted its first Pollution Control Standards, which required all municipal treatment plants along the Ohio River to provide at least secondary treatment of wastewater. These standards were adopted two years before secondary treatment became mandatory under the Federal Clean Water Act (CWA) of 1972.

Every three years since 1970, ORSANCO has revised its Pollution Control Standards for all municipal and industrial discharges to the Ohio River, as changing conditions require. These standards are enforced by ORSANCO's member states, primarily through permits issued under the National Pollutant Discharge Elimination System (NPDES) in Section 402 of the CWA. Provisions of the ORSANCO compact

require state standards for discharges to the Ohio River to be at least as stringent as the commission's Pollution Control Standards. Over the decades since its creation, ORSANCO's programs have broadened to include a spectrum of monitoring activities that help track changes in biological communities and provide a database for environmental decision-making.

In addition to ORSANCO's standards, several key governmental regulations and related initiatives influence water quality in the study area. **Table 3-2** presents information on important federal regulations and established programs, which directly or indirectly influence water quality in the Ohio River.

TABLE 3-2
Laws, Regulations, Ordinances, And Programs Relevant to Water Quality

Law/Program	Key Components	Relevance to Water Quality
Clean Water Act (CWA) (U.S. Environmental Protection Agency)	Establishes structure for regulating pollution discharges into U.S. waters (NPDES permits) Gives EPA authority to implement pollution control programs Requires establishment of water quality standards Recognizes need to address nonpoint source pollution	Provides a comprehensive framework for water quality improvement and protection applicable to all waters of the United States
National Environmental Policy Act (NEPA) (Council on Environ-mental Quality and other resource agencies)	Requires preparation of environmental impact assessments for new construction projects and other actions with significant environmental impacts by private and governmental agencies.	Includes water quality impacts of new projects along the Ohio River such as power plants, Corps projects and riverfront developments.
Safe Drinking Water Act (SDWA) (U.S. Environmental Protection Agency)	Provides for establishment of primary regulations for the protection of public health and secondary regulations related to taste, odor and appearance of drinking water	Helps protect public water supplies for approximately three million people who use Ohio River as their source of drinking water
Water Resources Development Act (WRDA) (U.S. Army Corps of Engineers)	Authorizes Corps' port development, navigation, flood control and erosion control projects through the 1986 act and subsequent amendments	Contains provisions for environmental assessment and mitigation
Oil Pollution Act (U.S. Environmental Protection Agency)	Strengthened EPA's ability to prevent & respond to catastrophic oil spills	Protects RFTR from pollution & damage from oil spills.
Corps' Permitting Statutes (U.S. Army Corps of Engineers)	• Section 10 of Rivers and Harbors Act (1899) prohibits the unauthorized obstruction or alteration of any navigable water of the United States. • Section 404 of CWA authorizes the Corps to issue permits for the discharge of dredged and fill materials into waters of the U.S..	Permits require assessment of impacts on water quality and aquatic ecological resources and mandate mitigation of adverse impacts
State Water Quality Certification (Appropriate state or interstate pollution	• Section 401 of the CWA requires certification from state or interstate water control agencies that a project is in	Provides opportunity for state or interstate scrutiny of such actions on fish and other aquatic

Law/Program	Key Components	Relevance to Water Quality
control agencies)	compliance with established effluent limits and water quality standards.	resources
Small Navigation Projects (U.S. Army Corps of Engineers)	Section 107 of Rivers and Harbor Act (1960) authorizes Corps to develop and construct small navigation projects for harbor protection.	Includes impacts of such actions on water quality
Site Remediation Statutes (U.S. Environmental Protection Agency)	Includes CERCLA, RCRA, SARA and related state program that focus on cleanup and restoration of contaminated sites.	Potentially reduces groundwater and soil pollution sources and contributions to pollution loads in the Ohio River
TMDL Program (U.S. Environmental Protection Agency)	Increasingly important section (§303) of CWA; regulates maximum pollutant load a water body can receive and still attain water quality standards.	Presents a more holistic option to water quality management than traditional "command and control" approaches.
Phase 1 & 2 NPDES Program (U.S. Environmental Protection Agency)	Also developed within the CWA, requires municipalities and certain industrial and construction sites to adopt BMPs to control nonpoint sources of pollution.	Should reduce pollution characteristics of stormwater discharges from urban and industrial zones along the Ohio River.
National CSO Control Policy (U.S. Environmental Protection Agency)	Published by USEPA, calls for communities to implement long-term plan for combined sewer overflows (CSOs) to comply with the CWA. Administered through each state's NPDES permit program.	Should reduce pollution from a major urban source.
Spill Response (U.S. Coast Guard & ORSANCO)	Includes emergency response activities for river-related spills and accidental discharges and is related to the Oil Pollution Act and Section 301 of the CWA..	Minimizes adverse impacts of spills and discharges on mussels and other aquatic life and on water quality
ORSANCO Monitoring (ORSANCO)	Encompasses ongoing water quality and aquatic ecology monitoring programs by the ORSANCO.	Helps track trends in water quality and biological communities and provides database that can inform environmental decision-making

3.7 PAST TO CURRENT BASELINE CONDITIONS FOR CHEMICAL/PHYSICAL INDICATORS AND SEDIMENTS

Limited background information prior to the ORMSS timeframe indicates that water quality in the Ohio River probably declined between 1820 to the 1940s in proportion to population growth and industrial development in the watershed (Pearson 1992). For much of the first half of the 20th century, the Ohio River was treated as an open sewer (ORSANCO 1984).

Pearson noted that overall mean turbidity, dissolved solids, chlorides, nitrates, and sulfates of the Ohio River increased up to the 1940s, while dissolved oxygen levels declined. Acid mine drainage in the upper Ohio River before 1950 contributed to depressed pH values of less than 4.0 in some reaches. Mean monthly counts of total fecal coliform bacteria often exceeded 20,000/100 ml during the same period.

The following information on baseline conditions of selected water quality indicators has been obtained from several sources over more than 60 years at many sampling locations using a variety of assessment methods. Several parameters are considered in determining ORSANCO's aquatic use designations along the Ohio River. Historical and current information on specific water quality indicators is followed by a brief discussion of the Ohio River's Warm Water Aquatic Use designations.

3.7.1 Dissolved Oxygen

Dissolved oxygen (DO) is one of the best indicators of the health of an aquatic ecosystem. Most aquatic ecosystems require 5 to 6 milligrams per liter (mg/L) of DO to support diverse populations. DO has long been an Ohio River parameter of primary concern. Monitoring and research on this parameter in the Ohio River date back to the DO surveys and model development of Streeter and Phelps (1925). DO concentrations in the Ohio River are influenced by numerous factors, including water temperatures, biochemical oxygen demand, photosynthesis, algae, travel and mixing times of pollutants, and daily fluctuations (Wellner and Dinger 1989). Sufficient DO levels, expressed as mg/l, are especially critical to fish spawning success.

ORSANCO's current minimum DO standard for the protection of aquatic life is an average of at least 5.0 mg/l for each calendar day with the minimum concentration not less than 4.0 mg/l. During the April 15 - June 15 fish spawning season, a minimum concentration of 5.0 mg/l is to be maintained at all times (ORSANCO 2003).

These ORSANCO DO standards are consistent with standards of the states along the Ohio River. However, DO standards now enforced by the states were generally designed to reflect the needs of aquatic life as reviewed by a National Technical Advisory Committee in the late 1960s, and the National Academy of Sciences/National Academy of Engineering in the early 1970s. Most state standards still reflect scientific judgment as of those dates. A classic study of DO concentrations and aquatic life conducted in the Ohio River established the notion that 5 mg/l DO was the boundary condition between little fish life and a reasonably productive community of mixed warmwater fish species (Brinley 1944 as cited in US EPA 1986). It is not an unreasonable expectation that DO goals greater than minimum boundary conditions might be established before the year 2070 end of the ORMSS study period.

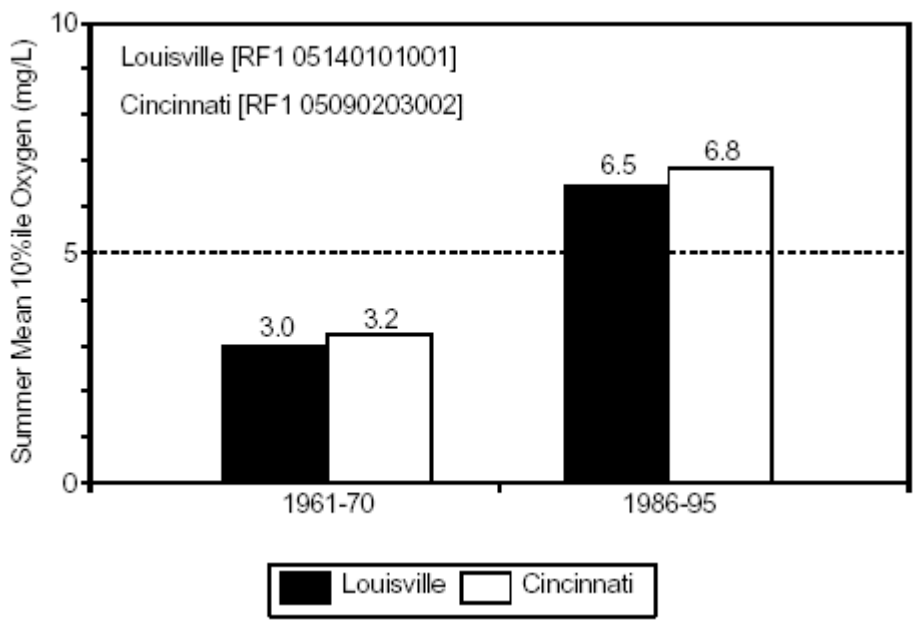
CWA antidegradation guidance (USEPA 1983) has already been applied to management of minimum DO concentrations along the Ohio River. Specifically, antidegradation policy guidance has been applied for the protection of aquatic life to hydropower development in the Ohio River basin portion of USEPA Region III (FERC 1988). Based primarily on USEPA review of numerous studies of DO effects on the survival of sensitive embryonic and larval life stages of nonsalmonid fishes (USEPA 1986), a minimum DO criteria of 6.5 mg/l was established as a lower boundary for no significant adverse impacts to warmwater fisheries.

Historically, DO levels along the Ohio River were depressed by the biochemical oxygen demand (BOD) of raw or insufficiently treated sewage discharges. In 1936, Congressman Brent Spence testified at a congressional hearing on the pollution of navigable waters that "the Ohio River is a cesspool." At that same hearing the State Health

Commissioner of Kentucky added that "the Ohio River, from Pittsburgh to Cairo, is an open sewer" (USEPA 2000). Following 1948 advances in cooperative management which included signing of the ORSANCO compact, water quality conditions in the Ohio River began to improve. Following the 1965 Federal Water Quality Act, ORSANCO adopted stream water quality recommendations. In 1970, ORSANCO Pollution Control Standard I-70 made secondary level treatment the minimum requirement for wastewater treatment plants. As a result, BOD effluent loading decreased significantly, even as influent loading continued to increase with population increases. Massive Federal cost sharing construction grants to local authorities from 1972 to 1995 helped support planning design and construction of wastewater plants to meet minimum treatment requirements. Corresponding to decreasing levels of pollutant loading, DO available in the river to support aquatic life increased substantially (USEPA 2000). **Figure 3-1** compares DO levels near Cincinnati and Louisville before and after implementation of the CWA.

Prior to effective wastewater treatment, low DO values were typically recorded downstream from the three major population centers of Pittsburgh, Cincinnati and Louisville. Until the late 1960s and mid 1970s, substantial DO sags occurred downstream of these population centers. During October and November of 1963, for example, "HydroScience" (1969), (cited in USEPA 2003) carefully documented the degree and extent of the DO sag of the Ohio River downstream of Cincinnati. At the normal bottom of the sag between miles 495 and 500, DO concentrations during this period did not exceed 2.0 mg/l. Zero DO concentrations were recorded at both miles 455 and 505. As recently as 1978, DO concentrations as low as 4.0 mg/l were occasionally reported from nearly all ORSANCO monitoring stations during June through September, when temperatures are generally highest and flows lowest. Koryak (1976), studying the upper 130 miles of the Ohio River, found development of DO stratification in navigation pools during low summer flow. Better reaeration occurred at low flows when navigation dams released water through fewer gates with larger openings to create greater turbulence.

FIGURE 3-1
Before And After Comparison of Summer Mean 10th Percentile DO Near Louisville, KY (RM 364-368) and Cincinnati (RM 460-470) During 1961-70 and 1986-95



SOURCE: USEPA (STOrage and RETrieval Water Quality Information System).

Since the completion of secondary sewage treatment facilities at most major cities in the late 1970s, few low oxygen events occur unless wastewater treatment facilities are temporarily shut down for repairs, maintenance or emergencies (Pearson and Krumholz 1984). By 1987, Wellner and Dinger actually found elevated DO concentrations up to a mile downstream from major wastewater treatment plants, indicating the general effectiveness of wastewater treatment reaeration on DO. Additionally, flow augmentation from reservoirs on Ohio tributaries assists in maintaining oxygen levels and in waste assimilation.

Potential retrofit hydropower development at Ohio River navigation dams could affect DO levels in the river. At this time there are six operating hydropower facilities along the Ohio River mainstem: McAlpine RM 606.5, Markland RM 531.5, Greenup RM 341.0, Racine RM 237.5, Belleville RM 203.9, and Hannibal RM 126.4. However, increasing energy prices and favorable public policy could in the future create incentives for additional hydropower development. During the late 1980s, when such conditions occurred, nearly every navigation dam on the Ohio River and its tributaries, as well as most Federal storage reservoirs in the basin, were permitted or licensed by FERC for hydropower development.

Potential hydropower generation at the first five Ohio River navigation dams (Emsworth, Dashields, Montgomery, New Cumberland and Pike Island), in particular, could affect DO levels in the river, because diversion of river flows through turbines can interfere with the rapid introduction of oxygen which occurs when water passes over a dam. Since the 1970s, the USACE has operated these five dams to manage the energy of their discharges to promote efficient gas exchange and reaeration of discharged waters. These operations principally involve schedules of gate operations designed to promote tailwater turbulence and air entrainment during low flow periods. These operations have been very successful and have eliminated serious summer DO depressions along this reach. An additional benefit to water quality from these operations to maximize gas exchange, achieved perhaps at somewhat of a cost to local air quality, is the stripping of volatile organic compounds (VOCs) from the water discharged (FERC 1988, Koryak 1988, Kincaid et al 1988).

The Federal Energy Regulatory Commission (FERC) analyzed the potential cumulative impacts from stacked retrofit hydropower development at navigation dams along the upper 350 mile-long reach of the Ohio River (FERC 1988). The results of FERC model studies demonstrated that there would be substantial declines in dissolved oxygen concentrations from stacked hydropower projects then licensed or permitted along the upper 150 mile reach of the Ohio River during both low and moderate summer season flow periods. Essentially, this entire reach, which at present generally exceeds the minimum warmwater antidegradation DO criteria of 6.5 mg/l, would fail to meet this standard. Downstream of Willow Island Dam, adverse cumulative impacts from stacked retrofit hydropower development were predicted to be more moderate if mainstem hydropower were developed as then proposed. FERC also piggybacked a bioenergetics model on to their hydraulic/water quality model, which showed a very substantial adverse impact to fish growth in the Ohio River from the losses in DO. Again, this impact was most severe along the upper 150-mile reach of the river. DO concentrations along the longer and deeper pools downstream of Willow Island Dam do not appear to be influenced as strongly

by operations at the navigation dams, and are generally not as well aerated at low summer flows as the pools in the upper river.

At present, there are no hydropower facilities operational on the Ohio River upstream of Hannibal Dam. However, electrical energy costs and public policy changes between now and the year 2070 may again encourage additional hydropower development along the Ohio River which could influence future DO concentrations and fish growth in the river.

ORSANCO policies require hydropower developers to:

1) conduct studies to determine the level of aeration provided by the dam prior to hydropower construction,
2) replace the aeration capacity when needed to maintain river DO conditions, and
3) continuously monitor DO levels above and below the facility, with results made available to ORSANCO.

3.7.2 pH/Acidity/Alkalinity

pH is a measure of the acidic or alkaline (basic) nature of a solution as ranked on a scale to 1 to 14. pH affects many chemical and biological processes in water. Below a pH of 7.0, water is acidic; above 7.0, water is alkaline or basic. Because the pH scale is logarithmic, a drop in pH by one unit is equivalent to a ten-fold increase in acidity. Therefore, a water sample with a pH of 5.0 is ten times as acidic as a sample with a pH of 6.0. ORSANCO's current pH standard to protect aquatic life is between 6.0 and 9.0 standard units (ORSANCO 2003). Significant environmental impacts of pH involve synergistic effects with other substances (e.g., iron, aluminum, ammonia, and mercury).

Tributary waters to the Ohio River, especially the upper reaches, have historically experienced extreme variations in pH, acidity, and alkalinity. While pH values in excess of pH 9.0 maximum criteria have been observed, values depressed below pH 6.0 minimum criteria were most typical. Also, although massive dumps of acid metal pickling liquors and other episodic events have been documented, chronic acid mine drainage (AMD) from high-sulfur bituminous coal mines were primarily responsible for low pH conditions in the river.

AMD is the result of the oxidation of iron sulfides found in coal and coal underlays and overburdens. In the process of mining, these reduced minerals are uncovered and exposed to the oxidizing actions of air and water. Autotrophic sulfur and iron-oxidizing bacteria are major process catalysts of reactions, which form sulfuric acid and metal hydroxides. AMD is typically accompanied by mineralization of waters and heavy metal pollution, mostly dissolved, suspended, and/or deposited iron hydroxides and other associated absorbed and/or co-precipitated metals.

As early as 1912, the Pittsburgh Flood Commission identified AMD as a severe economic problem responsible for the corrosion of pipes, pumps, boilers, and navigation structures. By 1914 the U.S. Public Health Service had documented episodic acidification of the Ohio River as far downstream as river mile 172. Data collected by the U.S. Geological Survey and the Pennsylvania Department of Forests and Waters (White 1951) provide a record of conditions between October 1947 and September 1949, when total

acidity at Ohio River mile 17 ranged from 5 to 86 and averaged 30 mg/l as $CaCO_3$. The pH of the Ohio River ranged from 6.6 to 3.65 and averaged 5.3. Between 1940 and 1965 pH measurements of less than 5.0 (often less than 4.0) were commonly recorded in the upper 100 miles of the Ohio River. Below river mile 100, pH values usually increased gradually to mean values of 7.2 to 7.8 between Cincinnati and Cairo, river miles 463 and 981, respectively. During this same period, unusually high pH records of between 9.0 and 10.0 were occasionally seen in all reaches of the river, probably due to undocumented industrial discharges. During the 1960s and 1970s, much progress was achieved in reducing AMD pollution in the upper Ohio River Basin. The success of these efforts can be seen in the annual reports of ORSANCO for the period 1974-1980. In most of these years 100% compliance with established standards for pH were achieved at all monitoring stations in the Ohio River (Pearson and Krumholz 1984).

Unusually high pH and alkalinity values are a fingerprint of runoff from urban centers in the basin. Sewage is typically alkaline, as is runoff from paved urban surfaces. Alkaline steel mill slag leachates significantly influence the pH and alkalinity of runoff in the industrialized upper reach of the river (Koryak et al. 2002). Algal blooms during summer season low flow periods can also increase pH and alkalinity.

While it would appear that AMD problems in the Ohio River have been under control for the past several decades, much of the progress in the abatement of AMD has been achieved by mandatory treatment of the effluents of active coal mines. Treatment of these mine discharges was supposed to continue in perpetuity. However numerous mining operation bankruptcies have recently occurred, and will probably continue to occur in the future. Huge underground mining complexes have been abandoned, and are now flooding. Without intervention, these abandoned mines will eventually again discharge AMD to the waters of the upper Ohio River Basin. As of the time of this document preparation, plans of action have been developed to deal with individual problems but a basin wide solution has not occurred.

3.7.3 Fecal Coliform Bacteria

The presence of fecal coliform bacteria in aquatic environments indicates water has been contaminated with fecal matter of humans or other animals, generally from the overflow of domestic sewage or nonpoint sources of waste. At the time of contamination, the source water may have been contaminated by pathogens or disease producing bacteria or viruses, which also can exist in fecal material. Consequently, the presence of fecal coliforms is an indicator of a potential health risk for humans exposed to such water.

Typhoid fever statistics presented by Drake (1931) for the period between 1873 and 1930 show that, historically, human health in the Ohio River valley was severely threatened by fecal pollution. In 1907, for example, Pittsburgh typhoid fever cases and death rates were 1,119.2 and 125.2 per 100,000 inhabitants per year, respectively. Water filtration systems of river sources of public water supplies were constructed between 1907 and 1914, and by 1914 typhoid cases and death rates dropped dramatically to 64.5 and 15.4 per 100,000, respectively. Ironically, sixty years earlier on October 25, 1847, James H. Laning of Cincinnati had appeared before Pittsburgh Common Council to propose filtration of public water supplies. By 1930, typhoid cases and death rates had further declined to 11.2 and 1.5 per 100,000, respectively. Filtration treated only intake waters. Bacteriological pollution of the river later declined with the improved wastewater

treatment described in the previous section. Today, primary water born gastrointestinal human diseases of concern include giardiasis and cryptosporidiosis. Also, amoebic meningoencephalitis from thermophilic *Naegleria fowleri* is a unique potential health problem in the thermal discharges, recipient waters, and cooling towers of the numerous power plants along the Ohio River. Data developed by Sykora et al. (1983) suggests that the optimum water temperature for pathogenic *Naegleria* strains in artificially heated effluents is between 27 and 35°C. While the probability that heated effluents might contaminate large bodies of generally cooler water is limited, swimming and other water contact activities are not advisable in the heated effluents and in sections of recipient waters affected by elevated water temperatures. Pearson (1992) notes that direct effects of coliform bacteria on fishes are negligible, but that sewage contamination affects fishes by altering nutrient levels, biochemical oxygen demand, DO, and suspended sediments and by adding organic compounds.

Total coliform bacteria data for the Ohio River go back more than 60 years. The Ohio River Committee, reporting on the condition of the river from 1939-1943, found mean total coliform counts exceeding 20,000/100 mL for 31 to 61 percent of the time at monitoring stations (Pearson 1992). When the ORSANCO compact was signed in 1948, only one percent of all domestic sewage was treated before being dumped into the Ohio River. In 1951, ORSANCO established its first bacterial water quality standards of <5000 total coliform bacteria per 100 mL for drinking water and <2000 /100 mL for contact recreation. By 1964, when 97 percent of the population along the Ohio River was served by primary sewage treatment, concentrations of the coliform bacteria in the upper 100 miles of the Ohio River had dramatically declined. The mean at Wheeling, W.Va., for example, was 62,000/100mL in 1952, but only 950/100mL in 1964. In the river's middle and lower reaches (where historic levels were never as high as in the upper river), however, coliform bacteria levels in 1964 remained nearly the same as in 1952-53, or had declined only slightly (Pearson 1992). The greater assimilative capacity of the middle and lower river relative to the upper river is an important factor to take into account when making comparisons of river segments. In addition, much of the population growth along the lower river occurred after 1960, which allowed for concurrent construction of wastewater treatment plant (WWTP) capacity as the population grew.

In 1970, ORSANCO began to require all municipal wastewater treatment facilities to provide secondary treatment (ORSANCO 1984). Subsequently, coliform bacteria levels in the Ohio River were expected to decline. This decline did not occur in the river overall, although decreases did occur in the upper 100 miles. Complicating matters somewhat during the 1970s, ORSANCO began reporting only fecal coliform levels as a better indicator of sewage contamination. In 1976, ORSANCO adopted the new federal drinking water standard of 2000 fecal coliforms/100mL, a standard that has remained to date. By 1978-79, ORSANCO reported nearly 100 percent compliance in the lower two-thirds of the river and compliance about 75 percent of the time in the upper 100 miles, where problems had previously been most acute (Pearson and Krumholz 1984).

After reviewing bacterial data through the 1980s, Pearson (1992) noted that the largest decreases in coliform bacteria in the Ohio River mainstem apparently occurred after primary sewage treatment facilities became operational, with the most dramatic declines reported in the upper 100 miles. Nevertheless, most violations of the drinking water standard occurred in the upper river throughout the 1980s. The primary contact recreation

standard of ≤200/100 mL, established for full-body exposure recreation (e.g., swimming and water skiing), also was violated frequently (Pearson 1992).

Only slight declines in coliform levels occurred in the lower two-thirds of the mainstem during the same time period, despite major improvements in sewage treatment facilities. The relatively small declines were attributed to sewer overflows, nonpoint sources, inadequate disinfection at treatment plants and poor secondary treatment plant operation and design. Throughout the 1980s, however, the lower two-thirds of the Ohio River usually met the contact recreation standard of ≤200 fecal coliform bacteria per 100 mL (Pearson 1992). This standard is still used in 2005.

ORSANCO coliform bacteria monthly sampling data (May 1992 - October 1999) downstream from six urban areas along the river indicated that the highest number of exceedances of the primary contact recreation standard occurred downstream from Pittsburgh, where 62 percent of samples exceeded the standard of 200/100 mL as a monthly geometric mean. **Table 3-3** indicates the lowest number of exceedances occurred downstream from Evansville.

TABLE 3- 3
ORSANCO Fecal Coliform Sampling Exceedances
May 1992 - October 1999

Urban Area	Total samples	No. exceeding standard	% exceeding standard
Pittsburgh	48	30	63
Wheeling	48	17	35
Huntington	47	17	36
Cincinnati	46	18	39
Louisville	43	13	30
Evansville	46	13	28
Source: ORSANCO. 2000a. Biennial Assessment of Ohio River Water Quality Conditions for Water Years 1998 and 1999.			

The results of wet and dry weather cross-sectional surveys of the pool of Emsworth Dam near Pittsburgh by Knauer (2001) demonstrated some impacts of precipitation and combined sewer overflows (CSOs) on bacteriologic conditions in the river near urban areas. During dry weather in the 2001 recreation season (May 15-September 30), fecal coliform concentrations generally met target goals for recreational use (≤ 200 CFU/100 ml). Storms with precipitation intensities of less than 0.7 inches had little lasting impacts on fecal coliform concentrations. However, more significant and persistent fecal coliform contamination occurred following storms with greater than 1.2 inches of precipitation. Areas near the river banks tended to have higher fecal coliform concentrations, and to recover less quickly than mid-channel locations. Unfortunately, most contact recreation occurs near shore. Also, local small urban streams tributary to the navigation system, while not large enough to measurably affect the mainstem, tended to be contaminated with fecal coliforms even during dry weather. Shallow bars at the mouths of these streams were observed to be fishing and recreation concentration points along the river, as were actual CSO discharge locations. The exact number of CSOs along the mainstem Ohio River in this area is probably less important than the fact that there are a total of 420 CSOs in urban Allegheny County near Pittsburgh which impact the Ohio River.

3.7.4 Turbidity and Total Suspended Solids

Turbidity and total suspended solids (TSS) both indicate the amount of solids suspended in water, whether mineral (e.g., soil particles) or organic (e.g., algae). TSS is measured by weight of material per volume of water (mg/L) while turbidity is measured as the amount of light scattered by a water sample, with more suspended particles causing greater light scattering. Turbidity is reported as nephalometric or Jackson turbidity units (NTUs or JTUs), depending on the measuring instrumentation. ORSANCO has no specific standard for TSS or turbidity. Turbidity and TSS are closely related to stream flow and velocity.

High concentrations of particulate matter in a water body can cause increased sedimentation and siltation, which, in turn, can damage habitats for fish and other aquatic life. Further, suspended particles provide attachment sites for other pollutants such as heavy metals and bacteria. Turbidity and TSS of the Ohio River are influenced by erosion characteristics of native soils and geology, but dredging for channel maintenance and land use are probably greater factors. Soil loss and runoff to waterways are accelerated by human activities such as clearing, draining of wetlands, agriculture and development. Current agricultural practices, reforestation and runoff controls from construction sites help minimize sediment losses. Simultaneously, increased nutrient loads and runoff from impervious surfaces stimulate algal productivity and increase pollutants attached to soil particles.

Qualitative reports from the 19th century describe the Ohio River as naturally clear except for the higher turbidities of the spring "freshes" (periods of flooding). Pearson and Krumholz (1984) note that Mark Twain and others described the Ohio as naturally the clearest of the three major arms of the Mississippi River system. ORSANCO reported mean turbidity values from 2 to 576 JTU for 43 Ohio River stations monitored between 1952 and 1955 and 2 to 1301 JTU monitored in 1962-63. From 1953-1985, ORSANCO observed a decreasing trend in turbidity, coinciding with the construction of numerous flood control reservoirs on major Ohio River tributaries. These impoundments trap sediments and release clearer water. According to Pearson (1992), the range of turbidities to which Ohio River fish are exposed in modern times is probably not significantly greater than in prehistoric times, but the mean turbidities are higher now. Higher mean turbidities have influenced the fish community more indirectly (e.g., by reducing favored food supplies, visibility of food organisms, and spawning areas) than directly (e.g., clogging gills, smothering eggs or larvae). Higher turbidities and concomitant siltation also have contributed to the decline of native mussels in the Ohio River mainstem.

ORSANCO's 2000 Pollution Control Standards include no specific turbidity or TSS standard for protection of aquatic life, but generally state that waters discharged to receiving waters be free from materials that will settle to form objectionable sludge deposits or suspended materials that will be unsightly or deleterious. Sewage must be treated so as not to exceed the TSS arithmetic mean in monthly samples of 30 mg/L or a weekly arithmetic mean of 45 mg/L.

3.7.5 Nitrogen and Phosphorus

Less information exists for nitrogen and phosphorus than for the other water quality metrics discussed above. Both nitrogen and phosphorus are nutrients that stimulate growth

of algae and aquatic plants that provide food for fish. Major sources of nitrogen and phosphorus entering rivers include municipal and industrial wastewater, septic systems, agricultural runoff, and atmospheric deposition. Nitrate and phosphate are the forms of these elements most readily available for plant growth. Hynes (1970) notes normal concentrations of nitrate and phosphate in river water are low because plants rapidly take up both ions.

Nitrate is the fully oxidized form of nitrogen and, except under polluted conditions, is the form normally occurring in streams. Ammonia (NH_3) is the most common form of nitrogen in sewage and is toxic to aquatic life in relatively low concentrations. In flowing water, bacteria convert ammonia to nitrites and nitrates. An ORSANCO study of long-term water quality trends from 1977 through 1987 indicated a strongly decreasing trend in ammonia nitrogen and a decreasing trend in total nitrogen, primarily related to wastewater treatment plant improvements and stringent discharge permit requirements (ORSANCO 1990).

ORSANCO water quality criteria to protect human health are 10 mg/L for nitrite + nitrate nitrogen and 1.0 mg/L for nitrite nitrogen. Recent data from 17 sampling stations between New Cumberland L/D (RM 54.4) and Paducah indicated nitrogen levels well below the standards (ORSANCO 2000a).

ORSANCO has not established a standard for total phosphorus, although USEPA recommends a maximum limit of 1.0 mg/L for flowing waters. A strongly decreasing trend in total phosphorus observed basinwide during ORSANCO's 1977-1987 long-term study was attributed to the switch to phosphate-free detergents. More recent phosphorus data were collected at 17 navigation dams for 17 dates between November 1996 and September 1999. No samples exceeded 1.0 mg/L from Hannibal L/D (RM 126.4) upstream and only a few samples exceeded that level downstream to Markland L/D. Numerous recordings above 1.0 mg/L occurred downstream from Markland L/D, primarily during the first half of 1997 (ORSANCO 2000a). These higher levels may have been related to increased runoff of agricultural chemicals.

Concerns about the effects of algal blooms on aquatic life and drinking water quality have led USEPA to direct states to adopt water quality criteria for nutrients. Algal blooms have not harmed aquatic life in the Ohio River, but drinking water suppliers have reported increased algal activity, which may result in taste and odor problems. Data from ongoing algal and nutrient analyses of Ohio River water supplies should assist in the development of appropriate nutrient criteria (ORSANCO 2001).

Depressed oxygen levels (hypoxia) in the northern Gulf of Mexico, which have caused national concern during the past decade, are attributed in large measure to heavy nutrient loads from the Mississippi Basin, including the Ohio River. Nitrate-nitrogen, associated with intensive corn and soybean production in Midwestern states, including Ohio, Indiana and Illinois, is a major factor contributing to hypoxia. Additional factors increasing delivery of nutrients to the Ohio River and its tributaries and, subsequently, to the Gulf of Mexico, include loss of wetlands and riparian areas that naturally remove nutrients, use of field drainage tile systems that accelerate agricultural runoff, atmospheric deposition, and the natural occurrence of nitrogen in Ohio basin soils. The National Science and Technology Council estimates that 44 percent of the nitrate-nitrogen reaching the Gulf of Mexico originates in the Ohio River basin (National Science and Technology

Council 2002). ORSANCO is working to develop a nutrient reduction action plan for the Ohio River sub-basin of the Mississippi basin (ORSANCO 2004a).

3.7.6 Development of Total Maximum Daily Loads (TMDLs) for Various Pollutants in the River

Total Maximum Daily Load (TMDL) refers to the maximum amount of a pollutant that a water body can receive and still meet water quality standards. Consequently, a TMDL represents the sum of allowable loads of a single pollutant from all contributing point, nonpoint, and natural sources. The TMDL program originated from Section 303(d) of the Clean Water Act, which requires the development of TMDLs for all waters in which beneficial uses are impaired. During the 1970s and 1980s, however, TMDLs were largely overlooked as states focused on controlling point sources of pollution through NPDES permits. The present emphasis on TMDL program implementation has been driven by: 1) the realization that point source controls alone are insufficient to attain the nation's water quality goals and 2) citizen lawsuits forcing EPA to develop guidance for the TMDL program (CGER 2001).

Under USEPA regulations promulgated in 1992, states are required to identify water bodies that are not meeting water quality criteria established for specific designated uses. For each impaired water body, a state must determine the amount by which sources of point and nonpoint pollution must be reduced to meet stated water quality standards. Further, TMDL plan implementation should encompass water body restoration practices, such as habitat restoration and channel modification. Given the huge number of potential TMDLs for impaired river segments, lakes and estuaries nationwide and budget constraints, the National Research Council's Commission on Geosciences, Environment and Resources recently recommended changes to move the TMDL process forward (CGER 2001). TMDLs undergo technical review and public comment, and then are submitted to USEPA for final approval.

Within this complex regulatory and scientific context, TMDLs currently are being developed for the Ohio River. In 1995, ORSANCO initiated its Ohio River Watershed Pollutant Reduction Program to investigate specific pollutants on a watershed basis. The resulting pollutant-specific data have been valuable to TMDL development for dioxin and polychlorinated biphenyls (PCBs) in the Ohio River (ORSANCO 2001). These contaminants have been found in fish tissue at levels warranting the issuance of consumption advisories for certain fish species. The dioxin TMDL was developed in 2000 and applies to the Ohio River from Racine L/D (RM 237.5) to the Big Sandy River (RM 317). Related data indicated that dioxin levels must be reduced from the Kanawha River and Upper Ohio in order to meet water quality standards. ORSANCO is conducting sampling of fish tissue, water sediments and air to further identify sources of dioxin. A TMDL for PCBs was completed for the Pennsylvania (RM 0 – 40) and West Virginia/Ohio portions of the river (RM 40 through RM 317) during 2003 and is being implemented.

Since the completion and approval of these TMDLs, ORSANCO has been interacting with states along the Ohio River in considering the need and probability of extending both the dioxin and PCB TMDLs to include the entire mainstem. Further, ORSANCO has been collecting bacterial data along the entire river that may support the future development of a TMDL for *E. coli* (Sam Dinkins, personal communication).

3.7.7. Sediment Quality

The natural bottom substrates of the Ohio River are mainly sand, gravel, or clay overlain, especially in near shore or other sheltered areas, with silt and/or organic detritus. ORSANCO (1996) noted that fine-grained sediments are usually found at the mouths of tributaries, on river banks and near lock and dam structures. Ohio River sediments are somewhat mobile and dynamic because proportions of surficial bottom materials may be replaced with every storm event.

Bottom sediments are natural "sinks" for many toxic and persistent pollutants that enter waterways. Consequently, sediment quality can reflect historical changes in watershed economies related to industrial and agricultural activity. These deposits represent potential sources of contaminants that may reenter the water column through stream scouring, anaerobic release, and bioaccumulation, as well as through dredging for channel maintenance (Youger and Mitsch 1989).

Significant heavy metal contamination in the Ohio River has resulted from various sources including coal mine drainage with inflows of iron and manganese, and industrial activity, particularly the iron and steel industry of the upper Ohio River valley. Lyman (1987), as cited by Youger and Mitsch, mentions that even with increasing control of point and nonpoint pollution sources, sediments contaminated with heavy metals and other pollutants may continue to adversely affect overlying waters and food chains for years.

Youger and Mitsch's 1987 sediment study was conducted at 11 sites on the Ohio River, primarily upstream of navigation locks between Pittsburgh and Louisville. Samples typically consisted of fine grain silt/clay sediments taken within 100 m of the bank due to high sediment scour in the middle of the river. Concentrations of heavy metals generally decreased with distance downstream, paralleling a trend found in 1977 by ORSANCO. Lower concentrations of most metals, including cadmium, chromium, copper, iron, lead, nickel, and zinc, were associated with a dramatic decrease in the iron and steel industry in the upper river during 1977-87. The highest concentrations of barium, cadmium, copper, manganese, and nickel were found in pools immediately downstream of East Liverpool, OH (RM 54) and Wheeling, WV (RM 118-126). Chromium was highest in the pool below Steubenville, OH (RM 83). With the exception of cadmium and zinc, a slight upturn in concentrations of all metals usually occurred at RM 531 immediately upstream from Markland Dam, illustrating the effects of past and present discharges from the Cincinnati metropolitan region. Youger and Mitsch found concentrations generally were well above background and, therefore, may be a source of contamination in the river for years to come.

As the number of different water and sediment contaminants of potential concern is very extensive, practical and realistic guidance is essential in attempts at contaminant analysis and screening. In this respect, USEPA has developed several lists, one of which is its priority pollutant list. The CWA of 1977 emphasized the control of toxic pollutants and declared 65 priority pollutants to be toxic under section 307(a). This list of 65 toxic pollutants potentially included thousands of specific substances within its generic classes, many of which were then relatively unknown outside the scientific community. Also, many of these specific compounds had only rarely been examined in the environment and analytical methods to conduct monitoring for them were not available. Therefore, in order to implement the 1977 CWA and streamline its regulatory tasks, USEPA defined a high

priority list of 129 specific toxic pollutants, and subsequently (1979) developed and published approved analytical techniques. Also, the presence or absence of bulk contaminants found in sediments does not necessarily provide insight into the potential for these contaminants to reenter the water or food chain. Guidance for determination of the potential to remobilize contaminants in sediments by activities such as dredging and filling was developed initially by a USEPA/USACE technical committee in 1977 (USEPA/USACE 1977), as an implementation manual for Section 103 of Public Law 92-532 (Marine Protection, Research and Sanctuaries Act of 1972). A standard elution test of waters and sediments was one of the products of this effort. This elution test involves vigorous mixing of sediments with river water, and then analysis of the water (the elutriate) after centrifugal removal of suspended sediments.

An example of an early and informative effort to integrate the various guidances discussed above, and to apply such contaminant screening methods specifically to the sediments of the Ohio River, was a "worst case" river sediment study of the upper river conducted in 1980 (USACE 1981). In this worst case study, fine grain size, industrial legacy sediments were analyzed for USEPA designated priority pollutants in bulk sediment samples, river water samples, and sediment/river water elutriates samples. Also, 96-hour static bioassays of these sediment elutriates were conducted, under guidelines recommended by the joint USEPA/USACE Technical Committee on Criteria for Dredged and Fill Material.

The chemical data did not demonstrate a tendency for sediments to release priority pollutants to the water column with vigorous mixing. In fact, rather, there was a tendency for eluted sediments to adsorb to priority pollutant metals and remove them from the water column. This tendency was consistent with the principal findings of a study by Brannon et al. (1976), "no relationship existed between trace metal concentrations in the standard elutriate and total metal concentration in the sediments. This held true even though some sediments were apparently highly contaminated with some trace metals. This clearly suggests that sediments can be a stable sink or repository for some contaminants." As will be discussed later, the only statistically significant mortality to aquatic organisms observed in the bioassays was in a steel mill slag elutriate.

Other studies, however, have demonstrated that it is possible for some sediment contaminants to be remobilized under some hydrologic conditions. For example, severe episodic shock loads of phenols were being experienced at the Wheeling, West Virginia water intake during the 1980s. Total recoverable phenolics (TRP) concentrations in the Ohio River at the intake sometimes were in excess of 100 ppb, and created severe taste and odor problems in the city's water supply. Along with cyanides, phenolic wastes have long been associated with coking and primary metals manufacturing, but NPDES permits in place at the time and agency discharge monitoring efforts could not identify the source of the Wheeling phenol problem. Since the shock loads were mostly associated with rising hydrographs, during winter high flow periods, resuspension of river sediments was suspected to be contributing to the problem. The results of a 1988-1989 study (USACE 1989a) confirmed these suspicions. The primary source of the problem was found to be meta cresol. This phenolic compound was not released in quantities by any industrial discharger, but apparently formed as an intermediate by-product of the microbial decomposition of discharged aromatic hydrocarbons, most likely toluene from a nearby plant in Tiltonsville, Ohio. The meta cresol was apparently formed in biologically active fluff that accumulated in deep scour holes in the river, and was resuspended during rising

flow periods. Nichols et al. (1983) point out that fluid mud, an intermediate stage between mobile suspended material and mud that could be considered equivalent to the Ohio River fluff in question, is chemically important because it is a reservoir for potential toxics and a medium for chemical transfer. The Wheeling experience underscores the complexities of sediment contaminant problems in the river, and perhaps a future need for investigators to look beyond consolidated sediment deposits for potential problems.

Steel mill slag might also be considered as a category of sediment, which can influence the quality of the Ohio River. Not only have massive slag fills been used as a foundation material for extensive riverfront industrial developments in the upper Ohio River Valley (Josephson et al. 1949 and USACE 1982 and 1989b), it is also extensively utilized locally for placement of highway shoulder berms, driveway and parking lot fills, stream bank protection, and as railway grade ballast. Steel mill slags can produce mineralized and extremely alkaline leachates. In the above 1982 reference, it was noted that leachates from fresh slags could produce significant mortalities in 96-hour static bioassays. The elutriate from one 4:1 river water slag wash killed all aquatic organisms tested: fathead minnows (*Pimephales promelas*), midge larvae (*Tanytarus dissimilis*), and *Daphnia magna*. The LC_{50} (lethal concentration for 50% of organisms) for the fish and the daphnids fell in the range of 13 to 36 percent of the original 4:1 elution concentration. Further examination of this slag suggested that the caustic alkalinity of its leachate was sufficient to account for the observed mortality of aquatic organisms. The pH of a first wash, 4:1 elution of this slag, almost immediately increased to 11.2. Tributaries of the navigation system in urban/industrial Allegheny County, PA are generally mineralized and alkaline from the leachates of ubiquitous slag fills. Maximum pH values reported for Nine Mile Run and Thompson Run, two tributaries to the lower Monongahela River which drain slag dumps, were pH 11.1 and 10.4, respectively (Koryak and Stafford 2001a, and Koryak et al 2002). In the late 1960s, when coal field drainage still significantly acidified the Allegheny River, and more particularly the Monongahela River, Shapiro et al (1967) found that the Ohio River accrued significant alkalinity after flowing past the steel manufacturing complexes near Pittsburgh. Koryak et al (2002) proposed that slag leachate products contributed to this large, unexplained, alkalinity load.

Historical and ambient chemical data on industrial legacy contamination of sediments along the 981-mile Ohio River mainstream are limited. Studies which are available demonstrate that adsorptive/desorption behaviors vary for different parameters, and that sediment deposition and transport processes are complex. Therefore, any attempt at trend analysis based on this chemical data would be highly problematic. As with water quality, however, biological indicators might be expected to integrate stresses and provide insight to general sediment quality and trends. For instance, while concentrations of polychlorinated biphenols (PCBs) might be mostly undetectable or non-remarkable in the waters and sediments of the Ohio River, as will be discussed in the Attainment of Ohio River Designated uses portion of this chapter, PCB bioaccumulation in fishes is occurring. PCBs in the sediments are suspected to be contributing factors. PCBs have been found by ORSANCO (2002, 2000a) in fish tissue in sufficient concentrations to trigger consumption advisories along the entire river. Chlordane, probably mostly from termite control activities in urban centers along the river, was previously a fish consumption parameter of concern, but has recently been removed from the list of substances impairing fish consumption.

Burrowing mayflies spend their aquatic life cycle in fine grained sediment deposits, which are the most likely to be contaminated. These organisms were long absent from the upper Ohio River reach most severely degraded by industrial contaminants. Their failure to recolonize the upper river quickly in the 1970s, after water quality substantially improved and numerous previously extirpated fishes returned, suggests lingering adverse impacts from legacy sediment contamination. During the 1990s, however, small to moderate numbers of burrowing mayflies were observed in the upper five pools of the Ohio River. First in 2001, and then again in 2002, mass emergences of burrowing mayflies occurred as far upstream as Pittsburgh. These emergences suggest that the quality of the sediments of the Ohio River is improving.

3.8 BIOLOGICAL INDICATORS OF WATER QUALITY OF THE OHIO RIVER

All aquatic organisms, from minute microscopic plankton to the largest fish, reflect the water quality of their environment and, thus, potentially can serve as biological indicators of water quality conditions and trends. Smaller organisms, especially algae and macroinvertebrates, have most often been studied in this regard, in part, because of their relative ease in field collection and laboratory processing. Characterization of water quality has been the primary motivation for the biological surveys, which have been conducted along the river by ORSANCO since 1957.

Bioassessments in general may be used within a planning and management framework to prioritize water quality problems for more stringent assessments and to document "environmental recovery" following control action. Some advantages of using biosurveys identified by the Ohio Environmental Protection Agency (1988) follow:

1) Biological communities reflect overall ecological integrity (i.e., chemical, physical, and biological integrity). Therefore, biosurvey results directly assess the status of a waterbody relative to the primary goal of the CWA (i.e., fishable, swimmable waters)

2) Biological communities integrate the effects of different pollutant stressors and thus provide a holistic measure of their aggregate impact. Communities also integrate stresses over time and provide an ecological measure of fluctuating environmental conditions. Assessing integrated variable pollutant inputs offers a particularly useful approach for monitoring non-point source impacts and the effectiveness of certain Best Management Practices (BMPs).

3) Routine monitoring of biological communities can be relatively inexpensive, particularly when compared to the cost of assessing toxic pollutants, either chemically or with toxicity tests.

4) The status of biological communities is of direct interest to the public as a measure of a pollution free environment, while reductions in chemical pollutant loadings are not as readily understood by the layman as positive environmental results.

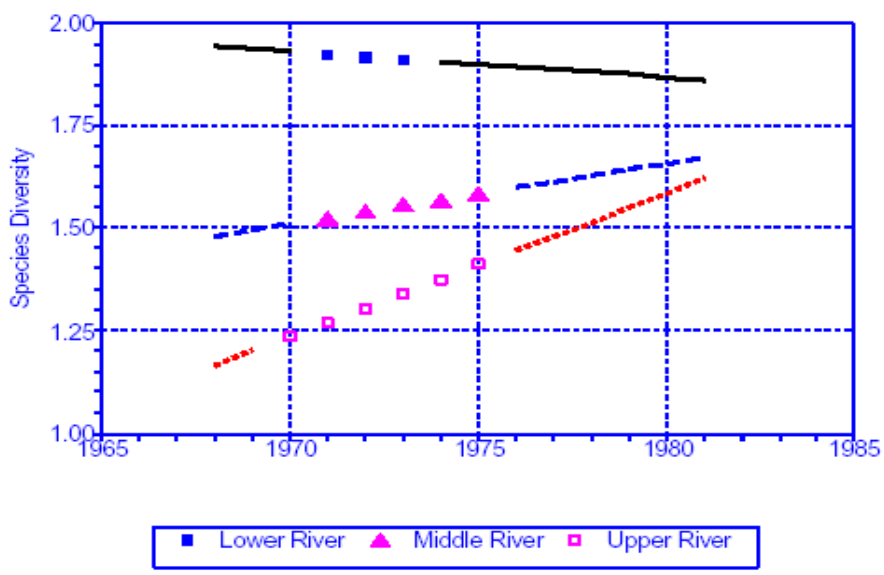
5) Where criteria for specific ambient impacts do not exist, biological communities may be the only practical means of evaluation.

3.8.1 Impacts of Water Quality on Ohio River Fishes

While the fishes of the Ohio River are discussed in Chapter 4 of this report, it is important to emphasize the strong historical link between water quality and fish inhabiting the river. An extensive inventory of the fishes of the Ohio River by investigators at the University of Louisville under the sponsorship of ORSANCO was begun in 1957 (Jackson and Weise 1962). Probably the most significant fish collections (124) were rotenone sampling of lock chambers along the river, and these rotenone sampling studies have been continued by ORSANCO almost on an annual basis since 1957. The 1957 to 1960 data represents the period when mostly primary but not secondary sewage treatment facilities were in place at communities along the Ohio River. The collections between 1967 and 1970 represent the period just preceding implementation of NEPA and the CWA. The 1974 to present period gives some idea of trends since these two important legislative initiatives were passed (Pearson and Krumholz 1984).

A 1982 review of the rotenone fish sampling data (ORSANCO 1982a) illustrates important changes, which occurred along the river between the late 1960s and early 1980s. An indication of the improving water quality in the Ohio River was the marked increase which was documented in diversity of fish species using the Shannon-Weaver index. The greatest improvements were observed in the upper reaches of the river **(Figure 3-2)**. Increases were primarily noted in sport and commercially valuable species, which tend to be more pollution-sensitive than other fish species. Fish diversity increased by 40 percent in the upper river, and 13 percent in the middle section. ORSANCO attributed the improvements to increased pH and DO concentrations, and to decreased levels of toxic materials in the river. Since 1982, additional continuing improvement, but at a somewhat reduced rate, has been observed and is discussed in Chapter 4.

FIGURE 3-2
Long-Term Trends in Fish Diversity in the Ohio River.



Source: ORSANCO 1982b.

3.8.2 Algae of the Ohio River Mainstem

Fish and mussel species have been studied and documented for the Ohio River since the 19th century; however, little is known of algae and macroinvertebrates (excluding mussels) before the mid-20th century. The following sections document algae and macroinvertebrates of the Ohio River during recent decades with implications for water quality conditions.

Algae form a basis of the food chain and are a foundational component of the Ohio River ecosystem. Not only are algae an important food source for zooplankton, mussels, and other invertebrates, but also for several species of fish which are extremely important to river ecosystems. Some shiners (*Notropis* sp.), catostomids (suckers), carpsuckers (*Carpiodes* sp.), and perhaps most critically, gizzard shad (*Dorosoma cepedianum*) are reported to feed directly and largely on algae (Hynes 1970). Algae in running waters may occur as attached forms on all types of solid objects including macrophytes and as films on mud and silt surfaces. Algae also occur as free floating or planktonic forms. Until relatively recent years, a debate ensued over whether or not apparently planktonic algae found in streams and rivers could be considered to be "truly" plankton. Hynes (1970) reviewed the literature and concluded that large rivers do support phytoplankton.

Hynes further noted that diatoms were almost always dominant. The most frequently encountered truly planktonic large river diatom genera were the pennates *Asterionella*, *Tabellaria*, *Fragilaria*, and the centric, disc-shaped forms of *Melosira, Cyclotella, Coscinodiscus*, and *Stephanodiscus*. Benthic diatoms, frequently encountered in large numbers, included the genera *Synedra*, *Nitzschia, Navicula, Diatoma, and Surirella*. During summer in temperate large rivers, these were joined by a variety of truly planktonic Chlorophyceae (green algae), such as *Scenedesmus*, *Ankistrodesmus*, and *Pediastrum*, and a variety of flagellates including *Cryptomonas*. Frequently, Cyanophyta/Cyanobacter (blue-green algae) occurred when the water was warm. Similarly, Ohio River researchers have confirmed that phytoplankton communities are very important in the Ohio River. Monitoring has to a large degree been motivated by a history of water supply taste and odor problems and public health concerns. In recent years these concerns have expanded to include control of cryptosporidious disease by filtration of the oocysts of the protozoan *Cryptosporidium parvum* during algae blooms (USACE 1994).

3.8.2.1 Ohio River Plankton Studies - 1957 to 1960

Between October 1957 and January 1960, Jackson and Weise (1962) collected 210 plankton samples along the Ohio River. Over the length of the river, they concluded that diatoms generally dominated the phytoplankton community. In particular, they found that filamentous diatoms of the genus *Melosira* were abundant, nearly ubiquitous, and a significant component of most Ohio River algae blooms. While species composition was similar along the length of the river, there were quantitative longitudinal variations, with generally depressed concentrations of phytoplankton in the polluted upper portion of the river. They suggested that acid mine drainage pollution contributed by the Monongahela River depressed phytoplankton abundance in the upper river.

A number of algae bloom events were documented at various locations between river miles 307 and 642, typically involving the diatoms *Melosira, Fragilaria*, and *Synedra ulna*; the green algae *Crucigenia* and *Dictyosphaerium pulchellum*; and the blue-green

algae *Anacystis aeruginosa*. The Louisville Water Company reported eight different taste and odor incidents lasting over a cumulative period of 136 days in 1957 and 1958. An Ohio River water supply taste and odor incident near Louisville in October 1959 was investigated by Jackson and Weise and found to have been caused by an intense bloom of *Anacystis aeruginosa.* Non-planktonic algae found growing in the Ohio River near Louisville attached to submerged objects such as sticks and rocks were *Cladophora, Oedogonium, Stigeoclonium,* and *Schizoneria*. In polluted waters near Beargrass Creek and in the municipal harbor, *Oscillatoria, Phormidium*, and *Lyngbya* were abundant.

3.8.2.2 Ohio River Plankton Studies - 1974 to 1975

The Corps (1975) sampled phytoplankton along the upper Ohio River between RM 1.0 and 129.2 in 1974. Similar to the findings of Jackson and Weise (1962), they observed that the microflora of the Ohio River was dominated by diatoms and green algae, particularly the centric diatoms *Melosira* and *Cyctotella,* and the green algae *Ankistrodesmus*. Except for a few occasional filaments of *Oscillatoria* and *Anabaena*, blue-green algae were conspicuously absent from the upper Ohio River, even during late summer. Since blue-green algae are very sensitive to acid conditions, it was speculated that the influence of acid mine drainage may have limited blue-green algae growth in the upper river at that time.

Algae concentrations at a 2 to 3 foot depth ranged from a low of 116 cells/ml in Emsworth Pool in June to 9,700 cells/ml in Hannibal Pool in September. The average for all navigation pools from June to November was more than 3,000 cells/ml. The lowest chlorophyll measurements occurred during the highest flow conditions. During a 50,000 to 70,000 cfs flow survey, total cell counts along the river were typically less than 1,000 cells/ml. During a 10,000 to 13,000 cfs low flow survey, phytoplankton total cell counts ranged from 2,000 to 9,700 cells/ml. Cell counts and chlorophyll concentrations were intermediate during moderate flow conditions. It was suggested that abundant phytoplankton in the upper Ohio River was probably related to vertical DO stratification patterns observed in the river during summer season low flow periods. The photosynthetic activity of large phytoplankton populations generates high amounts of oxygen. Light is necessary for photosynthesis and large rivers tend to carry heavy loads of suspended matter that restrict light penetration. During a July 1974 low flow survey, 50% to 80% of total incident surface light was extinct at a depth of 2 feet along the upper Ohio River. Penetration of 1% of surface light never reached 12 feet during that survey and the 1% level was only around 6 feet during a November survey. Photosynthesis, therefore, with subsequent oxygen production, is limited by light penetration to a relatively thin surface layer in the Ohio River.

Phytoplankton concentrations in near surface samples were generally elevated in the lower sections of navigation pools where velocities are low, and were reduced downstream of navigation dams. Other studies conducted by the Corps (1976 and 1991) confirm this impact of navigation dams on phytoplankton distribution. Ten surveys were conducted between 1975 and 1988 along the Monongahela River navigation system that included phytoplankton samples collected immediately upstream and downstream of navigation dams. On average, algae cell volumes decreased by 55.2% below Maxwell Locks and Dam. The mean decreases downstream of Locks and Dams No. 4, 3, and 2 were 13.5%, 20.1%, and 26.8%, respectively. These localized declines were likely the result of mixing at the dams of higher surface water algae concentrations with the lower algae

concentrations of deeper waters. A potential impact of such mixing is making fine organic materials more available to filter-feeding benthic invertebrates in the tailwaters of navigation dams than along other reaches of the navigation systems. Another observation from long term monitoring along the Monongahela River navigation system was that blue-green algae, formerly suppressed by acid mine drainage pollution, were becoming increasingly abundant as acid mine drainage pollution was abated. Blue-green algae concentrations in the Monongahela had become particularly high during summer low flow periods in the shallow, nutrient enriched, coal-fired electrical power generation thermal plumes and in the river. Blue-green algal concentrations created seasonal taste and odor nuisance problems for a major water supply utility downstream. It was suggested that thermal discharges to this lower reach of the river would be expected to generally stimulate algae growth, and selectively encourage the more thermophilic and problematic blue-green algae.

3.8.2.3 Ohio River Plankton Studies during the 1990s

No published plankton data from the 1980s are available. However, during the 1990s, Wehr and Thorp (1997) conducted a study of the effects of navigation dams, tributaries and littoral zones on phytoplankton communities in a reach of the Ohio River that extended roughly from Cincinnati to Evansville. Their study demonstrated that the Ohio River supports diverse, substantial phytoplankton communities, with densities comparable to other large rivers in North America. They observed 134 algal and cyanobacteria taxa, with about 60% of the species diversity contributed by diatoms. As with previous and subsequent investigations, cyanobacteria and green algae attained their greatest prominence in the summer, while diatoms were most prominent during the cooler months.

Wehr and Thorp concluded that Ohio River phytoplankton densities increased with temperature and decreased with current velocity. Tributaries to the study reach of the river appeared to have few effects on either phytoplankton or zooplankton, probably because of the considerably higher flow of the Ohio River relative to its tributaries in this reach. Consequently, the plankton community of the Ohio River would appear to consist of "true" resident populations. Comparison of littoral (nearshore) and pelagic (open water) habitats indicated almost no difference in phytoplankton densities. In contrast, average total densities of zooplankton were roughly 60 percent greater in littoral versus pelagic sites.

3.8.2.4 Distribution and Abundance of Phytoplankton along the Ohio River in 2002

In July 1999, ORSANCO, in cooperation with the University of Cincinnati, Northern Kentucky University and ten major public water supply utilities, initiated an ambitious program to monitor phytoplankton and chlorophyll along the Ohio River. Organisms are identified and enumerated at the genus level from samples collected twice per month, year round, at each of the ten water supply intakes **(Table 3-4)**. The most recent complete year with available organized sampling data is 2002. Chlorophyll samples are also collected and analyzed at least twice per month. Exclusive of samples that contained too much sediment to analyze, the 2002 ORSANCO phytoplankton data file contains the results of 217 phytoplankton and 366 chlorophyll samples.

TABLE 3-4
Ohio River Water Supply Intakes Sampled for Phytoplankton by River Mile (ORSANCO Data)

Supplier	River Mile
West View, PA	4.5
East Liverpool, OH	40.2
Follansbee, WV	71.0
Wheeling, WV	86.8
West Virginia American, Huntington, WV	302.0
Ashland, KY	319.7
Northern Kentucky Water Services	462.9
Louisville, KY	600.6
Evansville, IN	791.5
Paducah, KY	935.5

Table 3-5 illustrates the mean annual concentration of phytoplankton at all stations along the Ohio River in 2002 was 750 units/ml. The station with the lowest mean annual concentration was 368 units/ml at RM 86.8, and the highest was 1,859 units/ml at RM 935.5. The mean annual chlorophyll concentration at all stations along the Ohio River was 6.0 µg/l. The station with the lowest mean annual chlorophyll concentration (2.1 µg/l) was at RM 4.5, and the highest was 12.3 µg/l at RM 935.5. The tendency for concentrations of both chlorophyll and phytoplankton to increase in a downstream direction in the Ohio River during 2002 is shown in the following table.

TABLE 3-5
Phytoplankton Characteristics along the Upper, Middle and Lower Reaches of the Ohio River During 2002 (ORSANCO Data)

Characteristic	Upper Ohio River (Mile 0-299)	Middle Ohio River (Mile 300-599)	Lower Ohio River (Mile 600-981)
Mean Annual Chlorophyll Concentration (µg/l)	3.6	6.9	8.2
Mean Annual Algae Concentration (units/ml)	575	688	1,109
% Capable of Producing Taste and Odor Problems	23.7	29.3	35.9
% Tolerant of Pollution	17.4	18.7	9.7
% Diatoms	88.0	67.2	74.5
% Blue-green Algae	2.6	13.3	10.0

The percentage of phytoplankton organisms capable of producing taste and odor problems and the percentage of organisms which were blue-green algae were less in the upper river than in the middle or lower portions of the river. Conversely, the percentage of diatoms was highest in the upper river. The percentage of organisms generally considered to be tolerant of pollution was lowest in the lower river. Factors which might contribute to these spatial trends are the increasing size and lower relief of the river as it flows along its 981 mile long course, the longer navigation pools towards lower portions of the river, and warmer water temperatures in the more southerly lower reaches of the river.

Seasonal patterns apparent in the ORSANCO data show that phytoplankton is least abundant during the higher flow and colder winter months and most abundant during the lower flow and velocity warmer summer months. The mean monthly chlorophyll concentrations for all stations combined were lowest in January and February, 2.5 and 2.7 µg/l, respectively. Chlorophyll concentrations were highest in July and August, 11.0 and 10.9 µg/l, respectively.

The composition of the Ohio River phytoplankton community is complex, containing over a hundred genera. However, some generalizations can clearly be made:

- Overwhelmingly, the phytoplankton community of the river was dominated by diatoms, 88% in the upper river, 67.2% in the middle reach, and 74.5% in the lower reach. Also, pennate diatoms were much more important in the Ohio River in 2002 than centric diatoms.
- Of the pennate diatom genera, *Aulacoseira* was the dominant or co-dominant genus in 35.7% of the samples, followed by *Asterionella* (22.1%), *Skeletonema* (15.4%), *Nitzchia* (7.5%), *Fragilaria* (3.8%), *Navicula* (1.9%), *Syendra* (≤0.1%), and *Achnanthes* (≤0.1%).
- The green algae *Chlamydomonas* and *Chlorella,* and *Cryptomonas* were also occasional dominants.
- Despite the concerns related to blue-green algae blooms, blue-green algae were only dominant in 2.8% of the Ohio River samples collected in 2002. Though massive blooms of the blue-green algae *Aphanizomenon* were documented at Ashland, KY, first on July 8th and then on August 5th, 2002, these blooms appear to be more local and sporadic in occurrence than systemic.
- Differences noted in the phytoplankton community along different reaches were that centric diatoms were more abundant in the lower reach (21.5%) than in the middle or upper reaches of the Ohio River, 2.9% and 3.1%, respectively. Conversely, *Asterionella* were much less abundant in the lower river. *Nitzchia* and *Fragilaria* were substantially more abundant in the upper river than in the middle or lower reaches.

The 2002 ORSANCO length of river, year round sampling study initiative is by far the most ambitious and comprehensive attempt to monitor and characterize the phytoplankton community of the Ohio River. The results of this effort appear to be generally consistent with Hynes' (1970) characterizations of large temperate zone rivers, as well as the results of previous Ohio River phytoplankton investigations. An important possible exception to this concurrence is that in the 2002 ORSANCO data, centric diatoms, green algae, and blue-green algae taxa may have been less important along the length of the Ohio River than they had been in previous years. The use of different sampling stations and techniques in past studies make comparisons with recent ORSANCO data

somewhat speculative. However, an apparent decline in pollution tolerant and potential taste and odor causing phytoplankton organisms suggests possible improving water quality and ecological health along most of the Ohio River. Continued monitoring will allow for verification of potential trends.

3.8.3 Aquatic Macroinvertebrates of the Ohio River Mainstem

In addition to their intrinsic values and importance as food for fish and other forms of aquatic life and often non-aquatic life, benthic macroinvertebrate communities are also highly responsive indices of water quality. The advantages of using benthic macroinvertebrates for bioassessments are:

1) Macroinvertebrate communities are good indicators of localized conditions. Because many benthic macroinvertebrates have limited migration patterns or a sessile mode of life, they are particularly well suited for assessing site-specific impacts (upstream-downstream studies).

2) Macroinvertebrate communities integrate the effects of short-term environmental variations. Most species have a complex life cycle of approximately one year or more. Sensitive life stages will respond quickly to stress; the overall community will respond more slowly.

3) Benthic macroinvertebrates serve as a primary food source for many recreational and commercially important fish.

4) Most state water quality agencies that routinely collect biosurvey data focus on macroinvertebrates. Many states already have background macroinvertebrate data (OEPA 1988).

Macroinvertebrate quality evaluations are based on the principle that invertebrate communities of non-degraded streams are composed of many different types of organisms, including pollution intolerant taxa such as mayflies, stoneflies, and caddisflies (Ephemeroptera, Plecoptera, and Trichoptera, or EPT organisms). The invertebrate communities of polluted streams, on the other hand, are dominated by a small number of pollution tolerant taxa such as sludge worms and bloodworms (Annelida and Chironomidae, or AC organisms). Between the extremes are numerous organisms with intermediate tolerances.

The following discussion of Ohio River macroinvertebrates excludes freshwater unionid mussels. Although mussels are aquatic macroinvertebrates, which are of special interest in the Ohio River, they are not generally well sampled by typical invertebrate collection techniques. Mussels are discussed in Chapter 5 of this report.

3.8.3.1 Ohio River Macroinvertebrate Studies - 1957 to 1960

Between October 1957 and January 1960, ORSANCO (Jackson and Weise 1962) collected Petersen, orange-peel, and Eckman dredge invertebrate samples along the length of the Ohio River. They found the invertebrate communities of rocky substrates along the main channel of the Ohio River to then consist primarily of the coelenterate *Hydra americana*, the bryozoan *Urnatella gracilis*, the dipteran *Chironomus* sp., the copepod

Canthocamptus sp., and the protozoans *Vorticella* sp. and *Epistylis* sp., none of which are indicative of unpolluted water. The invertebrate communities of soft substrates nearer to shore were even more depauperate, consisting only of very pollution tolerant tubificid worms and a few specimens of the bloodworm chironomid *Tendipes* sp.

More intensive sampling near the intake of the Louisville Water Company at RM 600 confirmed that the distribution of benthic organisms in the Ohio River was related to its substrate type. Similarly, Thorp (1992) demonstrated that invertebrate taxonomic richness and density in the Ohio River is significantly influenced by substrate composition, and also references numerous supporting studies from other locations. In the sandy and clay bottom of the Ohio River midchannel, Mason et al. (1971) found the chironomid *Tendipes decorus* to be abundant. Gut analyses revealed this organism was the major food item of many smaller fishes. Stomachs of young channel catfish and freshwater drum and silver chub contained large numbers of these larvae. The midge larva *Procladius* was found in deep sediment. Other organisms of this particular bottom type included tubificid oligochaetes, several species of *Pisidium* clams and a few unionid mussels.

Rocky bottoms contained a strikingly different fauna comprised predominantly of triclad flatworms, leeches, crayfish, aeschmid dragonfly naiads, and other aquatic insect larvae. The snail *Pleurocera canaliculatum* was found exclusively on rocky substrates. The sphaeriid clams, especially *Pisidium*, and the snails *Somatogyrus subglobosus* and *Viviparus contectoives* occurred on hard substrates, as well as sometimes large populations of *Hydra americana*, and the bryozoan *Urnatella gracilis*.

Samples of different types of bottoms and from various depths revealed fewer organisms on bottoms of sand or sand and silt than on bottoms of silt alone. For example, on March 30, 1959, a sample from a bottom of sand and silt along the Kentucky shore at mile 602.1 contained 129 organisms/m^2, while on the same date a silt bottom along the Indiana shore at mile 602.1 yielded 73,100 tubificid worms/m^2. Jackson and Weise emphasized that only a few specimens of Ephemeroptera (mayflies) were found in the Ohio River during their 1957 to 1960 study period. Ephemeroptera are generally considered to be indices of good water quality, and burrowing species of the genera *Ephemera* and *Hexagenia* are indices of both good water quality and sediment quality. They may be present in huge numbers in large unpolluted rivers where they are important components of the aquatic ecosystem and can be major sources of forage for fishes and other aquatic life. Jackson and Weiss commented that Ephemeroptera were very sparse at that time in the Ohio River compared to the large numbers then present in the Mississippi River.

It is interesting to note, that due to water quality improvements over the more than four decades since completion of the Jackson and Weise survey, burrowing mayflies have gradually returned to the entire Ohio River. Huge, newsworthy, emergences of burrowing mayflies finally returned to the Pittsburgh reach of the Ohio River only in 2002/2003.

3.8.3.2 Ohio River Macroinvertebrate Studies - 1963 to 1967

The results of an intensive Ohio River cooperative aquatic macroinvertebrate monitoring effort, conducted between 1963 and 1967, were published by U.S. Environmental Protection Agency in 1971 (Mason et al.). This effort included artificial substrate sampling (rock baskets). As was clearly demonstrated by Jackson and Weise

(1962), Thorp (1992), and many other studies not specific to the Ohio River, site-specific variations in natural substrate composition profoundly influence invertebrate communities. Use of standard artificial substrate sampling devices control this variable, as well as other physical challenges unique to invertebrate sample collection in large rivers. This approach also allows opportunities for legitimate and reasonable comparisons between different sampling stations, which can be utilized for water quality assessments of patterns and trends.

Important conclusions developed by Mason et al were that artificial substrate sampling techniques tended to collect more diverse samples than dredge samples and that during the five year study period the abundance and diversity of macroinvertebrates increased at stations along the lower and middle reaches of the Ohio River, but not yet in the upper reach of the river near Pittsburgh. Throughout 1963-67, dredge samples from the upper part of the river contained only pollution-tolerant sludgeworms and a few bloodworms. Occasionally damselflies and midges were collected from the artificial substrate samplers. Caddisflies first appeared at Toronto, Ohio (RM 58); mayflies were first present at RM 260 near Addison, Ohio; and stoneflies occurred at Huntington, West Virginia (RM 301). The invertebrate taxa found to be nearly ubiquitous along the Ohio River were the midges *Dicrotendipes nevosus*, *Procladuis* sp., *Coelotanypus* sp., *Cricotopus* spp., *Ablabesmyia* spp., *Crytochironomus* spp., and *Psectrocladius* spp. Also present at most stations were the caddisfly *Cyrnellus fraternus*, the damselfly *Argia*, the mayfly *Stenonema,* and the coelenterate *Cordylophora lacustris*.

Taxa more limited in distribution included the midge *Chironomus riparius* (upper river), *Chironomus attenuatus* and *Xenochironomus xenolabis* (middle river), and *Tanypus* sp. (lower river). The crayfish *Orconectes obscurus* occurred in the upper river and *O. rusticus* in the middle river. The pollution intolerant caddisflies *Potamyia flaxa* and *Hydropsyche orris*, stoneflies *Isoperla bilineata* and *Acroneuria* spp., the mayflies *Hexagenia* and Caenidae, and the dragonfly *Neurocordulia* sp., were restricted in distribution to the middle and lower reaches of the Ohio River.

3.8.3.3 Invertebrate Community Condition Scores - Patterns and Trends

Including the Mason study data, ORSANCO has Ohio River rock basket sampler aquatic macroinvertebrate data from 1964 to 1974, and Hester-Dendy multiple-plate artificial substrate sampler data from 1975 to 2001. The older rock basket data predates the CWA of 1972 and numerous other landmark national and local environmental initiatives, including, for instance, the 1974 initiation of secondary level sewage treatment by the Allegheny County Sanitary Authority at Pittsburgh. Of this baseline historical data, 1967 is a particularly interesting year because triplicate rock basket samples were collected at ten stations spaced along the entire length of the Ohio River between RM 6.2 and 980.4. Going back to the raw 1967 data and applying subsequently developed Rapid Biological Assessment (RBA) condition score rating analysis methodologies developed by the USEPA (Plafkin et al 1989) and the OEPA (1988) would allow for a comparison of relative invertebrate community impairment along the length of the river.

Unfortunately, most of the world's large rivers have scarcely been examined from an ecological perspective (Thorp 1992). Lotic research has rather focused on smaller and medium sized unregulated streams and rivers, and indeed only about 4% of the publications on running water have dealt with large rivers (Hynes 1989 in Thorp 1992). Therefore, there

has been little research and there is a lack of scientific consensus on appropriate metrics to use for rating impairment of large rivers. Currently, a draft index is being refined that uses benthic macroinvertebrates to assess biotic integrity in the Ohio River (Emery 2003). However, until such research is completed and consensus is reached, the following expedited attempt at rating the degree of impairment of the Ohio River invertebrate community must be considered highly tentative.

Table 3-6 shows the tentative condition scores developed from the 1967 data for ten rock basket sample collection stations along the Ohio River, as well as the metrics used to compute these scores. Only a few standard, simple, and non-controversial metrics were utilized. These include % EPT (Emphemeroptera, Plecoptera, and Tricoptera) organisms and % not AC (Annelida and Chironomidae) organisms. With no other large non-impaired river in the ecoregion to use as a reference, the reference used for the % taxa richness metric was the high diversity Ohio River station near Evansville, Indiana (RM 787.5). Because of the frequent poverty of numbers of invertebrates of any sort unanimously noted by all previously referenced Ohio River researchers, a metric was also deemed necessary to acknowledge invertebrate paucity and to reward productivity. Invertebrate paucity is likely related to the mix of historic pollution sources to the Ohio River, which have included not only domestic wastes, but also gross heavy industrial and chemical manufacturing wastes, and massive loads of acid mine drainage from bituminous coal mines. While organic waste and nutrient pollution typically result in large numbers of only a few tolerant taxa, acid mine drainage and other types of pollution can result in both drastically reduced species richness and standing crops (Koryak et al 1972, and Koryak et al 1998a). Number of organisms per sample metrics have been successfully used to rate impairment in streams influenced by acid mine drainage, urban runoff and active and legacy industrial pollution (Koryak et al 1998b, Koryak and Stafford 2001a, and Corps 2000c). While the 1967 Ohio River invertebrate community condition scores (listed in **Table 3-6** and graphically shown in **Figure 3-3**) must be considered tentative depending on a future consensus of appropriate large river metrics, they are, nonetheless, highly consistent with patterns of chemical water quality degradation which are examined and discussed in previous sections of this chapter.

TABLE 3-6
Ohio River Macroinvertebrate Metrics and Expedited Condition Scores from Triplicate Rock Basket Sample Data Collected in 1967

Station Location (Ohio River Mile)	Mean # Taxa as % Reference Station (17.7)	Mean Total # Organisms	Mean % EPT Taxa	Mean % EPT Organisms	Mean % Not AC Organisms	Mean % EPT Organisms *Cyrnellus fraternus**	Expedited Condition Score
6.2	32.2	100.0	20.1	0.3	20.1	100.0	26.5
57.5	32.2	20.0	0.0	0.0	8.7	0	12.2
167.5	62.1	40.0	6.1	5.3	31.3	50.0	29.0
260.0	45.2	40.0	40.0	49.1	54.4	50.3	45.7
301.4	69.5	100.0	35.0	46.3	51.6	97.8	60.5
341.0	35.6	20.0	20.6	45.5	54.0	95.3	35.1
462.0	73.4	100.0	33.3	76.6	78.0	88.2	72.3
600.5	75.1	80.0	27.8	42.8	50.8	87.1	55.3
787.5	100.0	100.0	45.2	85.5	86.1	11.5	83.4
980.4	81.9	100.0	51.7	70.5	76.0	0.8	76.0

According to common usage of this scoring technique (OEPA 1988), an invertebrate condition score greater than 80% indicates that a stream is non-impaired, 60-79% slightly

impaired, 40-59% moderately impaired and less than 40% severely impaired. Consistent with the historical chemical water quality data, and also generally the fish data, the 1967 invertebrate condition scores range from an extremely depressed low of only 12.2% in the upper river to a high of 83.4% in the lower river. The upper river was definitely severely degraded, the middle reach of the Ohio River appeared to have been moderately to slightly impaired and the lowest reach of the Ohio River, sufficiently downstream of Louisville, Kentucky, was only slightly impaired, approaching and possibly reaching a non-impaired status. Re-initiation in 2002 of rock basket sampling by ORSANCO at 23 stations between river miles 6.2 and 436.2 provides an opportunity to assess changes in the Ohio River during the past environmentally proactive 35-year period.

Condition score and metrics for the 2002 ORSANCO data are shown later in **Table 3-7** and are plotted against 1967 condition scores in **Figure 3-3.** Twenty-two of the 2002 stations were located upstream and downstream of eleven dams on the Ohio River. For trend analysis and impairment pattern identification, these upstream and downstream of dam data sets are merged, though they will be discussed separately in subsequent paragraphs. The metrics used to develop condition scores from the 2002 data are identical to those used for the 1967 data, with two exceptions. Zebra mussels (*Dreissena polymorpha*) infested the entire length of the Ohio River in the interim between collection of the 1967 and 2002 samples. They were present sporadically in sometimes enormous numbers at stations sampled in 2002. Therefore, to make the 2002 data more consistent with pre-infestation data, the number of zebra mussels was subtracted from the 2002 total number of organism metric. Also, there are some variations in taxonomic identification definition apparent in the two data sets, especially for oligochaetes, which make using the 1967 taxa richness reference problematic for analysis of the 2002 data. Therefore, % of the mean number of taxa present per sample (21.3 taxa) was substituted as a reference station metric for the 2002 data. The results plotted on **Figure 3- 3** clearly demonstrate that dramatic improvements have occurred along the previous severely impaired upper reach of the Ohio River since 1967, but less so or not at all along the moderately to slightly impaired middle part of the river. Notwithstanding the progress to date, the plots on **Figure 3-3** for the upper and middle river, compared to the higher condition scores for the lower river, suggest that there is still considerable room for improvements along the upper and middle reaches of the Ohio River.

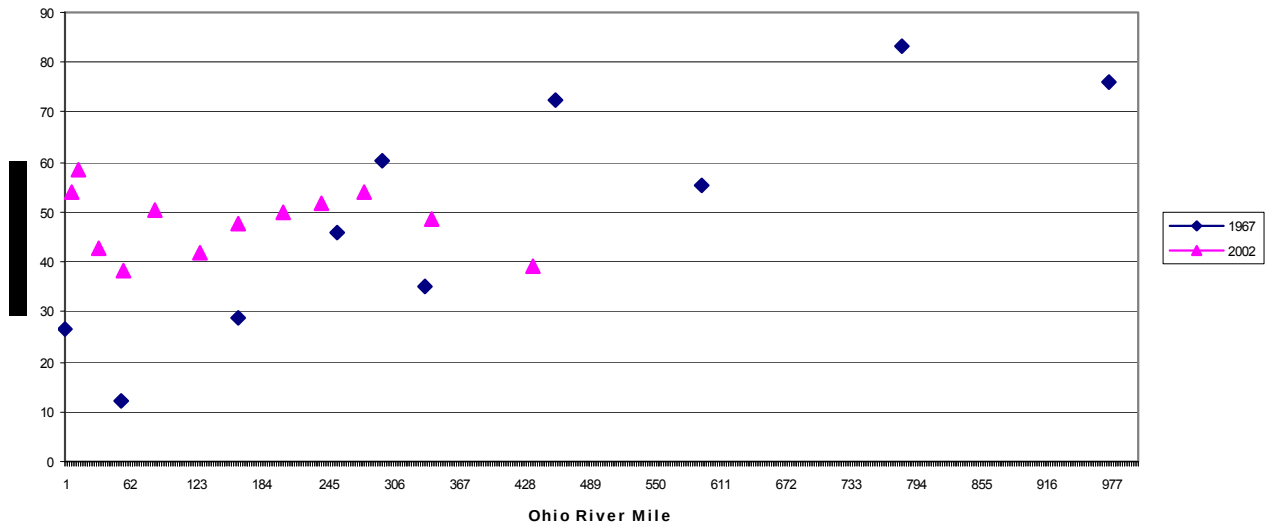
3.8.3.4 Invertebrate Signature Species

The extensive ORSANCO Ohio River aquatic macroinvertebrate data file is a unique and exceptionally valuable large river ecosystem information resource. Information mining of this file has the potential to yield numerous important insights into the ecology not only of the Ohio River, but also perhaps of other large temperate regulated rivers in general. While the examination of the file presented in this discussion should be considered to be cursory, some characteristics of the fauna are evident. Among these is the presence of certain organisms, which because of their ubiquitous distribution and/or abundance might be considered to be Ohio River invertebrate signature species. One candidate example is the net spinning, collector/filterer, and almost uniquely large river habitat caddisfly *Cyrnellus fraternus*. This organism was present in 88% of the rock basket samples examined. *Crynellus fraternus* comprised fully 58.1% of the total number of all EPT organisms collected from the Ohio River in 1967, and 39.4% of all 2002 EPT organisms. Identification of important system specific taxa, such as the crustacean

Gammerus minus and the mayfly *Baetis flavistriga* in urban drainage in the upper Ohio River Valley (Koryak et al 2003), can also be used to help refine rating metrics.

FIGURE 3-3

Ohio River Aquatic Macroinvertebrate Condition Scores Developed from Rock Basket Sample Data Collected in 1967 and 2002 by ORSANCO



3.8.3.5 Influence of Navigation Dams on Invertebrate Communities

Characteristics of invertebrate rock basket communities from samples collected by ORSANCO upstream and downstream of Ohio River navigation dams in 2002 are summarized in **Table 3-7.** These data show that taxa richness was somewhat higher downstream of the dams, a mean of 22.4 compared to 20.2 taxa per sample. Also the mean condition score (48.3% versus 46.9%) and mean % EPT taxa per sample (22.5 versus 17.8) was higher downstream of the dams. However, all other parameters demonstrated slightly more negative values downstream of dams and the data are probably inconclusive. If there are more diverse and healthier invertebrate macroinvertebrate communities in the tailwaters of the dams than within their pools, the composition of these communities is probably correlated with natural substrate. The artificial substrate sampling techniques used would not reflect such natural variations in the substrate of the river.

TABLE 3-7
Ohio River Macroinvertebrate Metrics and Expedited Condition Scores Developed from Rock Basket Sample Data Collected by ORSANCO in 2002

Station Location (Ohio River Mile)	Mean # Taxa as % Ref. Station (21.3)	Mean Total # Organisms Score (excluding zebra mussels)	Mean % EPT Taxa	Mean % EPT Organ-isms	Mean % Not AC Organ-isms	Mean % EPT Organ-isms Cyrnellus fraternus*	Expedited Condition Score	Mean Combined Condition Score
Emsworth Dam								
Above RM 6.2	100.00	100.00	13.6	1.0	78.4	64.3	58.6	54.1
Below RM 6.2	100.00	100.00	29.2	4.9	13.9	17.5	49.6	
Dashields Dam								
Above RM 13.3	94.0	100.0	20.0	10.7	68.1	75.4	58.6	58.6
Missing Sample	-	-	-	-	-	-	-	
Montgomery Dam								
Above RM 31.7	100.0	80.0	13.6	1.0	85.4	50.0	56.0	42.8
Below RM 31.7	65.7	40.0	21.4	3.9	17.5	0.0	29.7	
New Cumberland Dam								
Above RM 54.4	89.2	20.0	15.7	9.3	41.2	0.0	35.1	38.4
Below RM 54.4	100.0	80.0	15.4	2.5	10.8	62.5	41.7	
Pike Island Dam								
Above RM 84.2	70.4	20.0	26.7	51.9	62.0	17.1	46.2	50.2
Below RM 84.2	100.0	60.0	19.2	41.0	50.7	72.3	54.2	
Hannibal Dam								
Above RM 126.4	94.0	20.0	10.0	28.4	43.2	38.1	39.1	41.7
Below RM 126.4	100.0	60.0	22.7	16.3	22.5	28.9	44.3	

Station Location (Ohio River Mile)	Mean # Taxa as % Ref. Station (21.3)	Mean Total # Organisms Score (excluding zebra mussels)	Mean % EPT Taxa	Mean % EPT Organ-isms	Mean % Not AC Organ-isms	Mean % EPT Organ-isms Cyrnellus fraternus*	Expedited Condition Score	Mean Combined Condition Score
Willow Island Dam								
Above RM 161.7	100	80	18.2	25.0	36.3	41.5	51.9	47.8
Below RM 161.7	98.6	50.0	23.8	16.1	30.6	69.7	43.8	
Belleville Dam								
Above RM 203.9	75.1	80.0	18.8	36.8	43.0	66.1	50.7	49.8
Below RM 203.9	100.0	60.0	20.8	18.0	45.6	31.1	48.9	
Racine Dam								
Above RM 237.5	100.0	60.0	20.8	14.4	26.3	29.4	44.3	51.7
Below RM 237.5	100.0	100.0	29.0	29.8	36.6	2.7	59.1	
R.C. Byrd Dam								
Above RM 279.2	100	60.0	14.8	16.0	31.6	60.5	44.5	54.2
Below RM 279.2	100	100	18.2	11.5	89.1	90.9	63.8	
Greenup Dam								
Above RM 341.0	75.1	20.0	25.0	34.3	44.3	45.8	39.7	48.4
Below RM 341.0	94.0	40.0	30.0	54.5	67.0	1.5	57.1	
Meldahl Dam								
Above RM 436.2	89.2	60.0	15.8	3.7	24.4	40.0	38.6	39.0
Below RM 436.2	79.8	60.0	17.6	2.1	37.8	0.0	39.5	

* Not used as a condition score metric

3.8.3.6 Influence of Islands on Benthic Macroinvertebrate Communities

Thorp (1992) demonstrated linkages between islands and benthos in the Ohio River, with implications for riverine management and aquatic ecosystem restoration opportunities. He studied three reaches of the Ohio River in the McAlpine Pool, and found islands to have

significant positive effects on invertebrate density and diversity that appeared to be related to changes in physical habitat characteristics. He noted that islands interrupt the deepwater regions of the Ohio River ecosystem by providing shallow-water habitats and access to different forms of food. Jahn and Anderson (1986) also found that the macroinvertebrate fauna in large rivers show significant spatial variation among different habitats within the same pool. Macrophytes growing near islands and bank shores afford greater habitat heterogeneity for benthic species. By adding a riparian zone within the river, islands serve as an additional source of allochthonous organic materials. Thorp specifically recommends island preservation and construction to foster aquatic habitat heterogeneity, and notes that island construction has been employed in several large rivers, such as the Mississippi, with consistently satisfactory results.

3.9 ATTAINMENT OF OHIO RIVER DESIGNATED USES

Section 305(b) of the CWA requires biennial water quality assessment of the degree to which surface waters are attaining their designated uses. The Ohio River has four designated uses: 1) warm water aquatic life, 2) public water supply, 3) contact recreation. and 4) fish consumption. **Table 3-8 summarizes** the three classifications ORSANCO has developed to describe attainment of these uses.

TABLE 3-8
Assessment Criteria for Ohio River Designated Uses

Aquatic Life Support
Fully supporting: No pollutant exceeds criteria in as much as ten percent of the samples collected. AND Ohio River Fish Index (ORFIn) scores do not indicate aquatic life impairment.
Partially supporting: One or more pollutants exceed criteria in as much as ten percent of the samples collected. OR ORFIn scores indicate aquatic life impairment.
Not Supporting: One or more pollutants exceed criteria in greater than 25 percent of the samples collected. OR ORFIn scores indicate severe aquatic life impairment.
Public Water Supply Use
Fully supporting: No pollutant exceeds criteria in as much as10% of the samples collected.
Partially supporting: One or more pollutants exceed human health criteria in 11-25 % of samples collected. OR Frequent intake closures are necessary to protect water supplies due to instream concentrations exceeding finished water maximum contamination levels (MCLs) OR Frequent non-routine additional treatment is necessary to protect water supplies due to instream concentrations exceeding finished water MCLs.
Not supporting: One or more pollutants exceed human health criteria in greater than 25 % of samples collected. OR Source water quality causes MCL violations which result in noncompliance with provisions of the Safe Drinking Water Act.
Contact Recreation Use
Fully supporting: Monthly average or instantaneous maximum bacteria criteria are exceeded during fewer than 10% of the recreation season months (May – October).
Partially supporting: Monthly average or instantaneous maximum bacteria criteria are exceeded during 11-25% of the recreation season months.
Not supporting: Monthly average or instantaneous maximum bacteria criteria are exceeded during more than 25% of the recreation season months.
Fish Consumption Use
Fully supporting: No fish consumption advisories are in effect.
Partially supporting: Restricted fish consumption advisories are in effect or dioxin or mercury data indicate impairment.
Not supporting: "No Consumption" advisories are in effect for all commonly consumed species.

SOURCE: ORSANCO 2002. Biennial assessment of Ohio River water quality conditions.

For this CEA, ORSANCO's three most recent biennial assessments were reviewed to gain perspective on the current status of the Ohio River's designated uses. While comparisons of biennial assessments are generally indicative of trends, some variations between assessments may occur due to modifications in sampling procedures from year to year, including the number of Ohio River miles tested.

ORSANCO assesses Ohio River warm water aquatic life support based on chemical water quality data and measurements of fish communities using the recently developed Ohio River Fish Index (ORFIn). In 1996, ORSANCO further divided the partially supporting use classification into three categories to provide additional descriptions: substantially supporting, moderately supporting, and marginally supporting. Dramatic increases in the number of Ohio River miles fully supporting warm water aquatic life have occurred since the mid-1980s.

The biennial assessment for water years 2002-2003 indicated that 779 miles (almost 80 %) of the Ohio River were classified as fully supporting the aquatic life use and 16 miles (< 2%) were classified as partially supporting because of ORFIn scores below expected values (ORSANCO 2004b). Nineteen percent of the river (186 RM) was not assessed. During the assessment for water years 2000-2001, 974 miles (99.3%) of the Ohio River were classified as fully supporting aquatic life. Only seven miles (RM 354 - 361 in the Meldahl Pool) were classified as partially supporting, possibly due to poor habitat conditions (ORSANCO 2002). During the prior assessment (water years 1998-1999), 881 miles (90%) of the Ohio River were classified as fully supporting aquatic life. Within the partially supporting use classification, 61 miles (approximately 6%) were classified as moderately supporting, and five miles (0.5%) were classified as marginally supporting. RM 546 through 607 from the Kentucky River to McAlpine L/D were classified as moderately supporting due to poor habitat conditions; RM 177 through 182 were classified as marginally supporting "due to documented incidences of substantial impairment to aquatic life." (ORSANCO 2000b) A total of 34 miles (3.5%) from Racine L/D to the Kanawha River and from the Little Miami River to the Licking River were not assessed for aquatic life support (ORSANCO 2000b). These recent data stand in sharp contrast to water years 1980-1987 when ORSANCO classified all 981 Ohio River miles as partially supporting aquatic life (ORSANCO 1988).

Similarly, ORSANCO has reported dramatic increases in the number of river miles fully supporting public water supply use since 1980-1987, when all river miles were classified as partially supporting public water supply (ORSANCO 1988). Public water supply use is assessed based on chemical water quality data collected from ORSANCO's bimonthly sampling program, bacterial monitoring, and impacts on Ohio River drinking water utilities caused by source water conditions. During the assessment for 2002-2003, 949 miles (~ 97%) of the Ohio River were classified as fully supporting the public water supply use and 32.4 miles (~3%) were classified as partially supporting. Approximately 22 miles of impairment were based on violations of bacterial stream criteria for the protection of public water supplies (ORSANCO 2004b). During the 2000-2001 assessment, 970 miles (99%) of the Ohio River were classified as fully supporting the public water supply use. In both 2000-2001 and 2002-2003, approximately 10.5 miles from RM 161.7 though 172.2, were classified as partially supporting because the criterion for phenolics of 0.005 mg/L was exceeded in more than 10 percent of bimonthly samples at the Willow Island, WV, sampling station (ORSANCO 2004b, 2002). During the 1998-1999 assessment, 977 miles (99.6%) were classified as fully supporting public water

supply. Approximately four miles (0.4%) from RM 934.5 to 938.9 were classified as partially supporting because the human health criterion for 1,2-dichloroethane was exceeded in more than 10 percent of the samples at the organic detection system station in Paducah, KY (ORSANCO 2002). Both the phenolics and 1,2-dichloroethane exceedances indicated impairment of Ohio River source water, but did not indicate impairment of finished drinking water. Results of bacteria monitoring during both the 2000-2001 and 1998-1999 period indicated no violations of stream criteria for the protection of public water supplies in the Ohio River.

Contact recreation use support is assessed primarily from data collected from May through October at ORSANCO's six recreation season monitoring stations located on the mainstem downstream of urban centers with large combined sewer systems. Presently, 52 combined sewer overflow systems (CSOs) contribute effluent to the Ohio River **(see Table 3-10)**. CSOs and other nonpoint sources, including stormwater runoff and animal waste handling practices, have been identified as significant causes of bacterial problems in the Ohio River, particularly during heavy rains. The current ORSANCO water quality criteria is not more than 200 colony forming units (CFU) per 100 mL as a monthly geometric mean or 400 CFU/100 mL in $\geq$ 10% of samples for fecal coliforms taken during a month and 130 CFU/100 mL as a monthly geometric mean or 240 CFU/100mL in any sample for *E . coli* bacteria.

As **Table 3-9** illustrates, Ohio River miles impaired for contact recreation have fluctuated during the last three biennial assessment periods, reflecting to some extent the number of river miles assessed during each period. For the 2002-2003 assessment, approximately 367 miles of the Ohio River exceeded bacterial criteria and were classified as impaired for contact recreation use. Unlike the 2000-2001 assessment, the most recent assessment not only analyzed data from the six urban centers with large combined sewer systems but also analyzed data collected every five miles from Pittsburgh to RM 630. Approximately 345 (35%) miles were not assessed in 2002-2003. During 2000-2001, approximately 40 miles (4%) of the Ohio River were classified as partially supporting contact recreation use and 136.5 miles (14%) were classified as not supporting. In contrast to 2002-2003, a much larger percentage of the river – approximately 82% (804 miles) – was not assessed. During the 1998-99 assessment, 21 miles (2%) were classified as fully supporting contact recreation, 158 miles (16%) as partially supporting and 197 miles (20%) as not supporting. The remaining 605 miles (62%) were not assessed.

During all biennial assessments for 1998 through 2003, the entire 981 miles of the Ohio River were classified as partially supporting for fish consumption (ORSANCO 2004b, 2002, 2000a). Fish consumption use support is based primarily on the states' issuance of consumption advisories and ORSANCO's fish contaminant data. During all assessments, the entire 981 miles of the Ohio River were classified as partially supporting due to the state advisory restrictions for PCBs. During 1998-1999 and 2000-2001, the majority of river miles were partially supporting due to state-issued consumption restrictions related to mercury. However, during the 2002-2003 assessment period, ORSANCO compared mercury levels in fish tissue with the mercury criterion contained in ORSANCO's 2003 Pollution Control Standards and found no impairments. Dioxin and chlordane also have been fish tissue contaminants of concern from a public health perspective. Chlordane has recently been removed from the list of substances impairing fish consumption from the Ohio River. Dioxin, however, impaired 618 river miles in 2000-2001 and 412 river miles in 1998-99. Because of widespread exceedances of the

dioxin criterion during 2002-2003, the entire river was considered impaired due to dioxins (ORSANCO 2004b).

State-by-state water use summaries for the three most recent ORSANCO biennial assessments for all designated Ohio River uses are presented below:

TABLE 3-9
State by State Use Support Summary of Ohio River Miles Impaired During ORSANCO's Most Recent Biennial Assessments

2002 and 2003					
State	**River Mile**	**Aquatic Life Use Support**	**Contact Recreation Use Support**	**Public Water Supply Use Support**	**Fish Consumption Use Support**
PA	0.0 - 40.2	0	40.2	4.0	40.2
OH-WV	40.2 - 317.1	1.8	163.5	13.5	276.9
OH-KY	317.1 - 491.1	0	106.5	0	174
IN-KY	491.1 - 848.0	11.6	57.0	14.9	356.9
IL-KY	848.0 - 981.0	2.0	0	0	133
TOTAL MILES NOT FULLY SUPPORTING USE		**16.0**	**367.2**	**32.4**	**981**
2000 and 2001					
State	**River Mile**	**Aquatic Life Use Support**	**Contact Recreation Use Support**	**Public Water Supply Use Support**	**Fish Consumption Use Support**
PA	0.0 - 40.2	0	6.2	0	40.2
OH-WV	40.2 - 317.1	0	51.6	10.5	276.9
OH-KY	317.1 - 491.1	7	28.5	0	174
IN-KY	491.1 - 848.0	0	90.4	0	356.9
IL-KY	848.0 - 981.0	0	0	0	133
TOTAL MILES NOT FULLY SUPPORTING USE		**7**	**176.7**	**10.5**	**981**
1998 and 1999					
State	**River Mile**	**Aquatic Life Use Support**	**Contact Recreation Use Support**	**Public Water Supply Use Support**	**Fish Consumption Use Support**
PA	0.0 - 40.2	0	25.4	0	40.2
OH-WV	40.2 - 317.1	5.1	109.9	0	276.9
OH-KY	317.1 - 491.1		88.8	0	174
IN-KY	491.1 - 848.0	61	84.8	0	356.9
IL-KY	848.0 - 981.0	0	46.5	4.4	133
TOTAL MILES NOT FULLY SUPPORTING USE		**66.1**	**355.4**	**4.4**	**981**
Source: ORSANCO. Biennial Assessments of Ohio River Water Quality Conditions for Water Years 2002 & 2003, 2000 & 2001, and 1998 & 1999.					

TABLE 3-10
Combined Sewer Overflows along the Ohio River

River Mile	Discharger	State	Wastewater Treatment Plant Flow (MGD)	Permitted CSOs	CSO Plan
3.1	ALCOSAN	PA	250	21	Approved
3.1	Pittsburgh	PA	N/A	217	Required
3.1	Emsworth	PA	N/A	1	Required
3.1	McKees Rocks	PA	N/A	3	Submitted
3.1	Stowe Township	PA	N/A	7	Submitted
10.2	Coraopolis	PA	3	6	Submitted
12.3	Sewickley	PA	0.9	4	Approved
14.2	Leetsdale	PA	0.775	6	Submitted
25.0	Rochester	PA	1.4	3	Submitted
25.0	Freedom	PA	N/A	3	Required
25.6	Monaca	PA	1.15	6	Submitted
37.3	Midland	PA	1.25	1	Submitted
60.1	Toronto	OH	1	8	Submitted
68.0	Steubenville	OH	6	17	Submitted
70.5	Follansbee	WV	0.5	4	Approved
71.6	Mingo Junction	OH	0.6	6	Submitted
74.7	Wellsburg	WV	1.25	10	Approved
90.8	Wheeling	WV	15	211	Approved
93.2	Benwood	WV	0.3	14	Approved
94.0	Eastern Ohio RWA	OH	6.1	47	Approved
96.5	McMechen	WV	0.3	3	Approved
102.4	Moundsville	WV	2.34	5	Approved
128.7	New Martinsville	WV	2.3	10	Approved
250.4	Pomeroy	OH	0.345	13	Submitted
251.2	Middleport	OH	0.3	13	Reviewed
265.7	Point Pleasant	WV	0.7	2	Approved
313.2	Huntington	WV	17	23	Approved
313.2	Kenova	WV	N/A	2	Approved
317.1	Catlettsburg	KY	0.5	17	Submitted
322.5	Ashland	KY	11	8	Approved
327.4	Ironton	OH	1.7	9	Submitted
328.9	Worthington	KY	0.2	3	Suspended
351.8	New Boston	OH	N/A	2	Approved
356.0	Portsmouth	OH	5	10	Submitted
378.4	Vanceburg	KY	0.41	5	Required
411.8	Maysville	KY	3.4	11	Approved
464.5	Cincinnati	OH	200	234	Approved
477.4	No. Kentucky SD1	KY	46.5	97	Approved
493.0	Aurora	IN	N/A	3	Approved
558.8	Madison	IN	3.6	7	Approved
604.1	Jeffersonville	IN	5.2	16	Approved
612.0	Louisville	KY	105	117	Approved
726.6	Tell City	IN	2.063	5	Approved
746.2	Rockport	IN	0.5	1	Approved
754.6	Owensboro	KY	18.8	12	Approved
792.5	Evansville East	IN	18	8	Approved
794.0	Evansville West	IN	20.6	15	Approved
806.0	Henderson	KY	15	13	Approved

River Mile	Discharger	State	Wastewater Treatment Plant Flow (MGD)	Permitted CSOs	CSO Plan
829.0	Mt. Vernon	IN	4.1	3	Approved
936.0	Paducah	KY	9	10	Approved
944.0	Metropolis	IL	2.05	1	Approved
979.0	Cairo	IL	1.5	3	Approved
Total CSOs				1276	

Source: ORSANCO. 2002. Biennial Assessment of Ohio River Water Quality Conditions for Water Years 2000 & 2001.

3.10 INTERACTIONS WITH OTHER VECS

The recovery of the Ohio River during the last 50 years has had far-ranging effects on almost every VEC included in this CEA. The history and public perception of water quality conditions in the Ohio River mainstem, in large measure, illustrate the complex interplay between water and sediment quality and many other VECs, including those concerning human communities. During the mid-20th century when the Ohio River was perceived almost as an open sewer; fish, mussels and other aquatic organisms declined, recreation suffered and public health and safety were compromised.

Species composition and abundance of aquatic organisms are excellent indicators of overall water and sediment quality. Many fish species that took refuge in the lower Ohio River and in the tributaries of the Ohio during the worst decades of pollution have recovered and moved upstream. Densities, biomass, and fish community diversity have increased dramatically as water quality has improved. Sport fishing has improved and increased in popularity as fish populations have increased and taste and odor problems have generally declined. Fish consumption advisories, however, are still issued for certain species along specific river segments. Increased sport fishing has enhanced perception of the river's recreational value and, in turn, has benefited local economies.

While most fish species have increased in the Ohio River mainstem, several species requiring clean, gravel substrates for spawning have declined. Freshwater mussels, the most conspicuous component of the bottom fauna, have also substantially declined both in numbers and species diversity. Five mussel species are presently federally listed as endangered and others are proposed as candidates for designation. The impacts of the recent invasion of zebra mussels have not been documented fully.

Improved water quality and associated monitoring systems (e.g. ORSANCO's early-warning spill detection system) have combined with regulatory actions to ensure safer drinking water for more than three million people that rely on the river as their primary drinking water source. Improved water quality also has led to increases in boating and contact recreation, including water skiing and personal watercraft use. Improved water quality, consequently, has stimulated increases in recreational lockages along the river, especially near the larger metropolitan areas.

Water quality also is related to aesthetics, especially with regard to appearance and odor. The improved aesthetics of water in the mainstem have helped attract people to the riverbanks for recreation and special events. Increased public interest in the river has, in turn, stimulated land use changes with potential impacts on historical and archaeological

resources, as the demand for more parks, restaurants, bike trails and other public facilities along the Ohio River has increased.

3.11 RELEVANT ACTIONS AFFECTING WATER AND SEDIMENT QUALITY

Of 87 actions included in the RFFA matrix, seven actions were ranked "high importance" while 20 actions were ranked "medium importance" for water and sediment quality. Of the remaining 60 actions, 46 were ranked "low importance" and 14 were not ranked. **Table 3-11** lists actions ranked high or medium, indicates if the action is generally beneficial (+) or detrimental (-), and lists the action's effects according to the following key:

T/S = causes turbidity and sedimentation
PS = contributes to point source pollution
NPS = contributes to nonpoint source pollution
PR = contributes to pollution reduction

Water and sediment quality of the Ohio River cumulatively reflect the river's designated uses of warm water aquatic life, public water supply, contact recreation, and fish consumption, as well as the river's role as an important national economic and transportation artery. In discussing similar large North American rivers, Sheehan and Rasmussen (1993) state the greatest challenge to large rivers clearly is to maintain ecological integrity while sustaining multiple human uses. The cumulative effects (CE) of human activities have compromised some aspects of the Ohio River mainstem's water quality, although some favorable trends have occurred in recent decades.

TABLE 3-11
RFFAs Ranked High or Medium for Water and Sediment Quality

RFFA	Net Effect	Types of Effects
Actions of High Importance		
Channel dredging/dredged materials disposal	-	T/S, NPS
Instream sand and gravel mining	-	T/S,PS
Coal utilities	-	PS, NPS
Other coal utilities	-	PS, NPS
Industrial users, excluding coal-related	-	PS, NPS
More stringent quality standards for environmental media	+	PR
Pollutant source control	+	PR
Actions of Medium Importance		
L&D operation and maintenance	-	T/S, NPS
Dry dams, other projects off mainstem	-	NPS
ERP projects - 5 categories	+	PR
Port development (Sec.107) and maintenance dredging	-	T/S
Fleeting areas/barge storage	-	T/S, PS
Terminals	-	T/S
Multi-modal sites	-	T/S
Increased traffic	-	T/S
Accidents/spills	-	PS
Floodplain sand and gravel mining	-	NPS

RFFA	Net Effect	Types of Effects
Industrial development in floodplain	-	NPS
Marina development and operation	-	T/S, NPS
Agriculture	-	NPS
Industrial wastewater discharges	-	PS
Stormwater discharges	-	NPS, PS (from CSOs)
Phase 1 & 2 NPDES program	+	PR
TMDLs	+	PR
Effluent trading	+	PR
Control of agricultural discharges	+	PR
Environmental awareness education	+	PR

The following discussion focuses on the primary effects of RFFAs ranked high and medium in the Water & Sediment Quality RFFA matrix. RFFAs are grouped according to their primary effects, but it should be understood that most actions have multiple interrelated environmental effects.

3.11.1 Actions Causing Turbidity and Sedimentation

A wide array of actions in and along the Ohio River mainstem contributes to turbidity and sedimentation. These actions are undertaken by the USACE, navigation industry, mining industry and other river users. Such actions and their importance rankings include:

- Channel dredging/dredged materials disposal (H)
- Instream sand and gravel mining (H)
- Lock and dam maintenance and operation (M)
- Port development and maintenance dredging (M)
- Terminals and multimodal sites (M)
- Fleeting areas/barge storage (M)
- Increased traffic (M) and
- Marina development and operation (M)

The environmental effects these actions have in common include disturbance or removal of bottom substrates, temporary increases in turbidity and suspended sediments, and subsequent settling out and blanketing of portions of the river bottom. Additional impacts include: 1) reduction in light penetration, which inhibits photosynthesis of algae and aquatic macrophytes, 2) interference with respiration and feeding of aquatic organisms, 3) habitat impairment or loss, and 4) resuspension of contaminants in sediments. Further, activities involving dredging or excavation may alter flow patterns depending on local channel morphology and weather conditions. Information on specific actions follows.

Channel maintenance dredging is a significant activity that continues from early spring through late fall and involves the removal and disposal of sand and gravel deposits from the navigation channel of the Ohio River to maintain a nine-foot depth. This activity not only removes natural substrates, but also results in the effective replacement of these substrates by fine-grained sediment and detritus. Past practices have generally utilized in-stream disposal of dredged materials; potential future constraints on in-stream disposal

may require land disposal of dredged materials, which would reduce water quality impacts. In some cases, dredged materials may be utilized to create new sandbars or islands that would provide additional aquatic habitat.

In-stream sand and gravel mining also involves the removal of sand and gravel deposits from the river and their subsequent transport to land or on the river. Like channel maintenance dredging, this activity potentially results in the disturbance and removal of bottom substrates, with increased turbidity and the release of contaminated sediments, followed by the redistribution of sediments, which may cover aquatic habitats, including mussel beds and other macroinvertebrate habitat. Further, when coarser substrates are dredged, they may be replaced with fine sediments and detritus that are less conducive to colonization by aquatic life. The cumulative impacts of in-stream mining are high because of the magnitude of localized impacts and the number of locations where such activity occurs.

Port development and maintenance also has potentially adverse impacts on water quality. Knowledge of potential sediment contaminants and care in handling them, as well as use of turbidity curtains to limit downstream siltation are among measures that can mitigate such impacts. The associated development of new terminals and multimodal sites and increased commercial traffic would be expected to further impact the Ohio River's water quality because of increased turbidity and release of sediment contaminants during construction of these facilities and continuing turbidity and deposition related to barge traffic during their operation.

Traffic projections prepared by the Corps indicate that barge traffic growth will occur independently of navigation improvements addressed by this study. The second generation of high-lift lock and dam projects, which was largely completed in 1980, provides sufficient capacity to meet most projected barge traffic growth (see Chapter 10, Transportation and Traffic). Therefore, it can be expected that expanded activities and development of related facilities will occur independently of navigation improvements.

Barge queuing, fleeting and storage, and dispersed barge traffic are all navigation-related actions with impacts on water quality and sediment quality. Barge queuing has the potential to cause turbidity increases due to sediment resuspension and physical damage to bottom substrates and the organisms that inhabit them. However, in a nine year study comparing two sites with differing traffic levels, Miller and Payne (1998) found that recruitment of *Amblema plicata plicata* proceeded at similar rates regardless of traffic levels. Queuing activity increases during periodic lock and dam maintenance and repair activities and, conversely, would be reduced as a result of increased lock capacities and associated decreases in lock maintenance events. The impacts of barge fleeting and storage are similar to barge queuing and also may include the release of petroleum products into the water column and their deposition in bottom sediments. Unlike queuing, fleeting and storage would not be relieved by lock expansions and, in fact, would be expected to expand in proportion to increased commercial traffic.

Another navigation-related action with potential turbidity and sedimentation impacts is the construction of lock chamber extensions. This RFFA was ranked in the matrix as "low," primarily because of minimal occurrences over the study period and mitigation measures that could be implemented, including:

- Installing turbidity curtains to surround construction areas.
- Using environmentally acceptable fill materials.
- Scheduling construction to minimize in-river activities.
- Using dewatering techniques that minimize suspended solids in the water column.
- Implementing erosion control plans that emphasize phased clearing, containment of soils, water detention and temporary reseeding of cleared sites and timely permanent revegetation.
- Installing floating mooring buoys that restrict queuing tows to the navigation channel.

Careful positioning of buoys, channel markers and other navigation aids and information systems and "green" tow design have potential for reducing the cumulative environmental effects of navigation, but the quantitative extent of these reductions is difficult to project.

Recreational activities, including the development and operation of marinas, boat launch ramps and support facilities and operation of power boats cumulatively impact water quality and sediment of the Ohio River. Because the recent growth rate of recreation appears to outpace population and development growth, river recreation and facilities that support it are predicted to continue growing in the foreseeable future.

Marina facilities tend to be concentrated in embayments, which are especially vulnerable to water quality degradation. Embayments represent a very limited resource within the Ohio River floodplain. They provide rich habitats for spawning and juvenile fish, diverse macroinvertebrate populations, and migratory birds, as well as favorable conditions for the growth of aquatic macrophytes. Dredging of embayments is generally required to maintain accessibility to marinas and/or launch ramps. The predicted growth of marinas and dredging of embayments will likely compete with or displace valued natural resources. Continuance of this trend will inevitably impact aquatic resources. Careful siting of recreational facilities and implementation of appropriate BMPs can help reduce related water quality degradation and its negative impacts on aquatic habitats. (See Marina Development and Operation below.)

3.11.2 Actions Contributing to Point Source Pollution

Point sources of pollution have been the intensive focus of pollution reduction nationwide for more than 30 years. While most point sources to the Ohio River have been cleaned up or eliminated, the following RFFAs ranked high or medium still pose potential risks to the river's water and sediment quality:

- Coal and other related industries (H)
- Industrial river users, excluding coal-related (H)
- Industrial discharges (M)
- Accidents/spills (M)
- Marina operation (M)

A number of industrial activities congregate along the Ohio River or its major tributaries and benefit directly from the availability of barge transportation and/or availability of water supplies through maintenance of navigation pools. While some industrial activities are conducted within major urban centers, much is dispersed through

less populated areas along the length of the floodplain. These include nearly 50 coal-fired electric utilities, industries utilizing coal as a fuel and/or process material, and other industries with bulk transport needs. Continued growth of these industries is expected to occur in proportion to ongoing population and urbanization/development growth within the broader economy of the Ohio Valley region and the nation in general.

Although industrial discharges to the Ohio River are highly regulated under NPDES permitting, water and sediment quality concerns remain because of the large number of industries and their high volume of discharges to the Ohio River mainstem. Potential impacts from coal utilities include thermal pollution, chemical pollution from corrosion inhibitors, and suspended fine particulates from coal piles. Industrial discharges from manufacturing sites may include suspended solids, heavy metals, and nutrient- and oxygen-demanding constituents. Industrial sites also can be sources of nonpoint pollution during construction activities or storm events, if appropriate best management practices to reduce sediment and erosion are not implemented.

Other water and sediment quality impacts related to industrial activities along the river primarily focus on transfer of potentially harmful materials and maintenance of port/docking facilities. Coal transport alone currently accounts for more than 55% of all barge traffic on the Ohio River and is projected to account for a larger percentage of traffic for the foreseeable future. Because of the coal industry's prominence, potential environmental impacts of related barge activities and spillage of coal fines and other harmful substances are particularly important.

Spills of hazardous materials during both routine navigation and product transfer also pose threats to water and sediment quality, as well as to aquatic life resources and public water supplies. Pollution from spills is generally considered short-term, but can cause serious harm depending on the amount and nature of substances released. ORSANCO's advance spill notification system and Coast Guard spill reporting procedures have ameliorated related impacts in recent years.

Marina operations are potential point sources for petrochemicals and other toxic substances used to repair and maintain watercraft. Marinas in turn support power boats and personal watercraft which cumulatively impact water and sediment quality:

- through the release of fuel, chemical pollutants, sewage, and trash related to boat operation and maintenance,
- by contributing to shoreline erosion and subsequent turbidity and siltation, and
- by inadvertently facilitating the spread of nonnative species such as zebra mussels.

Harmful impacts to aquatic life include habitat disturbance and reduction of light penetration, inhibiting photosynthesis. In some locations, disturbance of contaminated sediments may present human health risks.

3.11.3 Actions Contributing to Nonpoint Source Pollution

Nonpoint source pollution is difficult to control because it does not come from any single point of entry, but from many diffuse sources throughout the Ohio River watershed. The following RFFAs, all ranked "medium" are nonpoint sources of pollution:

- Stormwater discharges (M)

- Agriculture (M)
- Industrial development (M)
- Floodplain sand and gravel mining (M)

Stormwater discharges result from precipitation and snow melt in excess of what can infiltrate soils or be stored in small surface depressions. Compacted soils, concrete, asphalt and other impervious surfaces allow runoff to flow quickly to the Ohio River, introducing nutrients, organics, suspended solids (which contribute to turbidity and sedimentation), and toxic substances. Regulatory programs to control and reduce pollution from stormwater discharges are discussed in the following section.

Agriculture constitutes the largest land use activity by area within or adjacent to the Ohio River floodplain. Erosion of cultivated land carries suspended solids and attached fertilizers, pesticides, and herbicides to the Ohio mainstem. These pollutants not only can degrade measurable chemical parameters of water quality but can also influence species composition and abundance of algae, macroinvertebrates, and other aquatic life. Livestock waste also may enter the river, causing elevated bacteria levels. BMPs promoted through the USDA Natural Resources Conservation Service can help mitigate these impacts, but have limited effectiveness because these BMPs are largely voluntary. Most future conversions of land use in the Ohio River corridor will occur on land currently in agricultural production or in forests. Consequently, nonpoint pollution is expected to persist unless stricter regulatory controls are implemented.

Floodplain ordinances, government programs and other constraints have limited residential, commercial, and industrial development in the Ohio River floodplain in recent years; however, some level of floodplain development is expected to continue throughout the study period. Of these development types, industrial development is potentially the most extensive and is expected to continue to grow in proportion to general economic/population expansion within the broader Ohio Valley region. Many industries along the Ohio River mainstem are to some degree dependent on the existence of an efficient and reliable navigation system. Possible development impacts related to water and sediment quality include increased erosion and attendant siltation during construction and increased stormwater runoff and associated pollutants as impervious surfaces, such as driveways, parking lots, and roof tops increase.

Floodplain sand and gravel mining, as well as limestone aggregate mining, contribute to nonpoint source pollution from surface runoff of soil and fine particulates. These mining activities benefit directly from the availability of barge transport along the Ohio River, but pose additional environmental risks related to materials handling and transfer, as well as the construction and maintenance of port/docking facilities.

3.11.4 Actions Contributing to Pollution Reduction

RFFAs that contribute to pollution reduction act as countermeasures to the cumulative effects of many previous listed RFFAs. All eight actions listed as beneficial in Table 6 contribute to pollution reduction. The two RFFAs rated as “high importance” - more stringent quality standards for environmental media and pollutant source control - are very similar and include various surface water and groundwater quality standards that have existed for some time. These are promulgated by legislation, including the CWA and Safe Drinking Water Act (SDWA). It is likely that current standards for various environmental

media will become more stringent, with implications that could strengthen environmental management of the Ohio River mainstem.

Actions with implementation deadlines and realistic provisions for enforcement over a large portion of the ORMSS study area potentially have the highest impacts. The Phase 1 and 2 NPDES program exemplifies such an initiative that is currently being implemented in urban areas and industrial and development zones bordering the Ohio River. Over time, this program should generate measurable reductions in nonpoint source pollution. The TMDL program, established by Section 303 of the CWA is a holistic program for developing allowable loads for both existing and new pollutant sources. Both the Phase 1and 2 and TMDL initiatives were ranked medium in the RFFA matrix for water and sediment quality.

Effluent trading, control of agricultural resources, and environmental awareness education, also ranked medium in the RFFA matrix, are primarily voluntary initiatives that should promote more responsible environmental decision-making and, consequently, should benefit water and sediment quality and other aquatic resources. These activities and other related voluntary efforts will need significant expansion from current funding levels to produce measurable impacts within the Ohio River corridor.

Ecological Restoration Program (ERP) projects are not listed with regulatory actions in the RFFA matrix, but have potential to contribute to pollution reduction because such projects typically include improvements in water quality and aquatic habitats among their goals.

3.12 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve environmental sustainability (ES). ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an “ultimate test” whereby the significance of cumulative effects can be evaluated. This test is applicable for programmatic impact studies wherein a broad, “high altitude” perspective is utilized. An analysis of environmental sustainability (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps: (1) identification of “common effects” on water and sediment quality from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix; (2) selection of indicators for ES for water quality, and their grouping, as appropriate; and (3) consideration of the “connections” between the common effects and the indicator groups. The output of the AES consists of a qualitative (descriptive) discussion of the “connections,” with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for water quality, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – the composite conditions for the selected indicators of ES for water quality do not reflect conditions that would facilitate attainment of permissible use designations in the Ohio River, nor would they sustain diverse populations of aquatic organisms in the river.

- Marginally sustainable – the composite conditions for the selected indicators of ES for water quality are such that the attainment of permissible use designations is accomplished for the majority, but not all, of the river miles in the Ohio River, and diverse populations of aquatic organisms are occurring along the majority of the river; however, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of water quality for the Ohio River).

- Sustainable – the composite conditions for the selected indicators of ES for water quality are such that the attainment of permissible use designations is accomplished for essentially all of the river miles in the Ohio River, and diverse populations of aquatic organisms are occurring along the majority of the river; further, the conditions of the indicators exceed regulatory thresholds, and various governmental programs are in place to control point and nonpoint pollution sources and to emphasize pollution reduction in the river.

Four common effects of multiple actions have been previously discussed in the section entitled "Cumulative Effects"; they include actions causing turbidity and sedimentation, actions contributing to point source pollution, actions contributing to nonpoint source pollution, and actions contributing to pollution reduction.

Six indicators of ES were identified earlier in the section entitled "Indicators of Environmental Sustainability", and relevant information on them have been presented in the section entitled "Past to Current Baseline Conditions." Regarding their relevance for ES, the following rationale is appropriate:

- measures of key water quality parameters

  (1) DO – related to the total organic loading from point and nonpoint sources at specific locations along the river; can also be used as a threshold indicator since the DO standard is 5.0 to 6.5 mg/l, depending upon several conditions

  (2) fecal coliforms – related to fecal matter contamination from humans or other animals, whether from point or nonpoint sources at specific locations along the river; can also be used as a threshold indicator since the standard is 2000 fecal coliforms/100 ml

  (3) turbidity and total suspended solids – related to solid material which can be attributed to point and nonpoint sources at specific locations along the river; can originate from both man-made wastewater discharges and natural erosional processes; no specific numerical standards exist for the Ohio River

(4) nutrients such as nitrogen and phosphorus – related to the total nutrient loading from point and nonpoint sources at specific locations along the river; the nitrogen standard is 10 mg/l (for nitrite plus nitrate nitrogen); no standard has been adopted for phosphorus

- level of conformance with state and federal water quality standards, including attainment of permissible use designations – water quality standards are based on various use designations, with the level of conformance representing a composite indicator of a sustainable aquatic ecological resource

- TMDL implementation – the TMDL program is for specific water quality parameters which may reflect an "overloaded" situation related to point and nonpoint sources at specific locations; implementation of the program reflects a coordinated effort to achieve appropriate water quality standards and promote a sustainable ecological resource

- effectiveness of specific point source control and nonpoint source control programs – such programs are focused on reducing pollutant discharges into the river, and thus they promote a more sustainable aquatic ecological resource

- ability to sustain diverse, healthy populations of aquatic organisms – an aquatic system which attains water quality standards while minimizing the effects of "legacy contaminated sediments" should sustain diverse populations of various organisms; further, it should attain permissible use designations.

- effectiveness of spill response, monitoring programs, and related precautionary measures – these represent both direct and indirect programs which are focused on more effective management of water and sediment quality, and thus the promotion of a sustainable aquatic ecological resource

For the purposes of this analysis, the six indicators are grouped into three tiers for the AES. The three tiers are as follows:

- first tier – "scientific measures of quality"

  (1) water quality parameters (DO, fecal coliform bacteria, turbidity, total suspended solids, N and P)

  (2) conformance with water quality standards

- second tier – "positive actions related to source control"

  (1) point source control and nonpoint source control programs

  (2) TMDL implementation

  (3) spill response, monitoring programs, and related precautionary measures

- third tier – "composite indicators of aquatic ecosystem sustainability"; this includes two measures developed from several indicators

(1) attainment of permissible use designations

(2) sustain diverse, healthy populations of aquatic organisms

Finally, the indicators and tiers are displayed into four figures, with each figure coinciding with the four groups of actions with common effects. **Tables 3-12 through 3-15** are on the following pages. **Table 3-12** relates to RFFAs causing turbidity and sedimentation. Turbidity and sedimentation represent historical water quality concerns in the Ohio River, even with the absence of specific standards. Control programs for municipal and industrial point sources have been implemented within the last several decades, while similar programs for nonpoint sources are largely in their first decade. Increased control programs, including operational measures, are expected in the future for channel dredging/dredged material disposal, and port and marine development and operation. Implementation of a TMDL program for turbidity could occur in localized reaches of the river. Further, spill-related programs and precautionary measures are expected to reduce accidental releases. As a result of these current and anticipated future source control efforts, for turbidity and sedimentation it is expected that permissible use designations will be more easily attained, thus increasing the sustainability of diverse populations of aquatic organisms.

Table 3-13 relates to RFFAs contributing to point source pollution. Of particular concern are industrial water users and dischargers who may introduce diverse chemicals and bacteria into the river. Existing point and nonpoint source control programs have already led to reductions in industrial discharges, thus increasing the possibilities for achieving conformance with water quality standards. Future source control programs may become more stringent, and TMDL requirements could be implemented for specific industrial pollutants in certain river reaches. Also, spill prevention and response programs are expected to reduce accidental point source pollution. As a result of these current and possible future point source control efforts, it is anticipated that additional river reaches will attain their respective permissible use designations, and the river itself will be able to sustain more diverse populations of aquatic organisms.

Table 3-14 denotes four RFFAs that are of medium importance relative to nonpoint source pollution. Nonpoint source control programs are being currently implemented for stormwater discharges from urban areas, and for runoff waters from industrial areas. Source control programs related to floodplain sand and gravel mining, as well as agriculture, are anticipated, although the specific requirements and their possible effectiveness are largely unknown. However, when considering the background of a minimal historical emphasis on controlling nonpoint source pollution, it does appear that the current efforts, when coupled with possible future emphases, are and will improve the ES of the aquatic ecosystem.

Table 3-15 delineates 8 RFFAs that are expected to contribute to pollution reduction in the river. Several of the listed RFFAs represent continuations of existing pollution reduction efforts. Accordingly, the sustainability of the aquatic ecosystem is expected to improve.

TABLE 3-12
AES Tiers for Actions Causing Turbidity and Sedimentation

Actions Causing Turbidity and Sedimentation	Scientific Measures of Quality	Positive Actions Related to Source Control	Composite Indicators of Aquatic Ecosystem Sustainability
• Channel dredging/dredged material disposal (H) • Instream sand and gravel mining (H) • Lock and dam maintenance and operation (M) • Port development and maintenance dredging (M) • Terminals and multimodal sites (M) • Fleeting areas/barge storage (M) • Increased traffic (M) • Marina development and operation (M)	• Water Quality Parameters • Conformance with Water Quality Standards	• Source Control Programs (point and nonpoint) • TMDL Implementation • Spill Response, Monitoring, and Precautionary Measures	• Attainment of Permissible Use Designations • Sustain Diverse Populations of Aquatic Organisms

TABLE 3-13
AES Tiers for Actions Contributing to Point Source Pollution

Actions Contributing to Point Source Pollution	Scientific Measures of Quality	Positive Actions Related to Source Control	Composite Indicators of Aquatic Ecosystem Sustainability
• Coal and other related industries (H) • Industrial river users, excluding coal-related (H) • Industrial discharges (M) • Accidents/spills (M) • Marina operation (M)	• Water Quality Parameters • Conformance with Water Quality Standards	• Source Control Programs (point and nonpoint) • TMDL Implementation • Spill Response, Monitoring, and Precautionary Measures	• Attainment of Permissible Use Designations • Sustain Diverse Populations of Aquatic Organisms

TABLE 3-14
AES Tiers for Actions Contributing to Nonpoint Source Pollution

Actions Contributing to Nonpoint Source Pollution	Scientific Measures of Quality	Positive Actions Related to Source Control	Composite Indicators of Aquatic Ecosystem Sustainability
• Stormwater discharges (M) • Agriculture (M) • Industrial development	• Water Quality Parameters • Conformance with Water Quality	• Source Control Programs (point and nonpoint) • TMDL Implementation	• Attainment of Permissible Use Designations • Sustain Diverse Populations of

Actions Contributing to Nonpoint Source Pollution	Scientific Measures of Quality	Positive Actions Related to Source Control	Composite Indicators of Aquatic Ecosystem Sustainability
(M) • Floodplain sand and gravel mining (M)	Standards	• Spill Response, Monitoring, and Precautionary Measures	Aquatic Organisms

TABLE 3-15
AES Tiers for Actions Contributing to Pollution Reduction

Actions Contributing to Pollution Reduction	Scientific Measures of Quality	Positive Actions Related to Source Control	Composite Indicators of Aquatic Ecosystem Sustainability
• More stringent quality standards for environmental media (H) • Pollutant source control (H) • ERP projects (M) • Phase 1 and 12 NPDES program (M) • TMDLs (M) • Effluent trading (M) • Control of agricultural discharges (M) • Environmental awareness education (M)	• Water Quality Parameters • Conformance with Water Quality Standards	• Source Control Programs (point and nonpoint) • TMDL Implementation • Spill Response, Monitoring, and Precautionary Measures	• Attainment of Permissible Use Designations • Sustain Diverse Populations of Aquatic Organisms

3.13 SUMMARY AND CONCLUSIONS

The CE on Ohio River water quality from past, present, and reasonably foreseeable future actions have been addressed herein. Water quality (and related sediment quality) is a VEC in the ORMSS. This resource is valued because it is interwoven with the health and sustainability of other aquatic ecological resources (such as mussels and fish), riparian resources (such as riparian habitats, wetlands, and islands), and human health (as related to the consumption of potentially contaminated drinking water and fish). Water quality in the Ohio River is influenced by land use changes associated with economic growth and development, by point source discharges of municipal and industrial wastewaters, and by nonpoint source discharges associated with urban and rural runoff. Further, both navigation traffic and recreational boating can influence the water quality VEC along with other aquatic and riparian resources. Accordingly, the geographic boundaries for the water quality VEC study includes the Ohio River mainstem, lands along either bank within the approximate 500-year floodplain, and terraces located adjacent to and above the floodplain. The temporal boundaries for most topics encompass from 1920 to 2070, with the earlier date approximating the initiation of the Corps' lock and dam construction activities on the Ohio River, and the latter date approximating the end of the 60-year planning horizon encompassed by the ORMSS.

Water quality was identified in early study planning by the Corps and the IWG as an important topical issue to be addressed. This identification was confirmed via the number of comments and specific concerns expressed in 12 public scoping meetings. A total of 21 direct comments on water quality were received, along with an additional 45 comments that have implications for water quality. These comments have been addressed herein.

Several federal laws are related to Ohio River water quality. The primary one is the CWA; others include the SDWA, various Water Resources Development Acts, site remediation laws, and the Oil Pollution Act. Regulatory and other permit programs exist under the auspices of the CWA and the Rivers and Harbor Act. ORSANCO, formed in 1948, has played a major role in the implementation of the requirements of the CWA, including interstate coordination, adoption of water quality standards for the river, promotion of the construction and operation of municipal wastewater treatment plants, and water quality and aquatic ecological monitoring.

3.13.1 Describing the Affected Environment

Six indicators for describing the affected environment and evaluating the environmental sustainability (ES) of the water quality VEC were utilized in this CEA study. They included: 1) several water quality parameters (e.g., DO, pH, fecal coliforms, turbidity, total suspended solids, and nutrients); 2) the level of conformance with state and federal water quality standards, including attainment of permissible use designations; 3) implementation of an appropriate TMDL program; 4) the effectiveness of specific point source control and nonpoint source control programs; 5) the effectiveness of spill response, monitoring programs, and related precautionary measures; and 6) the overall ability to sustain diverse, healthy populations of aquatic organisms. In assembling information on these indicators, along with related biological indicators such as algae and aquatic macroinvertebrates, approximately 70 scientific publications and reports were reviewed.

Limited information prior to 1920 indicated that water quality probably declined between 1820 and the 1940s due to population growth and industrial development throughout the Ohio River basin. Historical lows in DO occurred downstream of Pittsburgh, Cincinnati, and Louisville in the late 1960s to mid 1970s. New municipal wastewater treatment plants built by many cities along the mainstem from the 1970s to the 1990s contributed to increases in DO above the standard of 5.0 mg/l, and today, the entire 981-mile mainstem length is routinely in compliance with the DO standard. Operational practices at several navigation dams with hydropower have also enhanced DO levels in the mainstem.

Chronic AMD from high-sulfur bituminous coal mines has historically caused lowered pH readings for mainstem waters. During the 1960s and 1970s, AMD pollution was reduced by mandatory treatment of active coal mine effluents, and by the 1980s the pH standards (between 6.0 and 9.0) were achieved at all mainstem monitoring stations. However, a potential AMD concern has recently been identified. It relates to numerous mining company bankruptcies that have led to large underground mining complexes that have been abandoned and are now being flooded. Without intervention, these abandoned mines are predicted to again discharge AMD to upper Ohio River tributaries. Such discharges would disrupt the sustainability of upper mainstem water quality and related aquatic resources such as fish populations.

Total coliform bacterial data for the mainstem are available from the 1939-1943 time period, with the counts exceeding 20,000/100 mL for 31 to 61% of the time at the utilized monitoring stations. From the 1940s to the 1960s, implementation of primary treatment plants for municipalities along the river caused dramatic declines in coliform bacterial counts in both the upper and lower reaches of the river. Such declines were aided in the lower river by the greater available assimilative capacities. Completion of secondary treatment plants in the 1970s through the early 1990s still further reduced coliform levels. However, the current water quality standard is 200/100mL as a monthly geometric mean, and exceedances still occur downstream of major urban areas such as Pittsburgh, Wheeling, Huntington, Cincinnati, Louisville, and Evansville. Discharges of urban runoff via CSO have been identified as contributors to the exceedances of the standard; in fact, 52 CSO systems contribute discharges to the river. Such contributions may worsen as a result of further urban population growth and changes in land use patterns; however, continued implementation of Phases 1 and 2 of the NPDES stormwater permit program will provide further controls of coliform organisms.

The turbidity and total suspended solids (TSS) of the mainstem waters are influenced by river flows and velocities (particularly during flooding conditions), erosional characteristics of the native soils, dredging activities, sand and gravel extraction operations, clearing of lands, construction related to new urban or industrial developments, and discharges of treated wastewaters and untreated urban and rural runoff. Flood-induced turbidity and TSS have declined to some extent due to sediment retention in the pools upstream of the locks and dams. Further, there are no specific water quality standards for turbidity and TSS.

The historical information base for nitrogen and phosphorus in the Ohio River is not robust. However, a decreasing trend in ammonia nitrogen and total nitrogen was noted in the 1977 to 1987 time period. This trend can be attributed to improved wastewater treatment levels and some implementation of BMPs for control of both urban and rural runoff. Of particular importance are BMPs for rural (agricultural) runoff. Water quality criteria (not standards) for human health are 10 mg/L for nitrite plus nitrate nitrogen, and 1.0 mg/L for nitrite nitrogen. Monitoring data from the lower mainstem in 2000 indicated that the nitrogen concentrations were well below the standards. While these standards are not being exceeded, there is a concern related to the Ohio River basin's contribution to the nitrogen loading entering the Gulf of Mexico, and the associated depressed DO levels (hypoxia problems) in the northern Gulf area. It has been estimated that the Ohio River basin contributes 44% of the nitrogen loading basic to these problems.

Regarding total phosphorus in mainstem water, ORSANCO has not yet established a standard. Switches to phosphate-free detergents in the early 1980s led to a decreasing trend in the phosphorus concentrations in the Ohio River. Recent measurements have typically been below 1.0 mg/L (the recommended USEPA standard), except downstream from Markland L/D, where agricultural chemicals may have contributed to higher concentrations. Agricultural chemicals are a major contributor to current phosphorus loadings in the river, along with wastewater discharges from municipalities and industries.

The TMDL refers to the maximum amount of a pollutant that a water body can receive and still meet water quality standards. Consequently, a TMDL represents the sum of allowable loads of a single pollutant from all contributing point, nonpoint, and natural

sources. To date, TMDLs for dioxin and polychlorinated biphenyls (PCBs) have been established for specific segments of the Ohio River. These TMDLs are a result of the two contaminants being found in fish tissue, and the resultant issuance of consumption advisories for certain fish species. Consideration is currently being given to the future development of a TMDL for *E. coli*.

The natural bottom substrate of the Ohio River is mainly sand, gravel, or clay overlain, especially in near shore or other sheltered areas, with silt and/or organic detritus. These overlying sediments are generally mobile and dynamic, and storm events may lead to displacement and subsequent redeposition of various proportions of the materials. Further, such sediments are natural "sinks" for many toxic and persistent pollutants. Significant heavy metal contamination of sediments has resulted from coal mine drainage with inflows of iron and manganese and industrial activity, particularly the iron and steel industry of the upper Ohio River valley. These legacy-contaminated sediments may continue to adversely affect overlying waters and food chains for years. In addition, contaminated sediments have also been found in the middle river area between and below metropolitan areas. One concern related to legacy sediments is that the contaminants can be remobilized under certain flow and low pH conditions. Further, such dissolution of the contaminants could lead to toxicities to nearby aquatic organisms. However, only a few localized studies of sediment quality and related consequences have been conducted, thus the information base is not robust. In this regard, a systematic study of sediment quality, contaminant remobilization tendencies, and potential consequences on aquatic resources is needed for the entirety of the Ohio River mainstem. Finally, there is some evidence of natural recovery associated with legacy-contaminated sediments; for example, there has been a re-emergence of burrowing mayflies in the upper Ohio River in the last decade.

Biological surveys of fishes, algae, and macroinvertebrates have been conducted by ORSANCO since 1957. Such surveys provide evidence of the composite effects of water quality conditions on aquatic ecological resources. For example, improvements in fish diversity have been noted since the late 1960s for the middle and upper river segments, with such improvements attributed to increased DO concentrations and pH levels, and reductions in the concentrations of chemical toxicants (the accompanying discussion of fish resources in Chapter 4 provides more specific information).

Algae can occur in attached and free-floating (planktonic) forms, with diatoms often dominating the planktonic community. As such, they represent food sources that are foundational components of the aquatic ecosystem. Plankton (phytoplankton) studies of the Ohio River have been conducted at various times over five decades (1957 to 1960, 1974 to 1975, 1990s, and 2002). Depressed concentrations of phytoplankton were found in the AMD-polluted upper river in the 1957 to 1960 studies, and no blue-green algae, which are species sensitive to acid conditions, were found in the same area in the 1974-75 studies. The navigation system was also found to influence the longitudinal distribution of phytoplankton in the river. For example, several unpublished studies from 1976 to 1991 found that phytoplankton concentrations in near surface samples were elevated in the downstream sections of navigation pools where velocities are low; in contrast, such concentrations were reduced downstream of the locks and dams.

In a plankton study conducted during the 1990s, in the reach between Cincinnati and Evansville, it was determined that the Ohio River supports diverse, substantial phytoplankton communities. By this time period, the composite water quality in the river

had been markedly improved due to municipal and industrial wastewater treatment plants. Further, it was found that temperature increases enhanced phytoplankton densities; with flow velocity increases causing decreases in densities. A collaborative and comprehensive study conducted from 1999 to 2002 monitored phytoplankton and chlorophyll at 10 water intakes along the river (from mile 4.5 to 935.5). It was found that both phytoplankton and chlorophyll increased in the downstream direction, and this generally coincides with improved water quality conditions. Further, it was determined that the phytoplankton community is both dynamic and complex, containing over 100 genera.

Benthic macroinvertebrate communities are good indicators of localized water quality conditions, and they also serve as a primary food source for many fish species. Macroinvertebrate studies of the Ohio River have also been conducted at various times over five decades (1957 to 1960, 1963 to 1967, and at various other times to 2002). Specific types and quantities of benthic organisms have been found to be associated with certain types of substrates; for example, silt bottoms support larger numbers than do sand or sand and silt bottoms. Composite condition scores determined in 1967 for aquatic macroinvertebrates indicated improvements in the scores from the upper (scores of 12 to 45) to the middle (35 to 72) to the lower (55 to 83) segments of the river. In 2002, comparative composite condition scores were developed for the upper segment only, with the scores being higher (39 to 59) than those in 1967 (12 to 45). In general, these findings support a positive relationship between improved water quality conditions and more robust benthic macroinvertebrate communities. Because the information base for macroinvertebrates is robust, the possibility exists for the scientifically based selection of "signature species" for inclusion in longer-term monitoring programs for the Ohio River mainstem.

The designated uses of the Ohio River include support of warm water aquatic life, public water supply, fish consumption, and contact recreation. ORSANCO has developed assessment criteria for three categories for each of the four uses; the categories are "fully supporting", "partially supporting", and "not supporting." Water quality data and standards, along with measurements of fish communities and fish consumption advisories form the bases for the criteria (information on fish communities is in Chapter 4 and consumption advisories are addressed in Chapter 8, "Health and Safety"). Regarding support of aquatic life, in 1998-99, only 66.1 miles of the 981-mile length of the Ohio River were "not fully supporting" this use (915 miles were in the "fully supporting" category); in 2000-01, only 7 miles were "not fully supporting." For the public water supply use, only 4.4 miles were "not fully supporting" in 1998-99, and 10.5 miles were "not fully supporting" in 2000-01. In both 1998-99 and 2000-01, all 981 miles were designated at "not fully supporting" fish consumption (this designation is based on the criteria that "no consumption" advisories are in effect for all commonly consumed species, or that restricted fish consumption advisories are in effect). Finally, in 1998-99, 355.4 miles of the river were "not fully supporting" contact recreation use; and in 2000-01, the number dropped to 176.7 miles. Bacterial concentrations at six recreational monitoring stations are the primary cause of the "not fully supporting" designations for contact recreation. In the future, the "not fully supporting" designations should decline with further treatment of wastewater discharges, pollution prevention and control efforts, and compliance with CSO regulations.

3.13.2 Assessing the Cumulative Effects of Past, Present, and Future Actions

Multiple past and present actions have affected the water and sediment quality of the mainstem, and multiple future actions are also anticipated to contribute to the overall CEs on the water quality VEC. The systematic evaluation of 87 types of reasonably foreseeable future actions (RFFAs) indicated that seven were ranked as having "high importance" relative to CEs, and 20 were designated as having "medium importance." The importance ratings reflect the composite consideration of the future time period of occurrence, likelihood of occurrence, potential for multiple locations along the river, the spatial and temporal extent of the anticipated effects, the level of knowledge about the effects, the relative contribution to the CEs, and the possibilities for cost-effectively mitigating the negative consequences. These 27 RFFAs have been characterized by their common effects into those causing turbidity and sedimentation (T/S) during construction and/or operation; those contributing to point source (PS) pollution due to discharges of organics, nutrients, thermal content, bacteria, and/or toxic chemicals; those contributing to nonpoint source pollution (NPS) due to the bacterial, nutrient, or pesticide content of urban or agricultural runoff; and those contributing to pollution reduction (PR) via environmental restoration projects, regulatory controls, or educational efforts. Examples of how RFFAs contribute to both adverse and beneficial effects on water quality are included earlier in this chapter. Further, it should be noted that the 27 RFFAs reflect continuations of actions initiated in the past along the Ohio River mainstem.

The high importance actions that contribute to adverse T/S effects include channel dredging/dredged material disposal and instream sand and gravel mining. Medium importance actions include L/D operation and maintenance, port development and maintenance dredging, fleeting areas and barge storage, terminals, multi-modal sites, increased navigation traffic, and marine development and operation.

The high importance actions that contribute to adverse PS pollution effects include instream sand and gravel mining, coal utilities, other coal industries, and industrial users (excluding coal-related). Medium importance actions include fleeting areas and barge storage, accidents/spills, industrial wastewater discharges, and stormwater discharges (from CSOs). Regarding adverse NPS pollution effects, high importance actions include channel dredging/dredged materials disposal, coal utilities, other coal utilities, and industrial users (excluding coal-related users). Medium importance actions related to adverse NPS pollution effects include L/D operation and maintenance, dry dams and other projects off the mainstem, floodplain sand and gravel mining, industrial development in the floodplain, marina development and operation, agriculture, and stormwater discharges.

PR is expected to result in beneficial effects on water and sediment quality. The high importance actions (or programs) that contribute to such effects include more stringent quality standards for environmental media, and pollutant source control. Medium importance actions and programs include ecological restoration, Phases 1 and 2 of the NPDES stormwater permit program, the TMDL program, effluent trading, control of agricultural discharges, and environmental awareness education.

ES has been used as the "ultimate test" whereby the significance of CEs from multiple actions on water quality can be qualitatively evaluated. The AES involved "connecting" the four common effects from the 27 high and medium importance RFFAs to

the six indicators of ES used to describe the historical situation, trends, and current conditions of the water quality VEC. For purposes of this analysis, the indicators were divided into three tiers and re-grouped. The first tier included "scientific measures of quality" such as water quality parameters and conformance with standards. The second tier encompassed "positive actions related to source control" that included point source control and nonpoint source control programs, TMDL implementation, spill response, monitoring programs, and related precautionary measures. The third tier included two "composite indicators of aquatic ecosystem sustainability" developed from several of the indicators; they were attainment of permissible use designations, and sustainment of diverse, healthy populations of aquatic organisms. The qualitative discussion of the connections was based on some quantitative data, fundamental scientific information, and professional judgment. Three categories of ES were defined as follows:

- Not sustainable -- the composite conditions for the selected indicators do not reflect conditions that would facilitate attainment of permissible use designations, nor would they sustain diverse populations of aquatic organisms.

- Marginally sustainable -- the composite conditions for the selected indicators are such that the attainment of permissible use designations is accomplished for the majority, but not all, of the river miles in the mainstem, and diverse populations of aquatic organisms are occurring along the majority of the river; however, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences.

- Sustainable -- the composite conditions for the selected indicators are such that the attainment of permissible use designations is accomplished for essentially all of the river miles in the mainstem, and diverse populations of aquatic organisms are occurring along the majority of the river; further, the conditions of the indicators exceed regulatory thresholds and various governmental programs are in place to control point and nonpoint pollution sources and to emphasize pollution reduction.

Based upon the above-described affected environmental conditions, the multiple actions and effects, the tiers of indicators, and the ES categories, the ES of the water quality of the mainstem of the Ohio River can be characterized and depicted in **Figure 3-4** as follows:

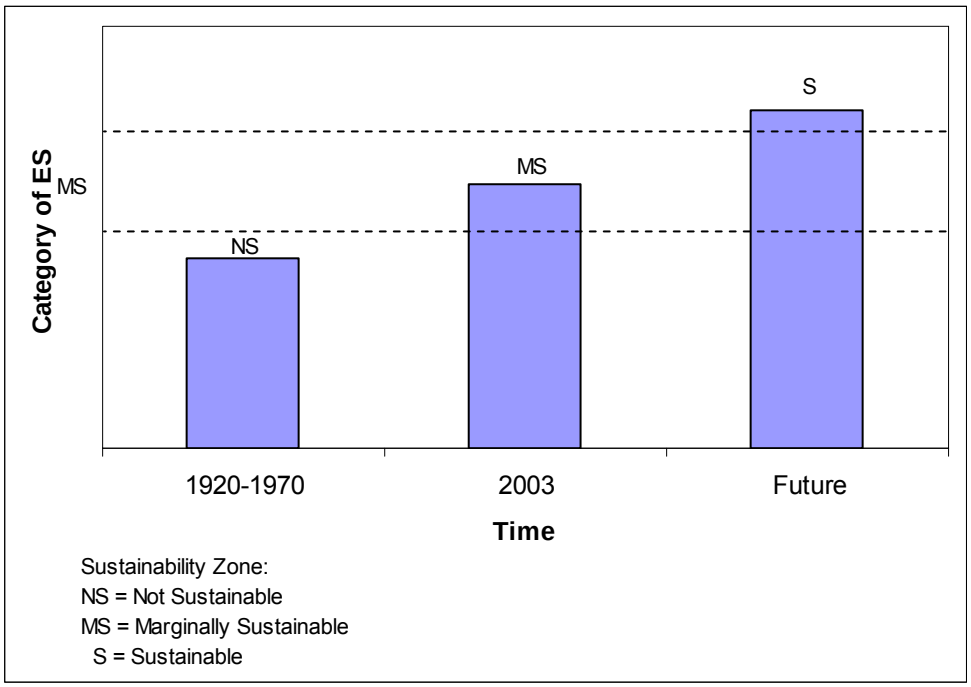
- In the time period prior to 1920, and continuing up to about 1970, the water quality of the mainstem was in a degraded state characterized by low DO concentrations, low pH levels in the upper river, high bacterial contamination, high nitrogen concentrations, and remobilization of potentially toxic chemicals that had become associated with river sediments. Essentially no pollution reduction, control programs, or regulatory programs, were in place during this period. Further, declines in the diversity and health of fish communities in the mainstem also were experienced (see Chapter 4). Accordingly, the ES of the water quality VEC was classified as "not sustainable." Primary contributors to these conditions were the largely untreated and uncontrolled point and nonpoint pollutant discharges from growing municipalities, mining, and various types of industries and land uses along the river.

- Due to the programs of ORSANCO, and the requirements of the FWPCA (and the amended CWA), water quality of the Ohio River has shown a steady improvement in recent decades. For example, DO concentrations are typically above the 5.0 mg/L standard, pH levels are between the 6.0 to 9.0 standard, and nitrogen concentrations meet current water quality criteria. However, bacterial contamination primarily associated with NPS pollution is still problematic downstream of major urban areas. Further, legacy "contaminated sediments" are a concern in the upper river along with fish consumption advisories throughout the mainstem. In contrast, the results of algae (plankton) and aquatic macroinvertebrate biological surveys in the five most recent decades have demonstrated steady improvements in these aquatic ecological resources, with the improvements paralleling water quality improvements. Regarding the attainment of permissible use designations, as of 2003, 779 of 981 miles (~80%) of the mainstem are "fully supporting" aquatic life, and 949 miles (~97%) are "fully supporting" public water supply use. None of the mainstem was "fully supporting" fish consumption due to restricted or no consumption advisories along its total length. For contact recreation, 269 miles (~27%) are "fully supporting" this use, with major impairment continuing from combined sewer systems in urban areas. Overall, implementation of NPDES permit programs for municipalities, industries, and stormwater has led to the reduction of discharges into the mainstem. Initiatives for increasing the use of BMPs have also been established. Also, information from the fish resources chapter has indicated that the diversity and health of fish communities along the mainstem has considerably improved from the 1920 to 1970 period. Accordingly, at this time (2004), although there are many positive signs, the ES of the water quality VEC is classified as "marginally sustainable." The primary concerns are associated with bacterial contamination and chemical remobilization from legacy-contaminated sediments.

- Regarding the future, it is expected that the water quality of the Ohio River mainstem will further improve as a result of the continuation of source control and other pollution reduction programs, and implementation of restoration and remediation efforts. Therefore, it is anticipated that the ES of the water quality VEC will achieve a "sustainable" condition. However, this characterization should not bring complacency; rather, vigilant efforts are still needed to continue effective water quality and aquatic ecological monitoring and management efforts. In this regard, it may be desirable to plan and implement source monitoring programs for selected RFFAs (actions) considered of high importance relative to cumulative effects. Further, special surveys for legacy-contaminated sediments are needed along with site-targeted efforts to reduce bacterial effluents from CSOs. Furthermore, several actions are expected to be beneficial to the water quality resource in the future. For example, adverse impacts related to barge operation (e.g., queuing, dispersed traffic) will be alleviated to some extent 1) through implementation of nonstructural navigation improvements and 2) through technological improvements related to communications and more environmentally-advanced barge design. Activities that support commercial navigation (e.g., port development and maintenance dredging) will continue to be scrutinized by both regulatory agencies and NGOs and may be more strictly regulated. Land disposal of in-stream dredged materials, for example, may become more common. Some development activity may revive or renovate underused urban space or industrial brownfields areas, with possible long-term water quality benefits related to surface

and groundwater clean up. Much development activity, however, will involve conversion of existing floodplain lands (e.g., farmland, riparian woods, and wetlands) that now afford habitat protection, open space, and ecosystem values. Once converted, such lands are unlikely to revert to their former more natural states. Increasing emphasis on pollution prevention, erosion control BMPs, and implementation of the Phase 1 and 2 NPDES programs could counteract some adverse impacts, particularly in more urban areas. In general, several regulatory initiatives in recent years, including TMDL development, the national CSO policy, and Phase 1 and 2 programs should measurably improve water and sediment quality, but, at this time, it is not possible to predict the magnitudes of their beneficial effects.

FIGURE 3-4.
ES of Water Quality



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Chapter 4
FISH

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4.2 IMPORTANCE OF FISH AS CUMULATIVE EFFECTS INDICATORS

This chapter considers how cumulative effects (CE) of human use of the Ohio River have influenced fish communities and what impacts on fish may be anticipated in the foreseeable future. Fish of the Ohio River represent a highly visible and important environmental component. Fish also are excellent indicators of cumulative effects and environmental sustainability for several reasons:

- Their multiyear life spans and mobility facilitate interpretation of long-term effects and larger-scale habitat conditions.
- Fish communities include a wide range of species, trophic (feeding) levels, and reproductive conditions that can reflect varying degrees of environmental change.

- Some fish species are very sensitive to chemical and physical changes that may be caused by pollutants, changes in flow patterns, and other factors.
- Fish are easier to collect and identify and more information is available on their life histories than for small invertebrates.
- Fish are of interest and concern to society due to their potential for food and sport.

Fishes of the Ohio River interact with several other Valued Environmental Components (VECs) including water quality, mussels, riparian/floodplain ecological resources, recreation, land use, and human health. Because of their importance to humans and their diversity, they have been studied more extensively than any other biotic group in the Ohio River.

4.3 OBJECTIVES AND SCOPE OF THE FISH STUDY

4.3.1 Objectives

This chapter assesses the system-wide cumulative impacts on fish of all likely major navigation improvements along the mainstem of the Ohio River during the planning period from 2000 to 2070. Impacts directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFAs) by the U.S. Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFAs. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, actions by non-governmental entities, and predictions of general economic expansion and development as well as regulatory changes.

The results of the Cumulative Effects Assessment (CEA) will lead to further consideration of:

1) the significance of the impacts of RFFAs on affected resources
2) the degree to which proposed navigation improvements contribute to those impacts and
3) what constitutes sustainable fish communities in the Ohio River mainstem.

4.3.2 Geographic Scope

The geographic focus for impacts on fish includes the Ohio River mainstem, which is most directly impacted by operation and maintenance of the navigation system, and also includes lands along either bank of the Ohio River lying “between the bluffs.” This “floodplain zone” is defined as the meander channel of the Ohio River and includes the 100- and 500-year floodplains as well as terraces of level land lying above these flood zones. Floodplain lands are considered in this assessment because fish communities are affected by siltation, runoff, and contaminants associated with construction, industry, agriculture, and other land-based activities. The contribution of tributaries to recruitment of mainstem fish populations is also considered.

4.3.3 Time Frame

The established time frame for this project is 1920 to 2070. The earlier date approximates the initiation of the Corps' long-term 20th century lock and dam (L&D) construction activities on the Ohio River while the latter date approximates the end of the 60-year planning horizon encompassed by the Ohio River Mainstem Systems Study (ORMSS). Discussion of impacts on fish, however, includes consideration of the condition of fish communities before 1920. Understanding pre-1920 conditions is important in determining how lock and dam construction/operation and other human activities have influenced fish communities.

4.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. A more detailed discussion of the scoping meetings is presented in Exhibits A and B of this report.

The meetings were attended by 185 persons and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Fish and fishing were frequently mentioned during the meetings. Comments that directly and indirectly addressed fish and fishing are presented in **Table 4-1**.

TABLE 4-1
Comments from Public Scoping Meetings

Direct Comments Related to Fish and Fishing	Relevance to Fish and Fishing	Total
Increased spills and accidents potentially affecting aquatic life and impairing water quality (WQ)	Lowering of WQ & damage to fish and other aquatic resources	1
Possibility of implementing mechanical aeration in mainstem pools	Need for sufficient oxygen levels for fish and other aquatic resources	1
Importance of continued water quality improvements as a high priority	Need for WQ improvements to benefit fish and other aquatic resources	1
Mouths of tributaries silted in, impairing fish habitat, limiting access, and damaging property	Damage/elimination of habitat for fish and other aquatic resources	5
Damage destruction of mussel beds and fish spawning areas	Reduction in mussels and fish	4
Impaired water quality and bioaccumulation in fish tissue of harmful substances stirred up by dredging	Uptake of toxic substances in the food web	2
Habitat damage caused by Corps permitted commercial sand and gravel operations	Reduction in fish and other aquatic resources	1
Effects on fishing caused by water level fluctuations	Unpredictability of fishing habitat	3
Under-representing of fishermen in ORMSS scoping process	Concerns that fishing-related issues will not be adequately addressed	1
Increase in barge loading/unloading facilities	Decreased availability of shore-based	1

Direct Comments Related to Fish and Fishing	Relevance to Fish and Fishing	Total
limiting fishing access from shore	fishing areas	
Need for fish habitat improvements, including fish passage around locks and dams	Need to overcome potential migration barriers	2
USACE role when fish kills occur	Clarification of agencies for notification and assessment of fines	1
Effects related to three crayfish, two fish, and seven mussel species in Illinois	Concern for species of special interest in the lower Ohio River	2
Need to prevent distribution of exotic/invasive plants and animals through USACE actions	Concern for impacts on native fish and other aquatic resources	1
Other Comments with Implications for Fish and Fishing		
Need for ongoing coordination and cooperation with concerned agencies and groups	Importance of working together to achieve WQ goals that support fish and other aquatic resources	3
Development of ongoing program to reevaluate cumulative effects every 5 years	Need for continual assessment of fish and other environmental components	1
Importance of including commercial dredging and associated permitting process in CEA	Dredging causes turbidity and can damage fish habitats	2
Need to consider 404 application approvals and resultant actions as direct USACE actions	Concern for potential impacts on fish habitat	1
Importance of coordination with resource agencies to determine baseline conditions	Concern that all relevant data is used	2
Cumulative effect of discharges on river may offset water quality improvements	Failure to attain WQ standards and potential damage to fish and other aquatic resources	4
Challenges to water quality presented by CSOs (combined sewer overflows) and SSOs (storm sewer overflows)	Failure to attain WQ standards and potential damage to fish and other aquatic resources	2
High levels of mercury, arsenic, fecal coliform bacteria and agrichemicals in surface water	Failure to attain WQ standards and potential damage to fish and other aquatic resources	1
Need for more stringent discharge permitting procedures or moratorium on permits	Failure to attain WQ standards and potential damage to fish and other aquatic resources	2
Need to improve sediment and erosion control from public and private developments	Potential turbidity and sedimentation harming fish and other aquatic resources	1
Need for long-term plan to address silt removal and prevent future sedimentation	Potential turbidity and sedimentation harming fish and other aquatic resources	1
Possible use of dredge spoils to improve riparian or island habitat or for upland filling	Creation of new habitat for fish and other aquatic resources	2
Bank undercutting and failure caused by increased barge traffic, queuing and wave action	Potential erosion and sedimentation lowering WQ and harming fish and other aquatic resources	7
Loss of significant farmland to urban development along river corridor	Increased stormwater runoff harming fish and other aquatic resources	3
Loss of green space and wildlife habitat with development of marina facilities	Increased runoff & potential pollution from marinas harming fish and other aquatic resources	5
Development of floodplains and wetlands resulting in increased runoff and habitat loss	Increased runoff and loss of wetland filtering capacity harming fish and other aquatic resources	4
Need to develop comprehensive plans for development along river	Importance of nonpoint pollution and cumulative effects on fish and other aquatic resources	3
Need for coordination with community floodplain coordinators along river	Could benefit fish and other aquatic resources	1

Direct Comments Related to Fish and Fishing	Relevance to Fish and Fishing	Total
Loss of unique, sensitive species due to water quality problems and habitat modifications	Reductions in aquatic life	2
Potential instability of Ohio River islands and futility of creating islands wildlife refuge	Related to island habitat for fish and other aquatic resources	2

Comments from public scoping meetings were reviewed as the list of RFFAs was developed for this assessment. In some manner, almost all comments in **Table 4-1** are encompassed by the RFFA list. Later in this chapter, the CE of RFFAs affecting fish are grouped and discussed according to their impacts which may cause: 1) habitat changes, 2) changes in disturbance regimes, 3) changes in hydrological patterns, 4) effects on ecological services, and 5) changes related to populations. The comments presented in **Table 4-1** are connected to these potential impacts. For example, the last comment in the table above, which concerns islands, is directly related to habitat and changes in disturbance regimes that can affect localized populations of fish. Almost all the public comments can be linked to one or more of the five impacts mentioned above. These impacts are discussed in more detail in the "Relevant Actions" and "Cumulative Effects and Environmental Sustainability" sections of this chapter**.**

Further, because of the interdisciplinary nature of CEA, public comments frequently are related to more than one VEC. Several comments applicable to fish, therefore, also apply to water quality, mussels, and /or Riparian/Floodplain Resources (RFR) and thus appear in the corresponding public comments tables in those chapters.

4.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

Indicators of Environmental Sustainability (ES), which vary by VEC, generally provide benchmarks for measuring CE on a given resource or VEC. The primary uses of indicators are to characterize the current status of a resource and to track or predict significant changes to the resource. It is desirable to select indicators that can be supported by data that are measurable and relatively straightforward to collect. Further, if an indicator is to be accepted and used to guide policy, the data upon which indicators are based must be available to a wide range of interested parties (NRC 2000).

ES indicators selected for fish encompass the basic essentials for diverse communities of fish to thrive and reproduce in the Ohio River. Key indicators, therefore, include:

- composition of fish communities, including numbers of intolerant and nonnative species, abundance, and diversity
- amount of habitat with stable substrates, adequate depths, suitable currents, and sufficient food supplies
- reproductive viability as measured by amount of spawning habitat, genetic connectivity, and numbers of gravid females, and larval individuals
- percent of population with abnormalities such as parasites, tumors, ulcers, and fin erosion
- water quality measurements such as levels of Dissolved Oxygen (DO), and pH and
- level of disturbance from biotic stressors, such as invasive species and from abiotic stressors, such as river traffic.

The entire suite of indicators may be essential to adequately characterize and track Ohio River fish communities. In contrast to several other VECs, long-term data are available for many indicators of fish sustainability. Data to assess the selected indicators are included in studies conducted by the Corps, USFWS, ORSANCO, universities, electric utilities, and others. Ohio River fish communities are discussed in further detail in the section titled "Past to Current Baseline Conditions."

4.6 LAWS, REGULATIONS, ORDINANCES, AND PROGRAMS

As Chapter 3, "Water Quality," details, a pivotal regulatory event for the Ohio River's water quality, fish, and other aquatic ecological resources was the signing of an interstate compact in 1948 that created ORSANCO. The principal mission of ORSANCO was to abate existing pollution and control future pollution of waters in the Ohio River basin (ORSANCO 1998). The marked improvements to Ohio River water quality made through ORSANCO and other governmental regulations and programs during the past half-century were key to reversing the declining state of Ohio River fishes in the mid-20th century.

Table 4-2 illustrates the spectrum of regulations and established programs related to fish of the Ohio River. In many cases, protection of the fish community and fishery resources is a consequence of other environmental objectives, such as improving water quality or protecting wetlands.

TABLE 4-2
Laws, Regulations, Ordinances, And Programs Relevant to Fish and Fishery Resources

Law/Program	Key Components	Relevance to Fish
Clean Water Act (CWA) (U.S. Environmental Protection Agency)	• Section 402 establishes National Pollution Discharge Elimination System (NPDES) for regulating pollution discharges into U.S. waters. • Section 316(b) requires cooling water intake structures to reflect best available technology to minimize adverse environmental effects. • Section 401 of CWA requires applicants proposing activity, which may result in discharge to U.S. waters, to obtain certification of compliance with state water quality standards. This section is administered by each individual state. • Gives USEPA authority to implement pollution control programs • Requires establishment of water quality standards • Recognizes need to address nonpoint source pollution	Protects fish within general context of water quality improvements and minimization of impacts from construction or other activities within state waters.

Law/Program	Key Components	Relevance to Fish
National Environmental Policy Act (NEPA) (Council on Environ-mental Quality and other resource agencies)	• Requires preparation of environmental impact statements for new construction projects by private and governmental agencies.	Includes water quality & habitat impacts of new projects along the Ohio River such as power plants, Corps projects and riverfront developments.
Water Resources Development Act (WRDA) (U.S. Army Corps of Engineers)	• Authorizes Corps' port development, navigation, flood control and erosion control projects through the 1986 act and subsequent amendments	Contains provisions for environmental assessment and mitigation that can affect fish
Oil Pollution Act (U.S. Environmental Protection Agency)	• Strengthened EPA's ability to prevent & respond to catastrophic oil spills	Protects fish and other aquatic resources from pollution & damage from oil spills
Emergency Wetlands Resources Act (US Fish & Wildlife Service)	• Authorizes purchase of wetlands from Land and Water Conservation fund • Requires states to includes wetlands in Comprehensive Outdoor Recreation Plans • Provides funding for the Migratory Bird Conservation Fund	Benefits fish habitat by encouraging federal-state cooperation in wetlands protection and outlines funding mechanisms
Endangered Species Act (USFWS)	• Authorizes determination & listing of threatened & endangered species • Prohibits unauthorized taking, possession, sale & transport of endangered species • Provides for land acquisition to protect endangered species	Establishes framework for protection of threatened & endangered species that are components of the aquatic ecosystem upon which fish rely
Fish & Wildlife Act (USFWS)	• Section 7(a) requires (U.S. Department of Interior) (USDI) to take steps required for management & protection of fish & wildlife resources through research, acquisition of land & water & other means.	Establishes a comprehensive national fish & wildlife policy applicable to fish and other aquatic and riparian resources
Fish & Wildlife Coordination Act (USFWS)	• Requires that whenever water bodies are modified by federal agency, that agency first shall consult with the USFWS and with appropriate state agencies with a view toward wildlife conservation	Provides for equal consideration and coordination of fish and wildlife conservation with other aspects of water resources development
National Wildlife Refuge System Administration Act & National Wildlife Refuge System Improvement Act (USFWS)	• Provide guidance for management and public use of refuge system, including development of comprehensive conservation plan for each refuge	Guide management & public use of Ohio River Islands National Wildlife Refuge, including fish habitat
National Invasive Species Act (US Dept. of Trans-portation and Aquatic Nuisance Species Task Force)	• Requires all vessels operating in US waters that are equipped with ballast tanks to comply with guidelines designed to prevent and reduce the dispersal of aquatic nuisance species	Helps reduce the further introduction and dispersal of invasive species that can disrupt aquatic ecosystems

Law/Program	Key Components	Relevance to Fish
Farm Security and Rural Investment Act of 2002 (aka Farm Bill) (USDA Natural Resources Conservation Service)	• Includes various incentive programs to promote installation of riparian buffers. • Swampbuster provisions withhold certain USDA benefits from farmers who convert or modify wetlands • Offers opportunities for wetlands mitigation	Helps improve and/or preserve environmental functions & value of riparian areas in the Ohio River floodplain, which also benefit fish and other aquatic resources
Corps Permitting Statutes (U.S. Army Corps of Engineers)	• Section 10 of Rivers and Harbors Act (1899) prohibits the unauthorized obstruction or alteration of any navigable water of the United States. • Section 404 of the CWA authorizes the Corps to issue permits for the discharge of dredged or fill material into the waters of the United States	Permits require assessment of impacts on water quality, fish and other aquatic resources and mandate mitigation of adverse impacts
Small Navigation Projects (U.S. Army Corps of Engineers)	• Section 107 of Rivers and Harbor Act (1960) authorizes Corps to develop and construct small navigation projects for harbor protection.	Includes impacts of such actions on water quality, fish and other aquatic resources
State Water Quality Certification (Appropriate state or interstate pollution control agencies)	• Section 401 of the CWA requires certification from state or interstate water control agencies that a project is in compliance with established effluent limits and water quality standards.	Provides opportunity for state or interstate scrutiny of such actions on fish and other aquatic resources
Site Remediation Statutes (U.S. Environmental Protection Agency)	• Includes CERCLA, RCRA, SARA and related state programs that focus on cleanup and restoration of contaminated sites.	Potentially reduces groundwater and soil pollution sources which may adversely impact fish and other aquatic resources in the Ohio River
TMDL Program (U.S. Environmental Protection Agency)	• Increasingly important section (§303) of CWA; regulates maximum pollutant load a water body can receive and still attain water quality standards.	Presents a more holistic option to water quality management than traditional approaches with potential benefits for fish and other aquatic resources
Phase 1 & 2 NPDES Program (U.S. Environmental Protection Agency)	• Also developed within the CWA, requires municipalities and certain industrial and construction sites to adopt BMPs to control nonpoint sources of pollution.	Should reduce pollution characteristics of stormwater discharges from urban and industrial zones that may adversely affect fish and other aquatic resources in the Ohio River
National CSO Control Policy (U.S. Environmental Protection Agency)	• Published by USEPA, calls for communities to implement long-term plan for combined sewer overflows (CSOs) to comply with the CWA. • Administered through each state's NPDES permit program.	Should reduce pollution from major urban sources with potential benefits for fish and other aquatic resources

Law/Program	Key Components	Relevance to Fish
Executive Order 11988, Floodplain Management & Executive Order 11990 (Both in 1977) (Executive Branch)	• Prevents federal agencies from contributing to the adverse impacts of floodplain development & modification	Restricts federal development in Ohio River floodplain wherever there are practicable alternatives with potential benefits for fish and other aquatic and riparian resources
Executive Order 13112, Invasive Species (1999) (Multi-agency National Invasive Species Council)	• Requires federal agencies to prevent the introduction of invasive species and provide for their control and to minimize their economic, ecological and human health impacts	Helps to maintain and/or restore the ecological integrity of aquatic and riparian ecosystems
Spill Response (U.S. Coast Guard & ORSANCO)	• Includes emergency response activities for river-related spills and accidental discharges and is related to the Oil Pollution Act and Section 301 of the CWA.	Minimizes adverse impacts of spills and discharges on fish and other aquatic resources and on water quality
ORSANCO Monitoring (ORSANCO)	• Encompasses ongoing water quality and aquatic ecology monitoring programs by ORSANCO.	Helps track trends in water quality and biological communities and provides database that can inform environmental decision-making
State Fishing Regulations (State resource agencies & Ohio River Fisheries Management Team)	• Establish regulations that consider fish habitat and reproduction. Ohio River state resource agencies are developing an Ohio River Fisheries Management Team to standardize fishing regulations for the entire river.	Has potential to enhance environmental sustainability of Ohio River fish communities through long-term collaborative fisheries management efforts.

4.7 PAST TO CURRENT BASELINE CONDITIONS

The Ohio River, as part of the Mississippi drainage, has provided continuous habitat for fishes for over 200 million years. Because large-scale geologic events have shaped the Mississippi drainage, its fish community is exceptionally rich in species and represents the center for adaptive radiation of freshwater fishes in North America (Pearson and Pearson 1989). Large-floodplain rivers (sometimes called “Great Rivers”), particularly the Ohio and Mississippi, are inhabited by a distinctive assemblage of fishes. Shovelnose sturgeon, paddlefish, skipjack herring, mooneye, emerald shiner, river shiner, and blue sucker are among the Great River species that occur in the Ohio River. The Great River assemblage of the Ohio has a higher faunal resemblance to other large rivers such as the Wabash, Illinois, and Mississippi than to its tributaries like the Scioto, Kentucky, and Green Rivers (Burr and Page 1986)

4.7.1 Early Accounts of Ohio River Fishes

Accounts of fishes collected from the Ohio River are not reliable prior to 1920 in terms of relative abundance because such accounts are typically anecdotal, but they are useful in understanding changes that have occurred in the fish community since that time. Constantine Rafinesque provided the earliest account of Ohio River fishes (Krumholz

1981). In "Ichthyologia Ohiensis" (1820), Rafinesque described and commented on the abundance of over 100 new species of fishes he had observed while traveling down the Ohio in the summer of 1818. Many of these species are no longer recognized, but careful consideration of Rafinesque's work led Pearson and Krumholz (1984) to conclude that Rafinesque had observed 52 species of fishes.

Records on Ohio River fishes from 1820 to 1920 are scarce, although many human actions affected the river's environment during that time, including the clearing of forests and draining of wetlands with the arrival of settlers from the Eastern U.S. Preston and White (1978) observed that after about 1900, increased siltation and turbidity caused changes in fish populations with black bullhead, goldeye, skipjack herring, gizzard shad, and spotted bass increasing in numbers. In 1885, the Corps began to install a series of wicket dams which were raised under low flow conditions and collapsed under higher flows, thus allowing tows and fish to pass upstream or downstream over the dams rather than through locks or gates on the dams, as occurs with the present generation of high-lift locks and dams. As the following sections illustrate, canalization of the Ohio River would have profound effects on its fishes.

4.7.2 Changes in the 20th Century

In 1909-1911, the U.S. Congress directed the Corps to maintain a 9-foot navigation channel in the Ohio River. This directive culminated in the completion of 50 wicket locks and dams by the late 1920s, providing a 9-foot navigation channel for the Ohio mainstem throughout the year (Pearson and Pearson 1989). Even before completion of the navigation system, various human activities had caused several fish species to decline in abundance by the early 20th century, including the lampreys, shovelnose sturgeon, paddlefish, muskellunge, and blue sucker. Fishes reported from the Ohio mainstem prior to 1920, but not collected since that time include the least brook lamprey, Alabama shad, hornyhead chub, Ozark minnow, and mud, longhead, crystal, and gilt darters (USFWS 2000). The crystal and gilt darters were already scarce species, which disappeared after their riffle habitats were inundated by the wicket dams (Pearson and Krumholz 1984).

As discussed in more detail in Chapter 3, "Water Quality," rapid growth of the human population in the Ohio basin during the first half of the 20th century led to larger inputs of domestic sewage, industrial effluents, and acid mine drainage. The pollution was concentrated in the upper river and immediately below Cincinnati and Louisville. Fewer people lived in the lower portion of the river and several large tributaries provided additional dilution, as is true today (Pearson and Pearson 1989). By 1950, abundances of lake sturgeon, shovelnose sturgeon, muskellunge, bigeye chub, and blue sucker were greatly reduced while gizzard shad, emerald shiner, freshwater drum, and the introduced common carp had increased in abundance (Pearson and Krumholz 1984). In the last half of the 20th century, actions of ORSANCO and implementation of the CWA and its amendments led to considerable progress in reducing point source pollution with the subsequent recovery of many fish species, as discussed in the following section.

As the series of wicket dams were being completed, the Corps constructed a new type of gated dam at Louisville in 1927. It was important because it was the first high-lift dam on the Ohio River. The new dam's 37 foot lift made it impossible for fish to pass upstream from Louisville except by locking through with tows, by negotiating the small-

gated sections, or by topping the dam at flood stages (Pearson and Krumholz 1984). The Corps' replacement and modernization program begun in 1955 gradually replaced the low, movable wicket dams with fewer high, non-navigable, gated high-lift dams. The present system consists of 17 dams 16 to 37 feet high and three dams 10 to 13 feet high (Dashields, Dam 52, and Dam 53). Dams 52 and 53 will be removed and replaced by Olmstead L/D at RM 964.4.

The present system of dams has altered aquatic habitats by converting the Ohio River from a free-flowing waterway to one of relatively constant width and a minimum maintained channel depth of 9 feet. The modern navigation system, combined with land use and flood control practices in the watershed, has resulted in the inundation and siltation of extensive areas of gravel substrate, preferred by important fish species, particularly in the lower half of the river (Pearson and Pearson 1989). Further, the range and population of such migratory fishes as the lake sturgeon, paddlefish, skipjack herring, and blue sucker have been greatly reduced in the last 80 years (Burr and Page 1986). Concurrently, the high-lift dams created nearly 80 embayments in creek mouths adjacent to the mainstem in the upper half of the river, which offer important habitat for basses and other sunfishes (Preston and White 1978), species more typical of lake-like conditions.

4.7.3 Trends in Abundances and Diversity along the River

A total of 159 species of fish (including introduced species) have been recorded for the Ohio River since the early 19th century (Pearson and Krumholz 1984, Pearson and Pearson 1989). Reports prior to 1920 list 111 species; those from 1920 to 1969 list 121; and those from 1970 through 1988 list 140 species. Combining data from all periods through 1988, 122, 132, and 119 fish species were reported from the upper (RM 0-327), middle (RM 328-654), and lower (RM 655-981) thirds of the river, respectively. Pearson and Pearson (1989) noted that greater species richness in the middle river possibly reflected greater sampling effort and suggested an equal sampling effort in the Ohio's lower third would reveal more species than reported from the upper and middle third, partly because the lower river reaches would draw from the Mississippian center of North American fish distribution. Biomass of all species combined is usually greatest in the lower, larger third of the river. Among the factors affecting species composition and biomass are such environmental conditions as gradient, effects of impoundment, and the actual size of the river (Krumholz 1981). Many fish species have a broad range of environmental tolerances and are wide-ranging in the Ohio River. Outstanding examples of the wide-ranging group include the gizzard shad, stoneroller, bluntnose minnow, creek chub, green sunfish, and bluegill (Burr and Page 1986).

The ORMSS Interagency Working Group (IWG) compiled a highly inclusive list of fish species that might be affected by the CE of navigation in the Ohio River. The list, begun in 2002, comprises nearly 200 species, including fishes that may have been present in lower tributaries of the Ohio prior to impoundment by high-lift dams.

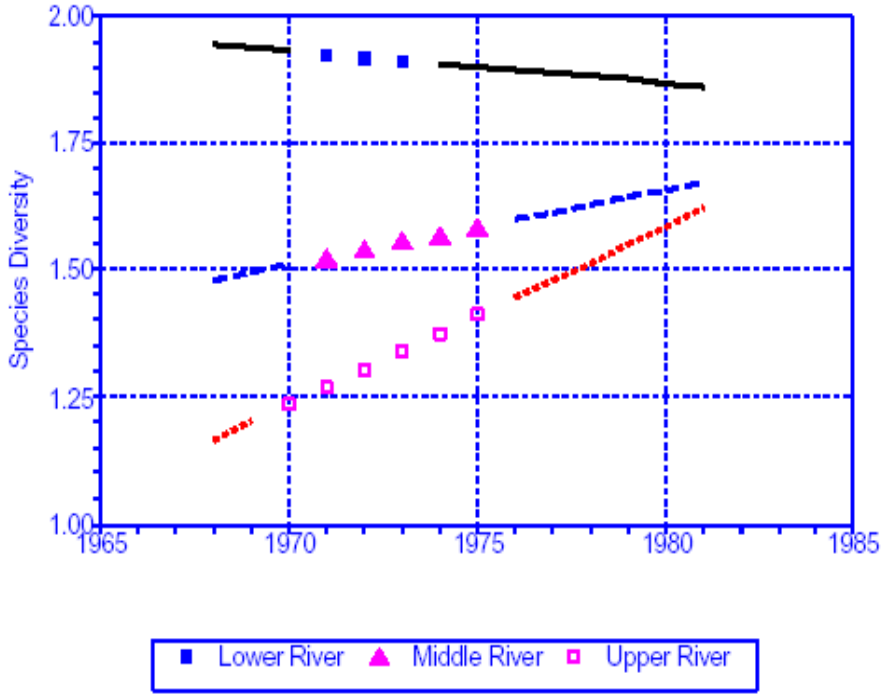
Several studies conducted in the last 20 years by various agencies and researchers in the last 20 years support the upward trend in fish diversity in the upper Ohio River since implementation of the CWA. A review of the rotenone fish sampling data (ORSANCO 1983) illustrated an important and positive trend, which occurred along the river between the late 1960s and early 1980s. An indication of improving water quality was the marked

increase documented in fish diversity as calculated by the Shannon-Weaver Index, with the greatest improvements seen in the upper reaches of the mainstem **(Figure 4-1)**. The Shannon-Weaver Index uses the number of species present and the distribution of individual fish among those species to compare survey findings from year to year and over segments of the river. Shannon-Weaver Index calculations range from three to zero, with three representing a perfectly diverse population (i.e., if there were 100 fish representing 10 species, there would be 10 individuals of each species). In the upper Ohio River, increases were primarily noted in sport and commercially valuable species, which tend to be more pollution-sensitive than other fish species. Fish diversity increased by 40 percent in the upper river, and 13 percent in the middle section. ORSANCO attributed the improvements to increased pH and DO concentrations, and to decreased levels of toxic materials in the river. As **Figure 4-1** illustrates, because indices of diversity combine numbers of species and their relative abundances, higher diversity occurs in the lower river with its larger size and higher biomass. Changes in diversity in the lower river over time were much less pronounced than upstream where historic pollution was much more severe. ORSANCO noted the slight decline in diversity in the lower river from 1.95 in 1968 to 1.88 in 1981 may be related to a lack of data from that section of the river.

Additional research confirmed that many species that disappeared from the upper river during the worst decades of pollution have returned to portions of the river approximating their historical ranges. Between 1984 and 1989, numerous range extensions of mainstem fishes were reported and included 12 species in an upstream direction, 14 species in a downstream direction and six species both upstream and downstream, as listed in **Table 4-3** below (Pearson and Pearson 1989).

FIGURE 4-1

Long-term trends in fish diversity in the Ohio River



SOURCE: ORSANCO 1983.

Further, fish samples collected by Van Hassel et al.(1988) from 1973-1985 in the upper and middle river suggested that range extensions of such river species as the paddlefish, mooneye, spotted gar, river carpsucker, smallmouth buffalo, and white bass were probably direct responses to improvements in water quality in the upper Ohio River.

Changes in species composition and abundances also are indicated in **Table 4-4**, which contrasts the ten most abundant fishes collected in the Ohio River for two different time periods and collection methods. Emerald shiner, gizzard shad, and freshwater drum are the three most abundant species on both lists. However, sauger ranked fourth on the list of fishes collected by electrofishing, though it did not even appear on the earlier list of fishes collected in lock chambers using the chemical rotenone. Other additions to the 1991-2001 list include the bluegill, temperate basses (*Morone* spp.), and silver chub. Deleted from the more recent list are the pollution-tolerant common carp and bullheads, as well as skipjack herring and white crappie.

TABLE 4-3
Fish Range Extensions Reported along the Ohio River since 1983

Direction of Extension & Species	1970-1983 Distribution (Ohio River Mile)	1984-1988 Distribution (Ohio River Mile)
Upstream		
Paddlefish	427-981	341-981
Spotted Gar	846-981	560-981
Threadfin Shad	390-981	341-981
Mooneye	260-981	54-981
Grass Pickerel	597-981	54-981
River Carpsucker	54-981	35-981
Highfin Carpsucker	170-981	54-981
Northern Hogsucker	35-604	13-604
Smallmouth Buffalo	54-981	35-981
Silver Redhorse	35-981	13-981
Rosyface Shiner	35-981	13-981
Striped Bass	126-981	13-981
Upstream and Downstream		
Silverjaw Minnow	54-287	35-605
River Chub	54-470	35-560
Striped Shiner	54-518	35-605
Fathead Minnow	161-279	77-560
Brook Silverside	54-260	35-981
Banded Darter	35-494	13-560
Downstream		
Northern Pike	35-344	35-494
Muskellunge	35-368	35-776
Central Stoneroller	35-571	35-605
Speckled Chub	260-494	260-981
Spottail Shiner	13-54	13-494
Sand Shiner	13-597	13-981
Suckermouth Minnow	177-494	177-981
Blacknose Dace	35-77	35-494
Blue Sucker	54-744	54-981

Direction of Extension & Species	1970-1983 Distribution (Ohio River Mile)	1984-1988 Distribution (Ohio River Mile)
Greenside Darter	54-494	54-560
Rainbow Darter	54-518	54-605
Fantail Darter	54-518	54-981
Johnny Darter	13-494	13-981
Orangethroat Darter	54-77	54-560

SOURCE: Pearson and Pearson, 1989. The authors assumed records from the last 80 miles of the river indicated a distribution down to the mouth (ORM 981).

TABLE 4-4
Ten Most Abundant Fish Species Collected from the Ohio River by Rotenone Lockchamber Sampling (1957-1980) and by Electrofishing (1991-2001)

Rank	Collected in Lock Chambers 1957-1980	Collected by Electrofishing 1991-2001
1	Emerald shiner	Gizzard shad
2	Gizzard shad	Emerald shiner
3	Freshwater drum	Freshwater drum
4	Mimic shiner	Sauger
5	Channel catfish	Mimic shiner
6	Common carp	Bluegill
7	Bullheads (all species)	Channel catfish
8	Skipjack herring	Morone spp. (temperate basses)
9	White crappie	Threadfin shad
10	Threadfin shad	Silver chub

SOURCE: Pearson and Krumholz 1984 and ORSANCO e-mail communication, July 2002.

4.7.4 Introduced and Extirpated Species

Introduced Species

Of the 14 fish species that were introduced into the Ohio River by 1992, only the common carp, goldfish, white catfish, and banded killifish had established reproducing populations (Pearson 1992). Krumholz (1981) described the carp introduction in the late 1800s as the "earliest and most noticeable introduction to date." A native of Asia, the common carp continues to be a substantial component of the Ohio River fish community in both biomass and numbers. Several more recently introduced Asian carps species, however, are now causing serious concern among fisheries biologists and recreational users in the lower mainstem.

Four additional species of Asian carps were introduced into the natural system over a period of years -- the grass, silver, bighead, and black carp. These species are of increasing concern for several reasons:

- All except black carp now have reproducing populations in the Ohio River, but are of little value to sport fishermen.
- Grass carp feed aggressively on aquatic vegetation, compete with native fishes for food and space and destroy fish and waterfowl habitat by eliminating

vegetation (Pflieger 1975). Unlike grass carp, common carp uproot vegetation as part of their feeding behavior.

- Silver and bighead carp are effective planktivores. Native larval fish also feed on plankton and may compete with bighead and silver carps for food resources if plankton becomes limiting. Competition requires a limited resource; plankton are not limited at this time, although proper species and sizes may not be sufficiently available when needed by larvae of native fishes. Some dietary overlap may also exist with native planktivores such as gizzard shad, paddlefish, and bigmouth buffalo. Larval fish must compete with these filter-feeding carp, while they risk being eaten themselves.
- Studies of the population dynamics of these species are complicated by the tendency of bighead and silver carp to startle easily and launch themselves out of water, potentially seriously injuring biologists monitoring them (Perea and Gittinger 2002).
- A triploid (sterile) black carp has been documented for Horseshoe Lake in southwestern Illinois near the confluence of the Ohio and Mississippi Rivers (Caswell, personal communication). Black carp are molluscivorous with the potential to seriously impact already precarious populations of native mussels and snails if they enter the Ohio River ecosystem. Further, at all life stages black carp will compete for food with native fish species. Animals of riparian zones, including turtles, waterfowl, raccoons, and muskrats also are likely to be affected through competition for food. Under the authority of the Lacey Act Amendments of 1981, the USFWS is in the process of listing the black carp as an injurious wildlife species. Such a listing would prohibit the importation and interstate transport of black carp (http://southeast.fws.gov/hotissues/Black_Carp_FS.pdf).

  According to a comment received from the USGS during review of this document, black carp do not compete for food with native fishes at all life stages. They will compete for food with native molluscivores if food resources are limited. Animals of riparian zones are only likely to be affected if they are dependent upon molluscan resources and these resources are limited in availability.

The 2005 publication (Nico, et al) will help develop a mitigation strategy for the Ohio River mainstem and tributaries. The USFWS also developed a National Asian carps Management and Control Plan, which was released for public comment in August, 2006. The plan, which is being developed by multiple resource management partners, including Canadian agencies, seeks to integrate prevention and control activities to limit the further distribution and negative impacts of these four nuisance species. The potential impacts of Asian carps on the Ohio River native fish communities may prove a serious challenge to fish community sustainability. Because relatively little is known about Asian carps' preferred habitats, prospects for long-term reproductive success, and best sampling methods, they also present challenges in adaptive management.

Extirpated Species

Pearson and Pearson (1989) reported 19 native species that had not been reported from the Ohio River since 1970. Most significant were three large river species: the lake

sturgeon, Alabama shad, and crystal darter. Pearson and Pearson suggested that navigation dams, including those located on tributaries, may interfere with migratory species such as paddlefish, sturgeons (shovelnose and lake), and shad, while inundation of riffles and siltation probably reduced the crystal darter. Recently lake sturgeon have been recorded from the Ohio River along Lewis, Union, Livingston, and Ballard Counties, Kentucky, although the species continues to be rare (Compton et al. 2004). Compton et al. suggest possible origins of recent specimens include a remnant Ohio River population and migrations from Missouri (where they have been stocked) or the Wabash River in Indiana.

4.7.5 Species Listed of Special Concern under the Endangered Species Act

In 1987, Johnson reported 18 percent (28 species) of Ohio River fish species are considered rare enough to be protected by law in one or more states bordering the Ohio River. An additional 13 percent (21 species) are of special concern in one or more states. Regarding Ohio River fishes listed under the federal Endangered Species Act (ESA), five species have been identified as species of special concern (SSC): the paddlefish (*Polyodon spathula*), blue sucker (*Cycleptus elongatus*), crystal darter (*Ammocrypta asprell*a), Eastern sand darter (*Ammocrypta pellucida*), and longhead darter *(Percina macrocephala*). Among the reasons for SSC designation are the species: 1) has a significant vulnerability to habitat modification or human exploitation which may result in its becoming a threatened species in the foreseeable future if effective management is not initiated, 2) may already meet certain criteria for designation as a threatened species but conclusive data are lacking, 3) has not significantly recovered from past depletion, or 4) may occupy such an essential ecological niche that its further decline would adversely affect other species to a significant degree (FFWCC 2004).

An Endangered Species Act (ESA) Section 7 consultation for on-going operation and maintenance of the entire Ohio River navigation system is in progress. Through the Section 7 process, the USFWS is working with the Corps 1) to provide information about listed, proposed, and candidate species and critical habitat in the ORMSS project area, 2) to proactively emphasize the identification and informal resolution of potential species conflicts, and 3) to advise the Corps on how to avoid adversely impacting listed species and their habitats (USFWS & NMFS 1998).

4.7.6 Fish Habitats

Changes in fish communities of the Ohio River during historical times reflect available spawning habitats and human alterations. Reproductive modes are important in evaluating fish communities because reproductive failure in response to environmental stressors leads to rapid decline and elimination of fish populations. Spawning habitat in the mainstem is critically important to Ohio River fishes because most species are spawned in the mainstem, not in tributary streams or recently created embayments (Pearson and Krumholz 1984).

Fish guilds, defined as groupings of species capable of exploiting the same environmental resources or habitats in similar ways, provide a framework for reflecting upon changing environments. Balon, as cited by Pearson and Krumholz (1984), developed a reproductive guild classification for fishes that considers behaviors, preferred spawning substrates, and morphological adaptations of eggs and larvae in relation to predation and the availability of oxygen. Pearson and Krumholz used Balon's classification system as a

framework for arranging Ohio River fishes into guilds based on their known spawning habits. They assigned 128 of the Ohio mainstem's 159 species into 13 guilds that they believe explain how human influences on the physical nature of the river have altered fish communities.

Early historical accounts of the river describe extensive reaches of clean gravel substrate in near-shore zones. Pearson and Krumholz note most fish species in the river were and are lithophils, species that spawn over clean gravel or rock. Siltation and inundation concomitant with agricultural clearing and channelization altered these spawning substrates. Consequently, lithophils such as the shovelnose sturgeon, lake sturgeon, redhorses, blue sucker, and paddlefish declined in abundance while pelagophils, which produce floating eggs or larvae, increased in abundance. The three most abundant species during the period of quantitative collections since 1957 are the emerald shiner, gizzard shad, and freshwater drum. All have eggs or larvae that float in the water column. Three other species with pelagic eggs, however, have not been as successful and are either rare (burbot) or low in abundance (mooneye and goldeye). The burbot always has been rare in the river, but the other three species are believed to migrate upstream before spawning and may be thwarted by dams (Pearson and Krumholz 1984).

According to Pearson and Krumholz, fishes such as carpsuckers and buffalofishes that spawn over vegetation and debris (usually from terrestrial sources) have maintained their relative abundance in the river. Nest-guarding species such as sunfishes, largemouth bass, smallmouth bass, and spotted bass are only abundant in protected embayments where spawning sites are available. Pearson and Krumholz theorize that disturbances from towboat wakes prevent successful spawning in the mainstem for almost all sunfish and bass species, but not white crappie. Van Hassel et al. (1988) observed overall that Ohio River habitats favor non-guarding (non-nesting), open substrate fish species. Pearson and Krumholz identified seven macrohabitats available to fishes in the Ohio River **(Table 4-5)**.

TABLE 4-5
Fish Habitat Types in the Ohio River

Habitat	Extent of Habitat	Substrate	Spawning Suitability	Other Comments
Main channel	At least 9 ft. deep and 300 ft. wide	Usually sand, but gravel, rubble and bedrock possible	Limited (e.g., freshwater drum, gizzard shad)	Current of at least 0.5 ft./sec. always present Rooted vegetation absent
Main channel border	Between main channel & shore-debris zone	Sand or silt, with occasional extensive gravel or rubble	Pelagophils & lithophils (e.g., blue sucker, redhorses)	Rooted vegetation absent
Shore-debris zone	5-150 ft. out from shoreline	Sand or silt with sunken logs & branches partially buried	Primarily vegetation & nest spawners (e.g.,buffalo,gar)	Rooted vegetation may be found
Tailwaters	Extending 0.5 mi. below navigation dams	Sand, gravel or bedrock	Local lithophils (e.g., sauger, walleye)	Extensive turbulence & elevated oxygen occur. Usually no rooted vegetation

Habitat	Extent of Habitat	Substrate	Spawning Suitability	Other Comments
Side channels	Areas separating near- shore islands from mainland	Soft-bottomed & often lined with eroded banks	Primarily nest spawners & some vegetation spawners (e.g., sunfishes, black basses)	Trees which have slumped into channel may be present. Contain running water at normal pools
Sloughs and embayments	Varying in size, depending on river water levels	Soft-bottomed, often with standing & submerged timber	Very important for nest spawners (e.g., sunfishes, black basses)	May have rooted vegetation No appreciable current at normal pools
Creek mouths & flooded channels	Variable in size & extent of flooding	Often steep-banked & soft-bottomed, but may have coarser substrates	Important for small stream species that only stray into main-stem (e.g., creek chub, stoneroller)	High gradient tributaries prevail above RM 450 while low gradient tributaries prevail below RM 450

SOURCE: Pearson & Krumholz 1984.

Islands, more numerous in the upper and lower river than in the middle third, also are excellent fish habitats. They are important to spawning fishes because:

- They offer resistance to currents, which in turn may result in an increase in current speed on one or both sides of an island head, which results in clearing of coarse sand or gravel bars where lithophils can spawn.
- They often are separated from the mainland by narrow back channels, which are sheltered from waves generated by tows and recreational craft.
- Narrow back channels often are bordered by undercut banks and fallen timbers, which can provide nesting cavities for certain species, including catfishes.

The influence of tributaries on community structure of fishes in large midwestern rivers is still not well defined. Pearson and Krumholz (1984) found no evidence that tributaries are important for spawning of Ohio River fishes. They suggested that tributaries serve as refuges where mainstem fish can avoid environmental stressors, as well as serving as reservoirs for small stream inhabitants such as the stoneroller, creek chub, northern hog sucker, madtoms, topminnows and darters, which stray only occasionally into the Ohio mainstem. Emery (personal communication) believes some species rely almost exclusively on tributaries for spawning, but are listed as Ohio River species because they are collected there as adults. Emery's observation corroborates Curry and Spacie's (1979) findings, cited by Reash (1999) that the importance of tributaries in recruitment of mainstem fish populations is species specific.

Sheehan et al. (1994), studying winter habitat and overwintering requirements for four river species in the Upper Mississippi and Illinois Rivers, found that fish migration into backwater winter habitats was influenced primarily by water temperature and not by river stage or photoperiod. Based on swimming performance tests, the ability of fish to winter in flowing water habitats is diminished with falling temperatures. The study also found that smaller fish in general are less capable of overwintering in channel habitats.

Details of winter habitat studies conducted by Garvey et al. (2003) are presented later in the section titled "Studies Concerning Specific Impacts on Fishes."

4.7.7 Indices of Biotic Integrity

Indices of Biotic Integrity (IBI) are used to assess the condition of water bodies by direct evaluation of biological attributes. IBIs involve integration of structural, ecological, trophic, and reproductive attributes of fish assemblages at multiple levels of organization (Karr 1981; Karr 1986; Fausch et al. 1990; as cited in Emery et al. 2003). ORSANCO has used the Modified Index of Well Being (MIwb) and, more recently, the Ohio River Fish Index (ORFIn) to assess the biotic integrity of the Ohio River.

The MIwb quantitatively measures the relative health of fish communities using four measures of fish communities that traditionally have been used separately: numbers of individuals, biomass, and the Shannon Diversity Index based on numbers and weight (two separate calculations). ORSANCO (1992) adapted the MIwb to prevent attainment of high scores from degraded sites with large numbers of pollution tolerant fish. A positive correlation between the MIwb and water quality, therefore, illustrates that less impacted stream segments support a larger variety and abundance of fish than stressed segments (Ohio EPA (OEPA) 1987). An analysis of 1989 OEPA electrofishing data and ORSANCO lockchamber data from 1968 through 1990, in general, indicated improving conditions in the fish communities from upstream to downstream, reflecting less concentrated human activity, lower levels of pollution, and less habitat deterioration (ORSANCO 1992). The study identified three river reaches that showed sags in the MIwb as follows:

- Montgomery L/D (RM 31.7) to Pike Island L/D (RM 84.2) - affected by point sources from heavy industry and acid mine drainage

- Racine L/D (RM 237.5) to Byrd L/D (RM 279.2) - influenced by heavy industrial discharges from the Kanawha River

- Meldahl L/D (RM 436.2) to McAlpine L/D (RM 606.8) - affected by nonpoint pollution from urban runoff and combined sewer overflows (CSOs) and chronic operation problems at the Mill Creek wastewater treatment plant in Cincinnati.

During the past several years, ORSANCO and other agencies have collaborated to develop an IBI specifically tailored to the distinctive ecological characteristics of the Ohio River. The resulting index, the Ohio River Fish Index (ORFIn) measures 13 attributes of fish communities that either respond predictably to measures of human disturbance or reflect desirable features of the Ohio River, as **Table 4-6** presents:

TABLE 4-6
ORFIn Metrics, Selection Rationale and Observations to Date

ORFIn Metric	Rationale for Metric Selection	Observations to Date*
Number of native species	Focuses on native species diversity by excluding nonindigenous species and hybrids that indicate a lack of biotic integrity	1) # of native species decreases from upstream to downstream, possibly related to river geomorphology. 2) # of native species was greater at deeper sites with coarser substrates than at shallower sites with more sand and fines. 3) Native species also declined with degraded water quality.
Number of sucker species	Suckers are a major component of Ohio River fish fauna. Round-bodied suckers are especially sensitive to habitat and water quality degradation and long life span provides a metric influenced by long-term environmental changes.	1) # of sucker species was significantly correlated with coarse substrates, submerged vegetation, woody cover, and conductivity and negatively correlated with elevated temperature, sands and fines, and degraded abiotic conditions. 2) # of round-bodied suckers decreased downstream.
Number of centrarchid species	Modified from Karr's 1981 IBI to include black basses (*Micropterus* spp.), the dominant centrarchids in Ohio River pool habitats	1) # of centrarchid species did not vary significantly from upstream to downstream 2) # of centrarchid species was greater at sites over coarse substrates and at sites with abundant woody or vegetative cover and lower at shallower sites with finer or embedded substrates. 3) Species richness declined with increasing turbidity and water temperature.
Number of Great River species (fishes typical of large flood-plain rivers)	Represents fish species expected to predominate in Great Rivers and expected to decline with loss of associated floodplain habitat	# of Great River species was not strongly correlated with any abiotic factors, but this metric was retained because it expresses historical conditions in the Ohio River.
Number of intolerant species	Reflected the highest levels of biotic integrity.	1) # of intolerant species decreased from upstream to downstream 2) They also decreased significantly with degraded water quality and at sites with increased sand, fines, and highly embedded substrates.
% Tolerant individuals	Represent the worst conditions in the Ohio River prior to implementation of the CWA in 1972	1) Tolerant species are becoming increasingly scarce as impacts of degradation are becoming more localized. 2) % of tolerant species increased with higher turbidity and lower dissolved oxygen levels.
% Simple lithophils (fish species that scatter eggs among gravel	Represents reproductive guilds that are most sensitive to substrate disturbance and degradation	1) Simple lithophils decreased from upstream to downstream, presumably as coarse substrates became increasingly less common. 2) They also declined with increased

ORFIn Metric	Rationale for Metric Selection	Observations to Date*
substrates without parental care)		temperatures.
% Nonnative individuals	Measures the degree to which non-indigenous species and hybrids have reduced biotic integrity in the Ohio River	% Nonindigenous species was significantly correlated with increased turbidity.
% Detritivores	Represents fishes that feed on dead plants or animals or their wastes	% Detritivores increased with increasing proportions of sand and fine substrates and higher water temperatures.
% Invertivores	Measures the proportion of specialized sight feeders that feed on insect and other small invertebrates	1) % Invertivores decreased from upstream to downstream. 2) % was higher at deeper sites with coarse substrates and lower at sites with finer substrates and higher temperatures.
% Piscivores	Represent fishes at the top of the aquatic food web	1) % Top piscivores increased slightly from upstream to downstream. 2) They also increased with increased depth and woody cover, but declined with increased water temperature.
Relative number of DELT abnormalities (deformities, ecoparasites, lesions or tumors)	Measures the effects of contaminants, diet and overcrowding	# of DELT abnormalities increased with increased turbidity and at sites with low dissolved oxygen.
Catch per unit effort (CPUE)	Measures community productivity	Greater productivity is expected to reflect greater biotic integrity.
* Based on data collected from by nighttime electrofishing from 709 Ohio River reaches from 1991-2001. SOURCE: Emery et al. 2003.		

The potential range of ORFIn scores is 1- 65. ORFIn is sensitive to a wide range of habitat and water quality conditions and is being used to develop numeric biological criteria for the Ohio River for eventual incorporation into ORSANCO's Pollution Control Standards (Emery and Vicory 1998). The application of ORFIn to 2000-2001 fish population data indicated that only seven miles of the Ohio River in the Meldahl Pool (RM 354-361) are impaired for aquatic life (ORSANCO 2002), thus, indicating an overall improvement in conditions compared to the earlier MIwb. ORFIn scores from non-outfall sites were significantly higher than those from sites within the first 500 m downstream from point sources of chemical, thermal, and wastewater effluents. ORFIn scores were lowest at shallow sites with sand and fine substrates and higher at deeper sites with coarse substrates, clear water and cooler temperatures (Emery et al 2003), conditions favorable to simple lithophilic fish species typical of the preimpoundment Ohio River. Evaluation and refinement of ORFIn as a sustainability assessment tool will continue over the next several years.

4.7.8 Activities of the Ohio River Fisheries Management Team

The Ohio River Fisheries Management Team (ORFMT) was formed in 1990 in response to a U.S. Supreme Court decision on multi-state ownership of the river and recognition of the need for long-term collaborative fisheries management efforts by the six

states bordering the river. The ORFMT, composed of fisheries personnel from the six bordering states, focuses on species with recreational importance and has facilitated the establishment of fishing license reciprocity and standardization of recreational fishing regulations up and down the Ohio River.

In addition, the ORFMT is implementing cooperative projects to restore and improve Ohio River fishery resources based on several management principles. The ORFMT members:

1) will implement strategies to improve the health, integrity, and productivity of the Ohio River ecosystem
2) will manage Ohio River fishery resources to sustain a harvestable surplus by implementing appropriate management strategies
3) recognize stocking as an appropriate management strategy, but encourage a thorough analysis of all relevant factors to ensure that stocking does not adversely affect existing fish populations or other aquatic resources
4) will manage, preserve, protect, enhance, and acquire habitats necessary for a healthy and diverse Ohio River fish community
5) will strive to provide additional access and fishing opportunities for Ohio River anglers
6) will conserve the genetic diversity of Ohio River fish
7) will implement strategies to prevent, control and abate the introduction of non-indigenous aquatic nuisance species and
8) will protect, maintain and restore Ohio River biodiversity and species richness. (ORFMT, not dated (a)).

Fisheries management plans have been developed for Ohio River populations of black bass and paddlefish and are under development for walleye and sauger.

The black bass management plan, including smallmouth, largemouth and spotted bass, recognizes the importance of these species to Ohio River anglers and seeks to develop a greater understanding of the dynamics of black bass fishing in the river. To improve black bass habitat along the river, the ORFMT plans to work with the Corps to identify opportunities for water level stabilization, embayment dredging and maintenance of snags and laydowns. Other activities include working with the USFWS and other groups to improve water quality and minimize the effects on black bass habitat of such activities as sand and gravel mining, barge fleeting and development (ORFMT, not dated (b)).

The paddlefish is an important interjurisdictional fish, which has had highly variable management strategies among the six states bordering the Ohio River. It is categorized as extirpated in the upper river (Pennsylvania), threatened (Ohio) and protected (West Virginia) in mid-river reaches, but commercially harvested in mid-river and lower river reaches (Kentucky, Indiana, and Illinois). Further, because of the decline of European sturgeon stocks, paddlefish have been increasingly harvested to meet worldwide demand for caviar. Kentucky and Indiana licensed 399 commercial paddlefish harvesters during 2000 alone. Snagging of paddlefish by sportfishers also is popular in some reaches. Management strategies outlined in the ORFMT's paddlefish management plan (2001) include: 1) monitoring abundance, 2) refining quantification of paddlefish movement, 3)

quantifying exploitation, 4) monitoring the commercial harvest, 5) monitoring sport fisheries, 6) improving data management, and 7) providing public information (ORFMT 2001).

The ORFMT currently involves a small group of resource managers with limited financial resources. The effectiveness of ORFMT's management plans will be better understood as collaboration increases, management strategies are implemented, and plans are developed for additional species or assemblages.

4.8 STUDIES CONCERNING SPECIFIC IMPACTS ON FISHES

Because of their conspicuousness, as well as their ecological, economic, and recreational importance, many studies have been conducted to determine the effects of various human actions on fishes of the Ohio River. Several studies have considered the specific effects of navigation infrastructure, commercial transportation, and power generation. Some studies discussed in the sections below were specifically designed and conducted to address data gaps identified in the ORMSS scoping process.

4.8.1 Upstream Fish Passage at Ohio River Mainstem Dams

Recent literature on the ecology of large rivers suggests that longitudinal connectivity is important to ecosystem structure and function of fishes with life-stage specific habitats that are spatially separated along a river system (Vannote et al.1980; Ward and Stanford 1995; Stanford et al.1996; as cited in Knights et al. 2003). While salmon studies in the Pacific Northwest perhaps most frequently illustrate the importance of longitudinal connectivity, numerous other studies indicate that longitudinal connectivity may also be important to sustaining the bioproduction and biodiversity of migrating fishes inhabiting Great Rivers like the Ohio. Examples of such migratory species include sturgeon, paddlefish, and herrings, as studied by Auer 1996; Johnson et al.1997; Bergkamp et al. 2000 (cited in Knights et al. 2003). If such species are intermittently or completely denied access to spawning habitats or encounter delays in reaching these habitats, variable recruitment or possible extirpation of existing stocks may result. Further, barriers to longitudinal movement affect freshwater mussel populations by deterring movement of fish species that serve as hosts during critical stages in the mussel life cycle.

Literature on native fishes in the Ohio River suggests that many species are migratory during the reproductive phase of their life cycles or move longitudinally between feeding and overwintering areas. Knights et al. (2003) undertook a study for ORMSS to more fully assess upstream fish-passage opportunities through Ohio River mainstem dams. The study related historical hydraulic conditions at the dams to swimming capabilities of select native and non-native fishes to determine if dams are restricting upstream movements of fishes. Additionally, abundances and distribution of 44 target species were examined in relation to upstream fish-passage opportunities at mainstem dams. Fish species included in the study were selected upon consultation with the ORMSS IWG and review of pertinent literature on the migratory behaviors of native and nonnative fishes in the Ohio River. Species selected included:

- widely distributed species or groups including paddlefish, skipjack herring, mooneyes, buffalofishes, temperate basses, sauger, and walleye;

- species with restricted distribution including lake sturgeon, shovelnose sturgeon, American eel, blue sucker, and blue catfish; and
- several nonnative, invasive species, including silver and bighead carp.

A comparison of the swimming speeds of target fishes with estimated water velocities through the gates of mainstem dams during various conditions and reports of upstream movement of target fishes through dams suggest that upstream fish passage opportunities generally occur during open river rather than controlled conditions at dams. Open river conditions occur when dam gates have been lifted clear of the water and are no longer controlling water levels upstream of a dam. Therefore, at open river, the water surface elevation immediately downstream of the dam in the tailwater is about equal to the water surface elevation immediately upstream of the dam. An analysis of historical water elevation data at Ohio River mainstem dams revealed that the frequency of open river by calendar week (hence, the potential for fish passage) varied spatially along the river by dam and temporally with discharge. The general spatial pattern of open river indicated that the potential for fish passage decreases from downstream to upstream. Consequently, the potential for fish passage through the gates of navigation dams is low to high at dams in the Louisville District (Dam 53 through Markland – eight dams), low to moderate at Huntington District dams (Meldahl through Willow Island – six dams), and low at Pittsburgh District dams (Hannibal through Emsworth – six dams). In general, open river conditions were more frequent during winter and spring, coinciding with the high-flow period from December through June, and generally were nonexistent during summer and fall, coinciding with the low-flow period. An additional avenue for fish passage is likely during flood conditions when fish can occupy flooded areas to move around dams. Pre- and post-dam abundance and distribution data for target species, along with life history information, suggest that mainstem dams on the Ohio River affect some species. Detailed information on life histories, swimming abilities, abundance, distribution, and fish-passage issues by species or major groups is included in Knights et al. (2003).

Fish species with greater prolonged or burst swimming speeds and with behavioral or morphological characteristics, such as those able to take advantage of lower velocities in the upper portion of the water column, are more likely to pass upstream through a dam (Knights, et al. 2003). These fish include Alabama shad, skipjack herring, goldeye, mooneye, striped bass, white bass, yellow bass, paddlefish, bighead carp, common carp, grass carp, silver carp, carpsuckers, white sucker, buffaloes, redhorses, largemouth bass, sauger, walleye, and freshwater drum. Fishes less likely to pass upstream through dam gates include blue sucker, spotted sucker, channel catfish, blue catfish, sturgeons, and northern pike (Knights, et al. 2003).

Knights, et al. (2003) suggested that many variables other than fish passage through dams are likely contributing to the present abundance and distribution of fish species in the Ohio River. Some of the variables are historical stressors, recruitment from upstream areas through drift of larval fish, and the likelihood of some species fulfilling their life cycle requirements within a single pool.

A contemporaneous ORMSS study of 121 Ohio River fish conducted by Wells (2003) analyzed fatty acid profiles of migratory sauger and white bass from six pools (Hannibal, Belleville, Greenup, Meldahl, Cannelton, and Smithland) to determine if genetic variations occurred among these populations. Using fatty acids as a biological

marker, the study indicated the existence of two distinct subpopulations of sauger and white bass, roughly separated into the upper and lower Ohio River reaches.

Uncertainty regarding the role of mainstem dams in the reduction in abundance and distribution of the target species remains because of the qualitative nature of pre-dam data and the influence of concomitant stressors, such as water and substrate quality and lack of floodplain connectivity. Despite uncertainties, Knights et al. (2003) suggest that because large river fish populations evolved under conditions less restrictive to longitudinal movement than presently exist, conditions created by mainstem dams probably affect the distribution, abundance and productivity of migratory species by imposing limitations on life cycle completion and interactions among localized fish populations. Analyses of open river frequency and critical lift (the minimum dam lift that allows fish passage between pools) suggest that Ohio River fishes are now more restricted longitudinally than under pre-dam conditions. Information on the abundance and distribution of highly migratory species (e.g., American eel, paddlefish, and Alabama shad) lends credence to the assertion that restricted longitudinal movement negatively impacts these fishes. Knights and his colleagues concluded that dams on large rivers may negatively impact potentially connected fish populations by reducing available habitat and immigration among subpopulations, thus making such subpopulations less resilient to disturbances and more vulnerable to decline. Further, their study recommended moving beyond species-specific and site-specific management towards more systemic considerations that could include both operational and structural measures to improve fish passage at mainstem dams on the Ohio River.

Four additional studies undertaken for ORMSS related to fish movement and passage in the Ohio River were conducted by the West Virginia Department of Natural Resources (WVDNR) in coordination with the ORFMT. These studies, which corroborate some of Knights et al. (2003) findings, are briefly summarized below:

1) The Fish Passage Direct Observations Study, conducted at Winfield L/D on the Kanawha River, was undertaken to ascertain:

- if fish community structure differs between lock chambers and tailwater areas
- what hydrologic conditions promote passage of six target species used in the study, and
- the short-term movement patterns of the target species.

Target species were selected to represent large river fishes occupying different behavior and habitat guilds and included hybrid striped x white bass, sauger, skipjack herring, channel catfish, smallmouth buffalo, and freshwater drum. In general, the study showed that large river migratory fishes (e.g., white bass, skipjack herring, and sauger) were more common in tailwater areas than in the lock chambers, while species typical of more lentic (lakelike) conditions (e.g., channel catfish) were more common in the lock chambers. The findings support ORSANCO data that have indicated that fewer large river species are collected in traditional lock chamber surveys than expected based on their overall abundance in the river. Further, the findings of the direct observation study led to the reasoning that many migratory species are not attracted to typically low flow conditions in lock chambers and, therefore, miss opportunities to pass through lock/dam complexes during typical navigational lockage operations.

2) The Fish Tagging and Recovery Study, conducted in nine tailwaters areas along the Ohio River, was undertaken to:

- determine movements of three target migratory species (sauger, white bass, and paddlefish) and
- ascertain hydrologic conditions that may promote movement of the target species.

In general, this study supported the findings of the Fish Passage Direct Observations Report and indicated that migratory fishes' affinity for flowing waters inhibits them from gravitating to lock chambers. Instead, their interpool movement appears to be facilitated by more open river conditions. For example, higher fish passage rates occurred at R.C. Byrd (RM 279.2) where open river conditions occurred 9.4% of the time compared to Belleville L/D (RM 203.9) and Willow Island L/D (RM 161.7) with open river conditions occurring 1.4% and 1.6% of the time, respectively.

3) The Recreational Fish Survey, conducted on more than 8,500 angler trips at eight tailwaters for at least a 12-month period covering all seasons, was undertaken to:

- determine recreational angling effort along the Ohio River
- obtain catch and harvest data for selected sport species
- provide demographic trend information, and
- compare current recreational angling activities with results from previous studies.

Tailwaters were the focus of this study because migratory fish species congregate in tailwaters making surveying anglers who congregate nearby in response to these concentrations of fishes much more productive. Tailwaters often concentrate migratory fish species as dams limit upstream migration of these species. Schell et al. (1996) reported that while tailwaters comprise only a small percentage of available angling habitat, they generated more than 66 percent of the total recreational catch for the Ohio River. Although angling efforts and species sought varied somewhat by tailwater, targeted angling efforts throughout the river were directed towards percids (24%), catfish (17%), black basses (16%), and paddlefish (10%). In most tailwaters, however, the number of anglers fishing for "any species" exceeded the number targeting a single species or group and totaled 33 percent of anglers on the river overall. Geographic differences also were observed in species sought. For example, percids were sought in more upstream tailwaters while catfish were sought more frequently in downstream tailwaters. Paddlefish were only sought in the Markland and Myers tailwaters. Consumption advisories may, to some extent, explain that fewer fish were harvested (kept) by anglers in the more industrialized upper river than in the more rural lower river. Lower angling effort compared to past surveys may be related to higher river levels and increased homeland security measures implemented following September 11, 2001. Increased security measures limited angler access at some tailwaters.

4) The Glochidial Infestation Study, during which fish were collected from ten areas, was undertaken to:

- determine mussel glochidial infestation rates of a wide diversity of Ohio River fish species and
- ascertain potential impacts of restricted fish passage on host/mussel glochidial relationships.

A total of 31 fish species representing a wide range of behavioral and habitat guilds were collected primarily in tailwaters because of the potential presence of mussels in these more free-flowing sections of the river as well as the congregation of fish just downstream from locks and dams. Of 1,067 fish collected, 536 were examined for infestation with the mussel glochdial life stage. Only four individuals - a longnose gar, gizzard shad, skipjack herring, and spotted bass – were infested. These four species previously have been reported as fish hosts for species of Ohio River mussels. Due to the low numbers of glochidia found during this study, no conclusions could be made related to the study objectives, especially as related to fish passage. The study, however, cited similar low infestation rates reported by Weiss and Layzer (1995) for fish from the Green River in Kentucky, a major tributary to the Ohio River. The influences of flow rates, water temperature, river location and season on infestation rates were not discussed in the study's results.

4.8.1.1 Longitudinal and Lateral Connectivity in the Ohio River

Hoskins, Koryak and Stafford (2003) examined the relative contribution of tributaries and mainstem populations to reestablishment of fish populations in the upper Ohio River as follows:

> "Historically, … the upper Ohio … River … maintained very poor water quality (Shapiro et al. 1967) and did not support any substantial fisheries. The demise of fishes from rivers of the Pittsburgh region during the late nineteenth and most of the twentieth centuries has been examined in detail by ORSANCO (1962), Preston and White (1978), Trautman (1981), Pearson and Krumholz (1994), and others. Species of smaller rivers and stream habitats persisted in more remote, non-urbanized and unpolluted refuge headwaters. However, those species associated with large river ecosystems such as sauger (*Stizostedion vitreum*), spotted bass (*Micropterus punctulatus*), freshwater drum (*Aplodinotus grunniens*), mooneye (*Hiodon tergisus*), goldeye (*Hiodon alosoides*), river carpsucker (*Carpiodes carpio*), highfin carpsucker (*Carpiodes velifer*), silver chub (*Hybopsis storeriana*), river shiner (*Notropis blennius*), the buffalos (*Ictiobius* spp.), lake sturgeon (*Acipenser fulvescens*), shovelnose sturgeon (*Scaphirynchus platorynchus*), paddlefish (*Polyodon spathula*), and other species became locally extinct due to the pollution. Historically, the water quality of five Corps reservoirs and two large private utility hydropower reservoirs in the upper Ohio River drainage basin was so grossly degraded that these systems were completely devoid of fish life (Koryak et al. 2001).

The improvements in water quality that began in the 1970s allowed fish to invade and recolonize reclaimed waters. This restoration of local river fisheries has been discussed by Preston and White (1978), Pearson and Krumholz (1984), and Koryak and Hoskin (1994). The first species to appear were those that had persisted in upstream

refuges. Recolonization by many of the large river habitat species occurred later and apparently originated from distant downstream areas.

Holland et al. (1984) showed that, depending on their design and operation, navigation dams on larger rivers can be relatively pervious to fish passage. Their observations of recolonization rates along the mainstem Ohio River, lower Monongahela River and lower Allegheny River, which have very heavy commercial barge traffic and frequent year-round lockages, suggest that fishes can generally move upstream through navigation locks. Along the five pools of the upper Allegheny River navigation system, where winter and spring lockages are very infrequent, extirpated fishes were not recolonizing the upstream navigation pools until a program of fish passage lockages was initiated.

Formerly extirpated species of fish are also returning to smaller tributaries of the Allegheny, Monongahela, and Ohio Rivers (Koryak and Hoskin 1994). As water quality conditions continue to improve, this process of recolonization now appears to include, or has the potential to include, utilization of even small recovering local urban and suburban streams by resident and transient populations of fishes.

4.8.1.2 Synthesis of Information on Fish Passage

Upon completion of literature reviews and studies, the extent to which navigation locks and dams may act as barriers to fish movement and the degree to which such barriers may be impacting fish and mussel communities of the river were discussed during a meeting of the ORMSS IWG. These questions and the responses follow:

Q.1. Will the dams be effective barriers to invasive aquatic species?

A.1. The consensus of the ORMSS IWG was that dams will not serve as effective barriers to invasive species but they may slow down the migration. The slowing down may extend the time to look for opportunities to counter invasives. The type of dam may help slow migrations to some extent, but, over the long term, navigation dams will not be effective barriers to non-native invasive aquatic species.

Q.2. Are there operational modifications that could encourage fish movements through lock chambers?

A.2. There may be operational opportunities to encourage fish passage such as were performed at dams on the Allegheny River, but a case-by-case evaluation should be performed at each project. Because evidence suggests that flow is important to encourage fish entrance into lock chambers, one possibility is to provide flow through open locks to draw fish into the chambers. It appears that, at lock and dam complexes where private hydropower plants are present, greater flows from the hydropower units as compared to lock flows may draw fish away from lock chambers and thereby discourage fish movement through locks. Further, there is seasonality in fish migration which is probably related to instinctive pre-spawning movements and subsequent dispersal to feeding areas throughout the growing season.

Q.3. Is there sufficient evidence to support the conclusion that there is an upper river and a lower river fish population?

A.3. In 2003, lower river fish species appeared in the Pittsburgh area. However, there was no consensus regarding existence of upper and lower river populations, with some evidence of three distinct fish communities as suggested by data collected by ORSANCO during fish assessment monitoring since 1993. Discussion ensued about a possible historical division at the Falls of the Ohio River where McAlpine Locks and Dam now exists, although tagging studies by WVDNR indicate the distinction between fish communities occurs at Markland Lock and Dam (the next complex upstream of McAlpine). If distinct fish communities exist, the differences were not attributed to a lack of fish passage and could not be attributed to dams on the rivers. Such differences were likely due to other reasons such as dissimilarity of geological formations and physical habitats from upstream to downstream areas, as well as effects of previous water quality perturbations along the river.

Q.4. Why do we see so little downstream movement?

A.4. Dams may slow down fish movement in a downstream direction but likely do not impede such movement. Downstream movement occurs and has been documented for paddlefish. It is possible that the sampling design, in particular the timing of tagging studies when migratory spawning species show a marked inclination to move in an upstream direction, have biased the results. The team felt that movement is very much cued with the time of year (i.e., prespawning). Downstream movement by way of larval fish drift certainly occurs, and the team felt there is sufficient drift to disperse fish from upstream to downstream areas irrespective of active movement by adults.

Q.5. Is there sufficient evidence to support the idea that recolonization of the Ohio River has occurred and is likely to continue primarily by fish moving from downstream to upstream in the river?

A.5. Big river species can only come in from downstream sources. Other species were from tributary streams. Both sources were important contributors to recolonization of stocks in upstream areas previously impacted.

Q.6. Should attempts be made to reestablish populations of fish extirpated from the upper river in order to have proper hosts available for mussels?

A.6. The OSU Mussel Database indicates that there are adequate fish hosts in the upper river and that is not a limiting factor to mussel recolonization. Although there were some opinions expressed in favor of reestablishment of fish hosts, there were also concerns with regard to ensuring populations are genetically compatible with historical stocks.

4.8.1.3 Summary of Information on Fish Passage

Navigation dams on the Ohio River do not completely block fish movements in an upstream direction. Some fish are able to migrate from downstream to upstream and recolonize now suitable areas from which they were previously extirpated. In addition, fish species from refugia in tributary streams are contributing to recolonization, particularly in uppermost portions of the river. As water and sediment quality, coupled with other habitat characteristics, continue to improve in the upper reaches of the Ohio River, fish populations could be expected to further recover.

Conversely, navigation dams serve to slow fish movements much of the time. While some movement probably occurs during normal lockages, special operations to encourage movements have been shown to increase movements. It appears that the greatest opportunities for upstream movement by fish are under high flow conditions wherein dam gates are lifted out of the water and “open river” conditions exist. Findings of these studies reveal that not all fish species can migrate through dams during periods of high velocity, that there are numerous migratory species of varying size and swimming abilities, and that connectivity was available at all flow conditions prior to the construction of the dams.

The potential for fish passage through the gates of navigation dams is higher for projects along the lower reach of the Ohio River because of design features of these dams. Relative to their tailwaters, their gates sills are submerged. On the other hand, fish passage potential through gates is near zero for some of the dams on the upper reach of the Ohio River because they have "dry sills,” well elevated above the water level of their tailwaters even under very high flow conditions.

For replacement navigation structures such as will likely be built along the Emsworth-Dashields-Montgomery portion of the upper river, based on fish passage issues alone, a logical recommendation would be to design the gate sills of the replacement dams to be submerged to the lowest elevation possible. However, there would be a serious negative impact from such a design change. Higher sill elevations promote more efficient gas exchange and reaeration, while dropping the sills to improve fish passage potential would result in depression of DO concentrations in the river.

A cost-effective and easy remedy to this apparent dilemma exists: Fish passage is associated with high flow periods, while most reaeration benefits accrue during summer low flows. Therefore, submerged sill gates can be designed for maximum discharge capacity and fish passage potential during high flows and an additional elevated sill water quality gate can be designed for use during low summer flows. Such a gate arrangement is now being constructed for the Monongahela River L/D 2 replacement dam at Braddock. The Corps’ Engineer Research and Development Center (ERDC) in Vicksburg contributed to the hydraulic design of the slope of the sill and the apron at Braddock L/D to maximize the reaeration efficiency of the water quality gate. The two-level gate arrangement should help to prevent the chronic summer low flow water quality problems from submerged sill gates discharges at Opekiska L/D on the Monongahela and at relatively new navigation dams on the Red River. Further, fish passageways should be considered where opportunities exist.

As addressed in the previous Q and A's, navigation dams on the Ohio River will not serve to block the spread of invasive aquatic species, but may delay their spread and allow time for development of preemptive measures.

Although fish movements are somewhat restricted compared to pre-impoundment river conditions, lack of suitable fish hosts does not appear to be a limiting factor to reestablishment of mussel communities in upper reaches of the river. The presence of fish hosts does not mean there are adequate abundances of host species or adequate movement throughout the river to allow for mussel populations to sustain, let alone expand. See CEA Chapter 5 for a more thorough discussion of mussel resources.

4.8.1.4 Conclusions Concerning Ohio River Fish Passage

Both upstream and downstream movements of some fishes occur on the mainstem Ohio River. These movements, however, are more restricted than under un-impounded conditions. Opportunities for fish movement in an upstream direction are greatest under "open river" conditions, which occur seasonally under high flow (e.g., flood) conditions. Fish hosts for mussel glochidia are not limiting reestablishment of mussel communities in upper portions of the river. Special lockage operations are likely to facilitate fish movements. To improve opportunities for year-round fish movement past navigation dams on the Ohio River, special lockage operations should be considered. Further, as future navigational improvements, such as auxiliary lock chamber extensions or lock replacements are developed, fish passage facilities should be considered in designs. Such facilities are most needed at upper river locations where open river conditions do not regularly occur. Plans for fish passage facilities should consider characteristics of target native species and, when possible, make provisions to limit movement by non-native invasive species. Fish passage is a systemic need and will be included as a consideration at all L/Ds as a mitigation need.

4.8.2 Effects of Towboat Operations and Recreational Boating on Fish in Large Rivers

Propellers of commercial towboats can cause abrupt changes in hydraulic patterns, including increased turbulence and water velocities with resulting injury or mortality of adult fish, eggs, and larval stages (Maynord 1990; Hyun and Patel 1991; as cited in Killgore et al. 2000). Field investigations of these effects have been limited, in part because of the difficulty of sampling organisms in turbulent water behind large vessels. Two recent studies prepared for the Corps on the Upper Mississippi River-Illinois Waterway may be applicable to other large river systems, including the Ohio mainstem.

Using fish species that occur in the Mississippi River, Killgore et al.(2000) evaluated mortality of early life stages of fish entrained through water currents induced by a scale model of a towboat propeller placed in a large circulating water channel. During early life stages, fish are particularly vulnerable to propeller impacts because they are fragile and unable to avoid turbulent conditions. Further, high mortality of eggs and young individuals may signal a subsequent decrease in adult recruitment, particularly for species that occur in main channel habitats. The five fishes studied by Killgore and his colleagues – larval shovelnose sturgeon, larval lake sturgeon, eggs and larvae of paddlefish, juvenile common carp, and larval blue sucker – also have been recorded for the Ohio mainstem.

Simulating actual propeller conditions, the study found low or nonexistent mortality of paddlefish eggs, most likely because of the eggs' spherical shape and flexibility. Juvenile carp also experienced low mortality, probably because of protection afforded by their more highly developed organs and more rigid integuments. In contrast, fish in the more fragile larval stage experienced higher mortalities, linearly correlated with increasing propeller velocities and more turbulent conditions that result in differential force (shear stress) across a fish's body. Larval mortalities varied by size and species, with higher tolerances by larger individuals and by species adapted to higher velocity habitats. The study concluded that shear stress created by propellers can be a major source of larval fish mortality. Linear relationships between mortality and shear stress suggest that mortality can be predicted for different towboat configurations and extrapolated to approximate impacts of increased navigation traffic.

The second Mississippi River-Illinois Waterway study, Gutreuter and Vallazza (2002), sampled entrained adult fish by following tows on Pool 26 of the Upper Mississippi and the Alton Pool of the Illinois River. The combined data from 1996-1997 and 2000-2001 yielded entrainment mortality rates for gizzard shad and skipjack herring of 2.52 and 0.13 adult kills/ km of tow travel, respectively. Gutreuter and Vallazza concluded that with high annual tow traffic, even small entrainment mortality rates can yield high estimates of annual losses. Other fish species qualitatively observed as injured by propeller entrainment were shovelnose sturgeon, shortnose gar and black buffalo. An upward-swimming fright response observed in the shovelnose sturgeon may place this typically bottom-dwelling fish at increased risk of entrainment through towboat propellers. Anecdotal evidence from Pool 26 also suggests that some fish are killed during acceleration of downbound tows as they exit locks.

Lowery et al. (1987) and others (cited by Gutreuter and Vallazza 2002) have studied the ability of some fishes to avoid approaching vessels. These results suggest that further research on acoustic emissions of towboats and behavioral responses of channel-dwelling fishes may lead to the development of measures to maximize the avoidance response and thereby minimize the risk of entrainment.

Although recreational boating surveys have been conducted along the Ohio River, such surveys generally have not focused on the effects of recreational boating on fish and their habitats. A 1999 literature review by the North American Lake Management Society (NALMS) emphasizes that impacts of recreational boating on fish and other aquatic life are most pronounced in shallow waters and are compounded by the fact that peak boating activity during the warmer months usually coincides with critical life stages of aquatic organisms in temperate regions. Wave action by high-speed watercraft can disturb or destroy spawning nests and promote shoreline erosion. Suspended sediments churned by recreational vessels in shallow waters not only can smother fish eggs and habitat, but also can damage gills leading to decreased growth rates and lower fish biomass overall. The NALMS' review also cited studies confirming that prolonged use of outboard motors destroys or reduces aquatic macrophytes and invertebrates that are important components of fish habitat. Most studies cited by NALMS focus on lakes and reservoirs and fish species that typically inhabit them. Because scant information exists on the effects of recreational boating on large rivers, it remains a topic ripe for additional research.

4.8.3 Winter Habitat Used by Fishes in the Ohio River

Winter is a critical period in which high mortality occurs in fishes. Many temperate fishes undergo a torpor-like state when exposed to prolonged cold temperatures and short days (Oliver et al.1979; Cunjak 1996; Garvey et al. 1998, and Crawshaw 1984; as cited in Garvey et al.2003). Swimming ability is compromised at low temperatures in many species. Further, given low food availability and energetic costs of maintaining position during winter, fish may seek low velocity habitats to avoid energy depletion. As in other large temperate rivers, winter habitat requirements for fish in the Ohio River revolve around temperature, oxygen concentrations, flow velocities, and food availability. A literature review conducted by Garvey et al. (2003) for ORMSS found that because many Ohio River fish species likely home to the same overwintering locations each year, such areas are important for survival during critical winter periods. In addition during winter, fish may be highly susceptible to vessel-passage induced displacement from velocity shelters. Relatively small velocity changes, such as those that can be induced by vessels, can displace small bluegill and channel catfish from low velocity habitats when water temperatures are low (1 - 4 degrees C) (Sheehan et al. 2000; as cited in Garvey et al. 2003)). If fish are displaced into flowing channels at such temperatures, mortality will probably increase (Bodensteiner and Lewis 1994; as cited in Garvey et al. 2003).

Because the Ohio River extends through mid-temperate latitudes, inter-annual variability in winter temperature may translate to highly variable responses of fish populations to changes in flow velocity and flow direction with navigation. Fish residing at different latitudes within the main channel may be confronted by fundamentally different temperature-dependent challenges that vary among years, as well as by life stage and species. Habitat characteristics affecting winter survival of fish may well vary locally among adjacent pools as well as geographically between the upper and lower reaches of the Ohio River ecosystem. To understand how abiotic characteristics (e.g., latitude, channel morphometry, depth) regulate winter habitat use of critical fish species, Garvey et al. 2003 conducted a two-year, winter survey of a lower pool (Smithland – RM 846 to 918) and an upper pool (Belleville – RM 162 to 204) of the Ohio River. The research was a joint project of Southern Illinois University and West Virginia University.

Species richness (i.e., total number of species sampled) differed between Smithland and Belleville Pools during the two sampling winters. In Smithland Pool, a total of 19 species were sampled each year. Species richness was much higher in Belleville Pool, with AC electrofishing generating a total of 28 species. During both years in Smithland Pool, freshwater drum and blue catfish dominated samples, often comprising > 90% of fishes. In Belleville Pool, freshwater drum were often abundant, but channel catfish was the dominant catfish species. These species typically comprised 80% of fishes sampled, with other species such as gizzard shad being important as well.

Winter habitat use by fishes differed between the pools, as did the types of habitat studied **(Tables 4-7 and 4-8)**. During both winters in Smithland Pool, catch per unit effort (CPUE - number of fish per hour) was higher in sites adjacent to the main channel (i.e., main channel and artificial) than in tributaries. CPUE varied considerably among sites in Belleville Pool, with maximum average catch rates exceeding those in Smithland Pool. Catch rates of fish were higher in tributaries in Belleville than in Smithland Pool. Also,

catch rates of fish in Belleville Pool were higher in sites associated with the main channel in 2003 as compared to other macrohabitats sampled.

TABLE 4-7
Winter habitat types sampled in the Smithland Pool of the Ohio River

Habitat Type	Description
Main Channel	Area extending from shore including the center of the channel.
Island/Backwater	Area between an island and the shore. May be closed at one end of the channel (i.e., creating a flow break).
Artificial Flow Break	Artificial structures such as wing dams and moorings that create relatively deep scour holes; includes lock and dam complexes
Tributaries	Streams that flow into the main channel.

Species richness in macrohabitats of Smithland Pool varied with abiotic factors during both winters. Both tributary and island backwater sites had high species richness at cold temperatures. Further, species richness in tributaries increased with a slight rise in flow rates. When DO concentrations declined below 5 mg/L in Smithland tributaries (which occurred at warm, late-spring temperatures), fish species richness declined. Small, young freshwater drum were associated with tributary sites during winter in Smithland Pool, suggesting that these areas may provide some refuge for early life stages. In Belleville Pool, high catch rates and richness in tributaries during winter were likely due to the low flow rates in these macrohabitats. However, when temperatures in these areas declined below 4 degrees C, fish were more abundant in main channel areas, suggesting that fish leave cold water areas to inhabit relatively warmer but higher flow areas in the river.

TABLE 4-8
Winter habitat types sampled in the Belleville Pool of the Ohio River

Habitat type	Description
Main Channel	Area extending from shore including the center of the channel.
Backwater	Area between an island and the shore without barge traffic.
Island head	Area adjacent to the upstream end of an island.
Island tail	Area adjacent to the downstream end of an island.
Tributary	Area encompassing a tributary mouth and its connection to the main channel.
Embayment	A shallow bay-like area connected to the main channel.
Artificial wing dam	A near-shore area of low velocity created by an artificial barrier.
Deep hole	Dredged or natural scour areas within the main channel or back channel.

Several conclusions and implications applicable to fish sustainability from the study include:

- During both winters and in both pools of the Ohio River, fish assemblages and abundances differed among the winter macrohabitats.

  - In Smithland Pool, habitats adjacent to the main channel appeared to be important for fish during the winter. Particularly, island backwaters and submerged boulders at the channel border were areas that contained large aggregations of fish during cold, winter conditions. Deep scours created by artificial structures (e.g., submerged wing dikes) also provided refuge for fish at cold temperature

  - Tributary macrohabitats in Smithland Pool only provide important winter habitat when temperatures were low and when these areas were connected to the main channel. Tributaries in Smithland Pool are often disconnected from the main channel by a shelf of sediment and debris that may inhibit the passage of fish from the main channel and are not available for fish to access.

- In Belleville Pool, tributaries and an embayment area appeared to play a critical role for wintering fishes. However, these macrohabitats may cool more than the main channel during some winter periods (e.g., as might be expected during a period of snow melt), necessitating the movement of fish into warmer main channel areas. Surface electrofishing of shallow areas adjacent to the main channel revealed that different fish assemblages may be using these areas during winter.

- When fish use main channel habitats during winter, they may be subjected to changes in flow as barges move into their proximity. Fish with impaired swimming ability at cold temperatures (e.g., freshwater drum) may be displaced by changes in flow direction and velocity.

- After barge passage, displacement of water caused flow velocity to increase and a multidirectional flow pattern to occur. Flow rates continued to be affected by barges 15 minutes following passage of the bow. Thus, fish seeking typically low velocity deep water habitats behind river structures may be displaced if low temperatures reduce swimming ability, a pattern consistent with other studies.

- This unique opportunity to conduct parallel research projects in two impounded Ohio River reaches during the same winters provided insight into the potential effects of increased navigation on fish assemblages as follows:

  - Tributary habitats are clearly important to wintering fish, and reduced connectivity in Smithland Pool likely compromises the success of many species. Improved connectivity, perhaps through dredging at confluences, may improve winter success of fishes in this pool. Higher species richness and greater tributary use by fishes in Belleville Pool suggest that connectivity may not be problematic in that pool.

  - Many fishes such as channel and blue catfish use sites adjacent to the main channel in Smithland Pool. Similarly, channel catfish use the main channel in Belleville Pool.

  - Artificial sites such as wing dikes in Smithland Pool create scours that are used by river fishes. Artificial sites may be subject to displacement by barges, although this potential needs further exploration before definitive conclusions could be drawn.

  - Island backwater areas appear to be particularly important for fishes during winter. These areas provide flow breaks and are relatively sheltered from barge activity (i.e., areas in which barges do not traverse but can be affected by flow and elevation changes as barges transit in the river).

In the Ohio River mainstem, quantity and availability of winter refuge may well determine the relative survival and abundance of resident fish populations. River habitat

management that enhances/maintains accessibility to these areas should be beneficial to wintering fish in the Ohio River.

4.8.4 The Navigation Predictive Analysis Technique (NAVPAT) Model

Since the 1980s, the Corps and interested resource agencies have conducted substantial research on the effects of commercial navigation on habitats in large river systems such as the Mississippi, Ohio, and Illinois. The potential for tows to disturb bottom substrates and interfere with fish feeding and reproduction are of particular concern. Over the past 20 years, the Louisville District of the Corps has developed the Navigation Predictive Analysis Technique (NAVPAT) model to assess potential incremental biological effects of various navigation planning scenarios. The goal of NAVPAT is to provide quantitative results, which can assess positive or negative changes in available fish habitat quality for a specific area of a river cross-section (called a "cell") or for an entire reach of river. In general, NAVPAT links tow movements to possible biological effects. The NAVPAT model consists of four primary input components:

- river reach characteristics – including information describing multiple reaches of a river which share basic aquatic habitat conditions; i.e., reaches with similar bathymetry, substrate, depth, and velocity profiles
- economic scenarios – including data on various navigation forecasts, as well as data simulating various tows by length, width, speed, travel direction, horsepower, propeller dimensions, and other measurable characteristics
- physical forces – including information about several types of hydraulic forces generated by tows moving through a waterway, and
- biological species life-stage models – including fish life-stages selected to represent guilds of all major habitats and life stages in a river system.

In consultation with the USFWS, the Corps - Louisville District has incorporated 15 life-stages of fishes into NAVPAT as explained in **Table 4-9**.

TABLE 4-9
Fish Life Stages Selected for Ohio River NAVPAT Model

Fish Species	Life Stages/ Functions of Concern	Rationale for Species Selection	Potential Impacts of Concern
Emerald shiner	Spawning, fry	Represents open water spawners in areas of lower ambient current velocity and fry with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of nonadhesive eggs as water velocity increases with tow passage 2) Destruction of fry caused by entrainment through propellers or associated pressure and turbulence

Fish Species	Life Stages/ Functions of Concern	Rationale for Species Selection	Potential Impacts of Concern
Paddlefish	Spawning, larval stages	Represents open water spawners in areas of moderate ambient current velocity and fry with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of adhesive eggs as water velocity increases wit tow passage 2) Destruction of fry caused by entrainment through propellers or associated pressure and turbulence
Freshwater drum	Adult food, egg/larval stages	Represents open water spawners in almost any portion of a river and adults that feed on organisms found in bottom sediments	1) Destruction of egg/larval stages caused by entrainment through propellers or associated pressure and turbulence 2) Dislodgment of substrates caused by water velocity from tow passage
Sauger	Spawning, larval stages	Represent spawners in relatively high ambient current in areas with coarse substrate and larvae that move to areas of lower ambient current velocity with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of adhesive eggs as water velocity increases with tow passage and/or abrasion of eggs due to substrate scouring 2) Destruction of larvae caused by entrainment through propellers or associated pressure and turbulence
Channel catfish	Young-of-year	Represents species whose young feed primarily on aquatic insects in shallow water with low ambient current velocity	Dislodgment of substrate caused by water velocity from tow passage which could reduce the availability of aquatic insects on which these fish feed
Black crappie	Spawning, fry food, juvenile food and adult food	Represents nest spawners in shallow water and fry, juveniles, and adult that feed significantly on benthic aquatic insects in predominantly different portions of a river channel throughout their lives	1) Dislodgment of eggs from nests because of water velocity increases with tow passage and vulnerability of eggs to predation 2) Disturbance of substrate that could deposit on eggs and smother them 3) Disturbance of substrate that could reduce the availability of aquatic insects on which these fish feed

Fish Species	Life Stages/ Functions of Concern	Rationale for Species Selection	Potential Impacts of Concern
Spotted bass	Spawning, juvenile food	Represents nest spawners in moderate depth water with coarse substrates and juveniles that feed significantly on small benthic invertebrates	1) Dislodgment of eggs from nests because of water velocity increases with tow passage and vulnerability of eggs to predation 2) Disturbance of substrate that could reduce the availability of aquatic insects on which these fish feed

SOURCE: U.S. Army Corps of Engineers, Environmental Effects of Commercial Navigation Traffic – McAlpine Lock and Dam Project, NAVPAT and QUEPAT (not dated).

Although refinements to NAVPAT continue, the model can be used to evaluate environmental effects on a given life stage for a given traffic scenario and, in fact, has been applied to studies near Olmstead L/D and McAlpine L/D. Life history, river stage, discharge, and water temperature data are sufficiently available to apply NAVPAT to the time period when a particular species' life stage may be vulnerable. The developers of NAVPAT emphasize, however, that while it is a useful tool for evaluating traffic-induced impacts, NAVPAT should not be extrapolated to other human activities on or in the river. It remains unclear whether verification of NAVPAT results could be made by long-term monitoring, primarily because of the potential cumulative impacts of other human activities that could be difficult to distinguish from impacts of commercial navigation traffic.

4.8.5 Effects of Cooling Water Intake Structures on Fish

Large volumes of cooling water are withdrawn from the Ohio River to cool various industrial facilities, including stream electric power plants, pulp and paper makers, chemical manufacturers, petroleum refiners, and manufacturers of primary metals such as iron, steel, and aluminum. Cooling water intake structures cause damage to fish and other aquatic organisms that are pulled (entrained) into industrial cooling systems. Once entrained, organisms may be killed or injured by heat, physical stress, or chemicals. Larger organisms, including fish, may be killed or injured when they are trapped against screens (impinged) at the front of an intake structure.

Section 316(b) of the CWA requires that the location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impacts. In accordance with new and proposed regulations related to §316(b), USEPA recently evaluated entrainment and impingement rates at nine power plants on the Ohio mainstem between RM 53.9 and 560 (USEPA 2002). The main fish species the study found to be at risk were emerald shiner, freshwater drum, gizzard shad, sauger, white bass, white crappie, and white sucker (USEPA 2002). Several of these species have floating (pelagic) eggs or larvae that make them more vulnerable to intake damage.

When extrapolated to all cooling water intakes on the Ohio River, the results of the study indicated that impingement at all power facilities along the Ohio River causes the mortality of approximately 11.6 million age 1 equivalent fish per year, or 15,500 pounds of

lost fishery annually. The entrainment results indicated that all facilities combined cause the mortality of approximately 24.5 million age 1 equivalent fish per year, representing nearly 40,000 pounds of lost fishery yield annually. However, because the study used limited 1977 data from a period when water quality in the river was worse and fish biomass was probably lower than it is presently, U.S.EPA suggests that the results probably underestimate current entrainment and impingement losses along the Ohio mainstem, consequently, underestimating the benefits of new and proposed regulatory action.

Lohner et al. (2000) and Perry et al. (2001) report on modeling exercises to assess 316(b) impacts on Ohio River fish populations using more recent data from the long-term Ohio River Ecological Research Program and ORSANCO electrofishing. In six of 22 scenarios of fish species and river pool, the projected fish population changes due to impingement and entrainment were greater than the expected natural variability of existing populations, consequently, indicating possible adverse environmental impacts (Perry et al.). The significance of these findings is obscured by the combination of other abiotic (e.g., river flow, water quality, habitat quality) and biotic factors (e.g., predation, exotic species, competition) to which fish populations respond. Further §316(b) studies at several power plants along the Ohio River are anticipated as additional phases of the 316(b) program are implemented by USEPA in the coming years.

4.9 INTERACTIONS WITH OTHER VECS

Because of their diverse ecological niches and their importance in river recreation and its related economy, fish interact with almost every VEC considered in this CEA. Unlike mussels, which have limited mobility, fish are highly mobile and widely distributed throughout the Ohio mainstem. One of the strongest links occurs between fish and water and sediment quality. Fish species composition, abundance, and condition are all excellent indicators of water and sediment quality. As documented in the discussion on baseline conditions, many fish species that took refuge in the lower Ohio River during the worst decades of pollution have recovered and moved upstream. Consequently, densities, biomass, and fish community diversity have increased measurably as water quality has improved. Sport fishing also has improved and increased in popularity as fish populations have increased. Increased sport fishing has enhanced the perception of the river's recreational value and, in turn, has benefited local economies. Despite ongoing improvement in water quality, however, fish consumption advisories remain in effect for a number of Ohio River fish species. (See Chapter 8, **Health and Safety**)

Fish and mussels are very closely linked aquatic groups with generally mutually beneficial interactions. Mussels are an important food resource for certain bottom-dwelling fishes, including suckers and catfishes. Conversely, fish are critical to mussel distribution, because they serve as hosts for the immobile glochidial (larval) stage of mussels. The recently introduced black carp may be an exception to the beneficial interaction between fish and mussels as it has the potential to feed on already vulnerable native mussels.

Fish also are conspicuous components of riparian ecosystems. Wetlands and embayments along the Ohio mainstem provide vital spawning and nursery areas for many fish species. During winter, lower current velocities and warmer temperatures in these

habitats offer refuges to fishes of all age groups. Waterbirds, including migratory species, rely on fish in riparian areas as an important food source. Islands, another riparian habitat beneficial to fish, add to habitat diversity within the mainstem, while islands' back channels offer fish quieter refuges from the currents and traffic of the open channel.

As was underscored in the section titled "Studies Concerning Specific Impacts on Fishes," a broad spectrum of human activities affect fish in the Ohio mainstem. Direct impacts include obstruction of fish movement, movements of commercial and recreational vessels, damage to fish habitats through removal or sedimentation of bottom substrates, and impingement or entrainment in cooling water intake structures. The following section discusses an array of floodplain and in-water activities that lead to changes that can reduce or impair fish habitat and contribute to point and nonpoint source pollution.

4.10 RELEVANT ACTIONS AFFECTING FISH

This analysis of relevant actions affecting fish attempts to integrate ecological processes related to species, habitats, and ecological services on a system level. As indicated previously, fish respond to multiple interrelated factors, making it difficult to examine any action or ecological process in isolation. While acknowledging that actions and ecological processes overlap and interact in complex ways, we have aggregated RFFA effects on fishes into five major groups:

1) habitat changes (Ha) – including the integrity of critical habitats, patterns and connectivity of habitats, and structural complexity of habitats
2) changes in disturbance regimes (DR) – including the alteration of conditions to which species and ecosystems have adapted over a long period of time
3) changes in hydrologic patterns (Hy) – including alterations to water connections that influence biodiversity and ecological integrity
4) effects on ecological services (EcS) – including impacts on nutrient cycling and purification services that break down toxins and transform soils and sediments, and
5) changes related to populations (P) – including impacts of exotic species, population dynamics, and genetic diversity

Of 87 actions included in the RFFA matrix, 32 actions were ranked "high importance" and 29 actions were ranked "medium importance" for fish. **Table 4-10** lists all high and medium RFFAs, indicates if the action is generally beneficial (+) or detrimental (-), and lists the action's effects according to the key above.

TABLE 4-10.
RFFA Cumulative Effects Matrix for Fish

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Effects on Fish	Impor-tance[5]	Ecological Processes Affected[6]
Navigation Investment Actions						
Lock Extensions/New Locks/ Replacement or Rehabilitation	A	H	SL, E	-	M	Ha, DR, Hy
L&D operation and maintenance	A	H	SL, E	-	M	All
Non-structural navigation improvements	A	H	SL, E	+	H	Ha
Dam replacement and rehabilitation	A	H	SL, E	-	H	All
Other Corps Actions						
Channel dredging/dredged material disposal	A	H	SL, E	-	H	Ha, Hy, ES
Flood damage reduction projects						
levees/floodwalls	A	L	E	-	H	All
dry dams, other projects off mainstem	A	M	E	-	M	All
channel modifications	A	H	E	-	M	All
Nonstructural measures (e.g., relocation)	A	H	E	+	H	All
Emergency streambank stabilization (Sec. 14)	A	H	SL, E	-	M	Ha, Hy
Modification of Corps structures for environmental improvements (Sec. 1135)	A	H	E	+	H	All
Environmental restoration of aquatic ecosystems (Sec. 206)	1,2	H	E	+	H	All
ERP Projects - 5 categories	A	H	E	+	M	All
Port development (Sec. 107) and maintenance dredging	A	H	SL, E	-	M	All
Pool maintenance	A	H	E	-	H	All
"But for" Actions						
Commercial Navigation						
barge queuing	A	H	SL, E	-	M	Ha, P
fleeting areas/barge storage	A	H	SL, E	-	M	Ha
terminals	A	H	SL, E	-	M	All
multi-modal sites	A	H	SL, E	-	M	All
increased traffic	A	H	E	-	H	Ha, P
dispersed barge traffic	A	H	E	-	M	Ha, P
accidents/spills	A	H	E	-	H	Ha, P
Instream sand and gravel mining	A	H	SL, E		H	Ha, Hy, P
Coal utilities	A	H	SL, E	-	M	Ha, Hy, ES, P
Other coal industries	A	M	SL, E	-	M	Ha, Hy, ES, P
Hydropower on dams	A	H	SL, E	-	H	Ha, P
Industrial users, excluding coal-related	A	H	SL, E	-	M	Ha, Hy, P

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Effects on Fish	Impor-tance[5]	Ecological Processes Affected[6]
Actions by Others						
Public lands acquisition and management	A	H	SL, E	+	M	All
Floodplain development						
residential	A	H	E	-	M	All
commercial	A	H	E	-	M	All
industrial	A	H	E	-	M	All
Crossings						
bridges	A	H	SL, E	-	M	Ha, Hy ES, P
utility	A	H	SL, E	-	M	Ha
industrial	A	H	SL, E	-	M	Ha
Riverbed crossings	A	H	SL, E	-	M	Ha
Marina development & operation	A	H	SL, E	-	M	Ha, Hy, ES, P
Water-based recreation:						
fishing	A	H	E	-	H	Ha, P
Agriculture	A	H	R	-	M	Ha, Hy, ES, P
WWTP discharges						
municipal	A	H	U	-	H	Ha, P
industrial	A	H	U, R	-	H	Ha, P
onsite systems	A	H	R	-	H	Ha, P
Stormwater discharges	A	H	U, R	-	H	Ha, P
Brownfields redevelopment	A	H	U	+	M	All
Hazardous waste sites	A	H	SL	-	H	All
Natural Climatic Events						
floods	A	H	E	+	H	All, especially DR
droughts	A	H	E	+	H	All, especially DR
severe storms	A	H	E	+	H	All
Regulatory Environment						
Phase I & 2 NPDES program	A	H	SL, E	+	H	Ha, Hy, ES, P
TMDLs	A	M	E	+	H	Ha, P
Site remediation	A	M	SL, E	+	H	All
More stringent quality standards for environmental media	A	M	E	+	H	Ha, ES, P
Pollutant source control	A	M	E	+	H	Ha, ES, P
Wetland Mitigation Banking	A	M	SL	+	H	All
Carbon sequestration	A	M	R	+	H	ES, P
Farmland preservation	A	M	R	+	H	All
Corps permitting programs	A	H	SL, E	+	H	All
Small navigation projects	A	H	SL, E	-	M	All
ORSANCO monitoring program	A	H	E	+	M	Ha, ES, P
Spill response	A	H	E	+	M	Ha, ES, P
ESA (Endangered Species Act)	A	H	E	+	H	All

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Effects on Fish	Impor-tance[5]	Ecological Processes Affected[6]
Environmental sustainability practices	A	M	E	+	H	All

Table Notes:

[1] Reasonably Foreseeable Future Actions

[2] Time period in which the RFFA may occur:
1 = within 10 years 2 = in 10 - 25 years 3 = in 25 - 60 years A = applicable to all time periods

[3] Occurrence probability or likelihood RFFA will happen:
H = high M = medium L = low

[4] Location or setting on river where RFFA is expected to occur:
U = upper (Pittsburgh - Huntington) M = middle (below Huntington - Louisville)
L = lower (below Louisville - mouth) E = along entire length of river
SL = selected locations, e.g., locks and dams U = urban setting R = rural setting

[5] Importance of RFFA:
H = high M = medium L = low

[6] Ecological Processes Affected:
Ha = habitat changes that affect critical habitats, patterns, connectivity and complexity
DR = disturbance regimes; includes alterations of conditions to which species have adapted over long periods of time
Hy = hydrological changes to the channel and/or river floodplain
EcS = ecological services; includes impacts on nutrient cycling and purification services that affect toxins, soils and sediments
P = population changes; includes impacts of exotic species, population dynamics and genetic diversity

The ecological processes listed above have been adapted from USEPA - Office of Federal Activities. 1999. Considering ecological processes in environmental impact assessments (es.epa.gov/oeca/ofa/eco/99.html).

4.10.1 Actions Contributing to Habitat Changes (Ha)

This group includes

- Actions that physically alter fish habitats by direct damage or removal of bottom substrates, spawning areas and/or bottom-dwelling organisms upon which fish feed. The Corps, navigation industry, power industry, and other river users undertake these actions.

- Such actions also may indirectly alter fish habitats by limiting prey visibility or blanketing spawning areas with sediment. Channel maintenance dredging and in-stream sand and gravel mining, both rated of high (H) importance, exemplify actions with both direct and indirect impacts on fish habitat.

Channel maintenance dredging (H) involves the removal and disposal of sand and gravel deposits from the navigation channel of the Ohio River to maintain a nine-foot depth. Mussels and other bottom-dwelling aquatic organisms upon which fish feed also may be removed during dredging. For most extended reaches of the Ohio River, channel maintenance dredging is an ongoing activity. Past practices in all but the upper 120 miles of the river have generally utilized in-stream disposal of dredged materials. This practice alters fish habitat through the redistribution of sediments, which may cover eggs and spawning areas of fish that prefer clean gravel substrates (lithophils) and interfere with fish

feeding and respiration. Dredging also may resuspend contaminants, increase concentrations of plant nutrients, lower or increase photosynthesis, and increase biological oxygen demand (Watters 1999), causing adverse effects throughout food webs. The elimination of suitable habitat, destabilization of bottom substrates, and the creation of deep pools also can inhibit recolonization of dredged areas by fish and other aquatic life (Kanehl and Lyons 1992). Conversely, carefully planned in-water placement of dredged material can effectively restore aquatic habitat. Recommendations for mitigating the adverse impacts of channel dredging include:

- restricting dredged areas to the minimum required to maintain the navigation channel,
- conducting long-term monitoring of aquatic habitats where dredging has occurred and/or continues,
- evaluating land disposal of dredged materials, and
- using dredged materials to create new sandbars, islands, or riparian habitat beneficial to fish and other aquatic life (e.g., using structural fill for streambank restoration projects).

Ongoing commercial in-stream sand and gravel mining (H) also involves the removal of sand and gravel deposits from the river and their subsequent transport to land. Such operations are numerous along the Ohio River, as the navigation system makes river-based extraction and transportation of dredged aggregates economical. In the Corps' Huntington District alone (RM 126-440), 20 river reaches, ranging from 0.5 to 4.2 miles, have permits for sand and gravel dredging. Environmental concerns related to commercial sand and gravel dredging include possible mobilization of contaminants, turbidity plumes, removal of shallow water habitat, modification of substrate particle size, adjacent bank stability, alluvium aquifer quality, decreased bathymetric diversity, creation of deep holes in the channel which may become anoxic during summer season low flow periods, and attendant adverse impacts of fish, mussels and other aquatic life (USACE 1992 and 2002). Like channel maintenance dredging, commercial dredging potentially results in the disturbance and/or removal of fish habitat and the redistribution of sediments, which may cover substrates preferred by fishes and interfere with feeding and other metabolic processes.

Concerns and potential impacts vary along the length of the river. All three states which regulate commercial sand and gravel dredging on the Ohio River (Pennsylvania, West Virginia, and Ohio) have established setbacks in their permits, or certified setbacks in Corps' dredging permits, to protect resources from adverse dredging impacts. The percentage of cobble and coarser gravel, versus finer gravel and sand in the riverbed, tends to decline in a downstream direction; the persistence of dredging impacts appears to be related to substrate sizes. For example, the Kentucky Division of Water (KDOW) has observed that except for direct disturbance of mussel beds, the impacts of commercial dredging tend to be relatively ephemeral, and 50 to 60 feet deep dredge holes may be completely filled in and restored within a period of only a few years. In contrast, along the upper Ohio River in West Virginia and Pennsylvania, where the substrate of the river is generally coarser and less mobile, dredging induced changes in the bathymetry of the channel and subsequent impacts to habitat tend to be much more persistent, if not essentially permanent. Historical dredging, before the establishment of permit setbacks, in

many areas occurred from bank to bank, eliminating substantial areas of shallow water habitat

Construction of lock chamber extensions (M) also can require dredging and excavation in the Ohio River which could result in destruction, partial loss, or siltation of existing fish habitat in proximity to the construction area. As previously described, dredging would temporarily increase turbidity and suspended solids and potentially release contaminants found in the sediments, though elutions of worst case contaminated sediments from the upper Ohio River failed to release priority pollutants (USACE 1982 and 1989). Increased sediments in the water column would harm the predatory ability of sight-feeding fishes including many sport species. Construction also would require placement around the foundations of extended walls of fill consisting of concrete, rock and earth (removed from the existing structure during demolition.) Dewatering of lock chambers to install additional filling/emptying systems would temporarily increase turbidity in the water column. Unlike channel dredging, construction of lock chamber extensions would be confined to selected locations with minimal occurrences over the study period.

On land, construction of lock chamber extensions would require establishment of parking and maintenance areas for equipment, a lay-down yard for materials, an onsite-disposal area for excavated materials, and some earthwork where portions of the new lock chamber connect with the riverbank. These activities would require clearing of vegetation with potential surface runoff and soil erosion that could result in siltation of fish habitat with attendant adverse effects on spawning, feeding, and respiration.

Barge queuing upstream and downstream of locks and dams would be expected to increase during temporary closures of main and/or auxiliary chambers, if lock chambers are extended. Queuing would create turbidity, mortality of eggs and larval fish, and potential damage to fish spawning beds, mussel beds, and other shoreline habitats while barges await lock passage.

The potential extent of impacts during all aspects of lock extension would vary at construction locations and in queuing areas depending upon the quality of fish habitat. Several actions, however, could be taken to minimize or mitigate impacts including:

- Installing mooring facilities that restrict queuing tows to the navigation channels, thus avoiding direct physical damage to bottom substrates.
- Keeping barges away from sensitive aquatic habitat, including mussel beds, by utilizing various traffic management measures that would reduce queuing (e.g., use of helper boats, lock scheduling with remote mooring, queuing fees/penalties, etc.).
- Installing turbidity curtains to surround construction areas.
- Using environmentally acceptable fill materials.
- Scheduling construction to minimize in-river activities.
- Using dewatering techniques that minimize suspended solids in the water column.
- Implementing erosion control plans that emphasize phased clearing, containment of soils, water detention, and temporary reseeding of cleared sites followed by timely permanent revegetation.
- Creating new side channel habitats with continuous flow and suitable substrate below dams.

- Disposing of dredged materials in a way that either does not affect fish and other aquatic life or creates new habitat.

Chapter 5, Mussels, lists additional measures to protect mussel beds, an important food source for fish.

Barge queuing (M) during normal commercial navigation and its attendant turbidity effects and potential physical damage to fish and habitats would be reduced during normal navigation operations, as a result of increased lock capacity and decreased lock maintenance events. However, barge fleeting and storage (M)**,** which also may cause direct damage to fish habitat and mussel beds, would not be relieved by lock expansions. In fact, barge fleeting and storage areas would be expected to increase in proportion to commercial traffic. Expansion of such facilities may result in temporary riverbed and/or land-based impacts during construction and installation. Using BMPs for sediment and erosion control and avoiding construction of mooring facilities within or adjacent to sensitive aquatic habitats, such as fish nursery areas or mussel beds, would help minimize impacts.

The ongoing commercial use of lock and dam facilities requires periodic upkeep, maintenance and operation (H)**.** This RFFA includes major and minor repairs of both existing primary locks and auxiliary locks. As existing locks age, the need for such repairs become more frequent. Past experience with Ohio River navigation structures indicates the frequency of repairs will generally increase as locks age and in proportion to increases in commercial traffic on the Ohio River. For the 60-year ORMSS study period, scheduled repair events are expected to occur on an average of once every five years for each lock and dam project (USACE 2000).

Impacts on fish and their habitat vary depending upon the location and extent of each lock repair event. Dewatering of lock chambers, establishment of areas for equipment, parking and materials, and barge queuing caused by delays at locks would all potentially impact fish near the work area. These impacts could be lessened through the corresponding actions listed under lock chamber extension in the previous section. Unlike lock extensions, maintenance and repair activities are not expected to require disposal of significant quantities of dredged or excavated materials.

Maintenance and repair events occur with or without lock extensions. Completion of lock extensions or lock additions, however, can reduce repair activities and associated impacts to fish and other aquatic life in three ways:

- It may be feasible to schedule each construction project to eliminate one complete auxiliary chamber repair event or major rehabilitation that would otherwise have been necessary.
- Each extension creates a lock in new condition, allowing for a longer time interval between the auxiliary chamber repair events.
- Finally, the original full sized locks will be used less, since total lockages can be shared equally between two full sized locks allowing for a longer time between main chamber repair events (USACE 2000).

Fewer repair activities lead to reductions in queuing, especially important in the more ecologically sensitive tailwater areas subject to queuing of tows bound upstream. If locks are extended, the impacts on fish directly attributable to maintenance and repair activities are reduced in proportion to the expected reduction in repair activity. Effects from major lock rehabilitation would be similar to those of repairs, but would likely occur over longer time periods.

Whether or not locks are extended, continuing operation of existing locks and dams (rated high) along the Ohio River will have ongoing effects on the composition of fish communities. These effects include siltation, modification of current direction and velocities, downstream scour that can affect reproduction and feeding, and restrictions on movements of fishes that limit genetic diversity (and, therefore, decrease population resiliency) along the river's longitudinal gradient. Further, the continuing operation of existing locks and dams dampens flood cycles, thus interfering with the river's natural disturbance regimes.

An infrequent action with potentially significant impacts on fish is dam replacement and rehabilitation (H)**,** which differs from rehabilitation of lock chambers. While the timing of rehabilitation projects is subject to numerous variables, this activity primarily corresponds to the useful life cycle of a dam. Of the 20 dams currently on the river, 6 have been rehabilitated in the past two decades, at an average age of 60 years following their initial construction. Assuming a life cycle of 60 years, all the dams currently on the Ohio River may require major rehabilitation or replacement during the 60-year cycle of the study period. Impacts related to fish from dam rehabilitation projects would be similar to construction site impacts described previously for lock extension projects. The activities would require similar temporary impacts for construction parking and laydown yards and would likely entail similar needs for the disposal of dredged materials.

Port development and maintenance (M) is another activity with potentially adverse direct impacts on fish habitat and food supply. Use of turbidity curtains to limit downstream siltation is among measures that can mitigate such impacts. Both the Corps and the private sector undertake Port development and maintenance. Development of new terminals and multimodal sites (both rated M) associated with commercial traffic would be expected to further impact fish by scouring of bottom substrates and mortality of sensitive life stages entrained by commercial vessels using the ports. Strict adherence to permit conditions (Section 10, 404 and state 401 certification) would help to minimize these impacts, but would have a lesser effect on continued use of terminal facilities.

Recreational activities, especially the development and maintenance of marinas and boat launch ramps and other support facilities, also can directly impact fish habitat in the Ohio River. Analyses of Corps' navigation charts from 2003 indicated a total of 394 marinas and launch ramps along the Ohio River mainstem, as compared to 356 shown on 1974 navigation charts. For both time periods, the largest number of such facilities occurred in the Louisville District (RM 436-981). Potential impacts of marina development include direct elimination or encroachment on fish habitat and erosion and resultant sediment damage to feeding and spawning areas, unless turbidity curtains or other containment procedures are used during construction. Marinas and related facilities tend to be concentrated in embayments and can be found throughout the floodplain, although marinas concentrate somewhat in proximity to urban areas. Embayments comprise a very

limited resource within the Ohio River floodplain and are especially valuable as fish spawning areas and nurseries for young fish. Additional concerns are related to dredging activity within embayments that is generally required to maintain accessibility to marinas and launch ramps. The expected continued growth of marinas and associated dredging of embayments will displace ecological attributes of embayments, including fish and benthic habitat, presence of macrophytes, and other features that add beneficial structural complexity and diversity to aquatic systems.

Other facilities supporting boating and non-boating activities include urban or rural riverfront parks, riverfront hotel/restaurant complexes, and casino boat/resort complexes. Virtually all recreation infrastructure along the Ohio River has been built in relation to and is dependent upon continued maintenance of the existing system of navigation pools. Construction of these facilities can temporarily increase sediment loads and affect fish habitat, can permanently alter hydrological connections with the river floodplain, and can eliminate riparian habitats that fish may use for spawning and nursery areas.

Because industrial discharges (H) to the Ohio River are now highly regulated under NPDES permitting compared to the pre-NPDES era, potential fish impacts related to industrial activities, coal utilities and other coal-related industries (both M) along the river primarily focus on transfer of potentially harmful materials and maintenance of port/docking facilities. Coal transport alone currently accounts for more than 55% of all barge traffic on the Ohio River and is projected to account for a large percentage of traffic for the foreseeable future. Because of the coal industry's prominence, the associated potential impacts on mussel beds and other habitats from barge activities and spillage of coal fines and other harmful substances are particularly important. Contaminated sediments from past industrial pollution or landfill materials also impair fish habitat. Such contaminants are most prevalent in the heavily industrialized upper river.

Fish communities have been affected by the loss of riparian habitats and hydrological connections along the Ohio River, especially near urban centers where widespread floodplain development has occurred. Floodplain ordinances, government programs and other constraints, however, have limited residential, commercial, and industrial development in the Ohio River floodplain in recent years. Nevertheless, all types of development are rated medium because some floodplain development is expected to continue throughout the study period. Possible impacts related to fish and other aquatic life include increased erosion and attendant siltation during construction and increased stormwater runoff and associated pollutants as impervious surfaces, such as driveways, parking lots, and roof tops increase. The implementation of the Phase 1 and 2 NPDES program (H) over time, however, should moderate stormwater impacts.

Riverbed crossings (M) that convey water or energy related materials frequently intersect the Ohio mainstem. The 1987 navigation charts for the Ohio River showed 282 riverbed crossings. When such lines are laid beneath the river, they directly damage fish and other aquatic habitats and can cause temporary downstream siltation. Because dredging is prohibited from occurring in the vicinity of crossings, some studies have speculated that these crossings may inadvertently protect mussels and other benthic organisms upon which fish feed. Other studies, however, may have suggested long-term habitat damage due to continued scouring of fill material within the crossing.

Corps permitting programs (H) are important because they are designed to regulate several activities related to potential fish habitat impairment. In addition to the Corps permitting program are state administered water quality certifications (§401 Clean Water Act). Corps programs regulate discharge of dredged or fill material into waters of the United States (§404 Clean Water Act), and construction of wharves, piers and other physical obstructions in navigable waters (§10 of the Rivers and Harbors Act of 1899). The Corps permitting programs potentially benefit fish and other aquatic life by providing habitat protection in waterways. Management of permitting programs, however, also must account for cumulative effects of permitted facilities, which can affect fish, mussels, and other aquatic resources.

Actions contributing to changes in fish habitat are of increasing concern to fisheries managers and aquatic biologists. The recently launched National Fish Habitat Initiative is a strategy aimed at focusing national attention and resources on common priorities to improve the quality of aquatic habitats. More information on this initiative and its indicators of habitat quality is found in Chapter 13, Adaptive Management.

4.10.2 Actions Contributing to Changes in Disturbance Regimes (DR)

Floods, droughts, severe storms, and earthquakes are natural disturbance events occurring along the Ohio River mainstem to which ecosystems and species have adapted over long periods of time. Such events occur with some regularity and result in significant changes in ecosystem structure and composition, including changes to fish communities. The natural disturbance regime of an ecosystem refers to the type, magnitude, and frequency of disturbances that would occur within the landscape in the absence of human activities (USEPA 1999). Floods, droughts, and severe storms are rated high in **Table 4-10**. Earthquakes are not included in **Table 4-10**; they are rated low because of their relatively low magnitude and frequency in the region. It should be noted that a high priority need identified during the ES workshops was to allow hydrologic regimes to mimic natural events such as extreme floods and droughts.

Flooding and severe storms redistribute dissolved and particulate organic materials throughout river channels and adjacent floodplains, including the transport of small and large woody debris that influences aquatic food webs and fish habitat. Because the dams of the Ohio mainstem were designed primarily for navigation instead of flood control, they have a negligible impact on natural flood regimes. A countervailing influence, however, has resulted from an increase in impervious surfaces in developed areas of the floodplain, leading to increased runoff and flashiness of urbanized streams during storms, which in turn causes flooding in the mainstem.

By detaining floodwaters, off-mainstem flood control projects (M)**,** contribute to modification of the natural flooding cycle. Conversely, natural drought effects are lessened by scheduled low-flow augmentation releases of water from reservoirs located along tributaries to the Ohio. Channel modifications designed to reduce flooding (M) also affect flow patterns and natural disturbance regimes.

4.10.3 Actions Contributing to Changes to Hydrologic Patterns (Hy)

Changes to hydrologic patterns are closely linked to changes in disturbance regimes and habitat and include alterations to water connections that influence biodiversity and ecological integrity

As discussed in other chapters, one activity frequently stimulates another, compounding negative impacts. Floodplain development, for example, can create a demand for flood damage reduction structures such as levees (H) and floodwalls that, subsequently, cause loss of floodplain habitat and severing of hydrologic connections. By altering connections between a main channel and riparian areas, levees eliminate and block access to potential fish spawning and nursery areas and restrict the transport of organic materials between riparian areas and the Ohio River mainstem.

In contrast to levees, nonstructural flood control measures (H) can help restore hydrological function and connections. Examples of such measures include relocation of housing and businesses out of floodplains and installation of vegetative buffer/filter strips along river corridors. Filter strips have the added benefit of helping to remove sediment and nutrients from runoff before they reach the river.

Land and channel impacts contributing to changes in hydrologic patterns occur during bridge construction, redesign, or replacement (M). This action is rated medium because it is expected to be a relatively infrequent occurrence during the study time frame. Bridges potentially affect fish and other aquatic life because of erosion and siltation during construction and possible long-term alterations of flow patterns, which in turn can cause velocity changes and silt deposition affecting reproduction and metabolic processes. Drastic flow alterations caused by bridges can lead to the disappearance of entire islands as occurred at Baker Island (formerly located at RM 49.5). Similarly, construction of the Interstate 79 bridge piers near Pittsburgh in the 1970s quickly led to the scouring away of Hughey Island a short distance downstream.

Ecosystem Restoration (ER) projects (M)**,** including restoration of wetlands and riparian habitats, have potential to restore ecological functions and services, including reconnecting the floodplain to the river. Fish could further benefit from ER projects that include water quality improvements among project objectives. Brownfields redevelopment (M) and remediation of contaminated sites (H) in riparian areas likewise are actions beneficial to restoration of hydrologic connections when such sites are returned to more natural soil and vegetation conditions. When redeveloped for commercial or industrial use, such sites also may spare conversion of other green space within the floodplain. The Phase 1 and 2 NPDES program (H) also is a beneficial regulatory action because it manages stormwater runoff to prevent further damage to hydrologic connections and promotes innovative ways to manage runoff. These actions and others that reduce sediment input or reverse severing of hydrologic connections improve conditions for fish and other aquatic life.

4.10.4 Actions Affecting Ecological Services (EcS)

Actions included in this category have impacts on nutrient cycling and on purification services that break down toxins and transform soils and sediments. Nutrient

cycling refers to the processes by which elements such as nitrogen, phosphorus, and carbon move through an ecosystem while purification services are the result of effective nutrient cycling.

Most actions affecting ecological services occur within the floodplain. An in-stream activity considered of high negative importance, however, is channel dredging (H) because of its potential to resuspend contaminants, increase concentrations of plant nutrients, lower or increase photosynthesis, and increase biological oxygen demand (Watters 1999), causing adverse effects throughout food webs. While results of studies by DeLaume et al. (1976) suggest that sediments can be a stable sink for some contaminants, other studies have shown that some sediment contaminants can be remobilized under certain hydrologic conditions. Dredging also is associated with construction, repair, and maintenance of navigation structures (all M) as well as with bridge construction (M). Because these activities are anticipated to occur at specific locations relatively infrequently throughout the ORMSS time period, they are expected to have a lower cumulative impact on ecological services than activities like marina development and operation (M) that are increasing in number and are more widespread.

Residential, commercial, and industrial floodplain development (M) can impair effective nutrient cycling and purification services by replacing riparian vegetation with impervious surfaces that increase stormwater runoff, by compacting soils, and by altering hydrologic connectivity. Floodplain ordinances, government programs, and other constraints have limited floodplain development in recent years; however, some level of floodplain development is expected to occur throughout the study period. Renewed interest in recreational opportunities along the river, including the development of parks, trails/bikeways, private campgrounds, and other related facilities also can adversely impact ecological services, although the cumulative importance of these actions was typically ranked low in the RFFA matrix. From a positive perspective, recreational facilities may include enhancements that help restore native riparian vegetation and afford educational opportunities to demonstrate innovative BMPs.

Agriculture (M) represents the largest land use activity by area within or adjacent to the Ohio River floodplain. Erosion of cultivated land carries suspended solids and attached fertilizers, pesticides, and herbicides into the Ohio River mainstem, increasing pressure on nutrient cycling and purification processes. Additional demands result when livestock wastes run off into the river. Soil compaction from years of overuse and removal of riparian vegetation to maximize space for row crops further accelerate sediment and nutrient delivery to the river. The influence of agriculture on aquatic life, including fish, is underscored by the fact that most future conversions of land in the Ohio River corridor will occur on land currently in agriculture or in forests. Control of agricultural discharges (L), including BMPs promoted by the USDA Natural Resources Conservation Service, such as no-till farming, can help mitigate these impacts, but have limited effectiveness because these BMPs are largely voluntary.

Several actions listed in **Table 4-10** are beneficial to nutrient cycling and purification processes. Carbon sequestration ranks high (H) as a beneficial action, but is limited in practice. Future reforestation projects to capture and securely store carbon emitted from fossil fuel-fired energy plants may not only help reduce greenhouse gases, but may also help restore native riparian buffers along the Ohio River. More stringent quality standards

for environmental media (H), pollutant source control (H), ORSANCO's monitoring program (M), and spill response activities (M) collectively also can enhance ecological services in the Ohio mainstem.

4.10.5 Actions Contributing to Changes in Populations (P)

Included in this category are actions that inhibit or prevent normal reproduction and actions that cause isolation of fish communities. Actions with negative effects on population dynamics manifest themselves in the loss of species, populations, or genetic diversity. Information on the life history and population dynamics of species affected by human actions is important to understanding how populations and their ecological functions can change. The preservation of genetic diversity is critical to maintaining the evolutionary potential for fish to adapt to future stresses.

As mentioned in previous sections of this chapter, development of the navigation system and continuing operation maintenance of the locks and dams (H) have had profound influences on the distribution and composition of the fish community of the Ohio River. Siltation of the river bottom as a result of impoundment has contributed to declines in species such as shovelnose sturgeon, redhorses, blue sucker, paddlefish, and other species that use clean gravel substrate for spawning. Conversely, species such as freshwater drum, emerald shiner, and gizzard shad that produce floating eggs and larvae have increased in abundance. Impoundment (pool maintenance (H)) also has altered the hydrology in backwaters and side channels, consequently creating more lake-like embayments preferred by slower moving catfishes and sunfishes that are popular with anglers. Locks and dams also affect longitudinal distribution and may serve as barriers to the natural exchange of genetic material within a species. Lock extensions/rehabilitation (M) and dam replacement/rehabilitation (H) also may adversely affect local populations by damage to spawning habitat and nursery areas. The infrequency of these activities relative to operation and maintenance activities, however, produces relatively low cumulative impacts to fish communities.

Barge queuing (L), dispersed barge traffic (M), and increased barge traffic (H) are all actions that can cause damage or mortality of the most vulnerable life stages of certain fish species. The previously mentioned NAVPAT model has been developed as a tool to assess environmental effects on vulnerable life stages under various traffic scenarios.

Many other actions that are likely to increase with population growth include in-stream sand and gravel mining (H), operation of coal utilities (H), bridge construction (M), and marina development and operation (M). These actions affect fish populations through habitat alterations that are often long-term, depending on local populations and conditions. Operation of coal utilities (M) also can result in damage and mortality of fish due to impingement and entrainment, issues of concern in §316(b) of the CWA.

Non-structural navigation improvements (H) constitute non-regulatory actions perceived as having high importance and benefit to fish populations and their supporting habitats. Nonstructural navigation improvements refer to traffic management alternatives that do not involve modifications of lock and dam infrastructure. Because these nonstructural measures can facilitate passage of barge traffic, the impacts related to barge queuing, siltation, and physical damage to fish habitat and mussel beds are reduced. Nonstructural navigation improvements include efficiency measures such as vessel

scheduling and prioritization, self-help coordination among towboat operators, and expanded mooring facilities near locks and dams. More detailed information on nonstructural measures is found in Chapter 10, Transportation.

Of several actions **(Table 4-10)** to assess effects on fish, ORSANCO's monitoring (M) represents the most long-term effort to assess fish communities in the Ohio River and understand the factors that influence their sustainability. As part of USEPA's regional Environmental Monitoring and Assessment Program (EMAP), ORSANCO is beginning a five-year rotational monitoring program that includes sampling 30 randomly selected sites in each of four pools per year. The program is designed to assess regional comparability across similar ecosystems, as well as to complement ORSANCO's fish monitoring within the upper, middle, and lower river. ORSANCO also has been sampling Ohio River tributaries, in response to needs of its member states. Further, ORSANCO will continue to develop and evaluate indices of biotic integrity (IBIs), potentially including an index for algae. With regard to resource assessment, fishing (H) is important because fishermen can exert pressure to support monitoring, assessment, and regulatory programs that in turn enhance sustainability of the fisheries resources of the Ohio mainstem.

4.11 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

The fish fauna of the Ohio River represents a highly diverse and visible resource that has been studied more extensively than any other biotic group assessed for ORMSS. Because fish have multiyear life spans, are highly mobile, and occupy high positions in food webs, they are excellent indicators of CE and ES. Changes in current velocities and sediment transport related to the construction and operation of dams, along with poor water quality led to degradation of Ohio River fish communities through the mid-20th century. Actions undertaken by ORSANCO and the implementation of the CWA have helped reverse this trend since the 1970s. While Ohio River fish communities will not return to preimpoundment conditions due to habitat modifications, indices of biotic integrity have documented that the river's fish communities are now more diverse and healthy than in many decades. With point sources of water pollution under control and nonpoint sources being addressed, one of the greatest threats to fish communities in the Ohio River at the beginning of the 21st century appears to be the recent and rapid invasion of Asian carps species that aggressively compete with native fishes for food and ecological niches. However, to date, negative effects of Asian carps and most other invasive species have not been demonstrated.

One of the seven environmental operating principles of the Corps is to strive to achieve ES. ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of cumulative effects can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An analysis of environmental sustainability (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps: (1) identification of five "common effects" on fish resources from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix; (2) selection of six indicators for ES for fish and their grouping, as appropriate; and (3) consideration of the "connections" between the common effects and the indicator groups. The output of the AES consists of a qualitative (descriptive) discussion of the "connections," with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for fish resources, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – the composite conditions for the six selected indicators of ES for fish do not reflect conditions that sustain diverse and healthy populations of fish in the Ohio River.

- Marginally sustainable – the composite conditions for the selected six indicators of ES for fish are such that diverse populations of fish are occurring in some segments of the river; however, the conditions of some of the indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of fish resources in the Ohio River).

- Sustainable – the composite conditions for the six selected indicators of ES for fish are such that diverse, healthy populations of fish are occurring along the majority of the river; as indicated by high values for indices of biotic integrity or other pertinent measures.

Five common effects of multiple actions have been previously discussed in the section entitled "Relevant Actions Affecting Fish." They include actions causing: 1) changes in habitat, 2) changes in disturbance regimes, 3) changes in hydrologic patterns, 4) effects on ecological services, and 5) changes related to fish populations. Six interrelated indicators of ES were identified earlier in the section entitled "Indicators of Environmental Sustainability," and relevant information on them has been presented in the section entitled "Past to Current Baseline Conditions." Regarding their relevance for ES, the following rationale is appropriate:

- composition of fish communities – including numbers of intolerant and nonnative species, abundance, and other metrics that have been incorporated into indices of biotic integrity; allows fish communities to be compared over time to determine trends affecting sustainability

- amount of habitat with stable substrates, adequate depths, suitable currents, and sufficient food supplies – related to reproductive success, condition of individuals in populations, and the overall diversity of fish communities

- reproductive viability as measured by amount of spawning habitat, genetic connectivity, numbers of gravid females, and larval individuals – directly related to the success of fish populations in attaining ES

- percent of population with abnormalities such as parasites, tumors, ulcers, and fin erosion – provides a measure of the health of individuals in populations and tends to increase with degradation in water quality

- water quality measurements such as levels of DO and pH – directly related to water quality standards established to protect aquatic life and human health and safety

- level of disturbance from biotic stressors, such as invasive species and from abiotic stressors, such as river traffic – refers to an array of activities and conditions that can disrupt ecological processes and alter ES of fish communities and other aquatic organisms.

For the purposes of this analysis, the six indicators are grouped into two tiers for the AES. The tiers are as follows:

- first tier – basic measures related to fish resources

  (1) percent of population with abnormalities such as parasites, tumors, ulcers, and fin erosion

  (2) water quality measurements such as levels of DO and pH

  (3) level of disturbance from biotic stressors, such as invasive species, and from abiotic stressors, such as river traffic

- second tier – composite indicators of fish resources sustainability

  (1) amount of habitat with stable substrates, adequate depths, suitable currents, and sufficient food supplies

  (2) reproductive viability as measured by amount of spawning habitat, genetic connectivity, numbers of gravid females, and larval individuals

  (3) composition of fish communities, including numbers of intolerant and non-native species, abundance, and diversity

As noted in **Table 4-10**, the 61 RFFAs ranked as having high (H) or medium (M) importance to cumulative effects on fish can be grouped into categories in accordance with five common effects. **Table 4-11** summarizes the 38 RFFAs that cause adverse habitat changes (HA), including the integrity of critical habitats, patterns and connectivity of habitats, and structural complexity of habitats; and **Table 4-12** does similarly for the 22 RFFAs that cause beneficial habitat changes. In general, and as described above for selected examples of actions contributing to habitat changes, the 38 RFFAs in **Table 4-11** cause increases in the turbidity and suspended solids in water, decreases in DO, and changes in pH from normal conditions. Biotic stressors can occur and thus promote the occurrence of invasive species; and abiotic stressors can result from increased navigation and recreational boat traffic. Some actions may induce increasing percentages of abnormalities in existing fish populations. As a result of these undesirable changes in

basic measures related to fish populations, along with action-induced declines in adequate fish habitats and reproductive viability, the composite effect of these 38 RFFAs on the ES of fish resources in the Ohio River mainstem would lead to a reduced ES condition. Such reductions could exacerbate existing marginal ES conditions for many species, and create further concerns for currently nonsustainable species.

TABLE 4-11
AES Tiers for Actions Causing Adverse Habitat Changes (HA)

RFFAs That Cause Adverse Habitat Changes	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(1) Lock extensions, new locks, replacement or rehabilitation (M) (2) Lock and dam operation and maintenance (M) (3) Dam replacement and rehabilitation (H) (4) Channel dredging/dredged material disposal (H) (5) Levees/floodwalls (H) (6) Dry dams, other projects off mainstem (M) (7) Channel modifications (M) (8) Emergency streambank stabilization (Sec. 14) (M) (9) Port development (Sec. 107) and maintenance dredging (M) (10) Pool maintenance (H) (11) Barge queuing (M) (12) Fleeting areas/barge storage (M) (13) Terminals (M) (14) Multi-modal sites (M) (15) Increased traffic (H) (16) Dispersed barge traffic (M) (17) Accidents/spills (H) (18) Instream sand and gravel mining (H) (19) Coal utilities (M) (20) Other coal industries (M) (21) Hydropower on dams (M) (22) Industrial users, excluding coal-related (M) (23) Floodplain development -- residential (M) (24) Floodplain development -- commercial (M) (25) Floodplain development -- industrial (M) (26) Crossings -- bridges (M) (27) Crossings -- utility (M) (28) Crossings -- industrial (M) (29) Riverbed crossings (M) (30) Marina development and operation (M) (31) Water-based recreation -- fishing (H)	• Percent of Fish Populations with Abnormalities • Water Quality Measurements • Level of Disturbance from Biotic and Abiotic Stressors	• Amount of Adequate Habitat • Reproductive Viability • Diverse and Healthy Composition of Fish Communities

RFFAs That Cause Adverse Habitat Changes	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(32) Agriculture (M) (33) Wastewater treatment plant discharges -- municipal (H) (34) Wastewater treatment plant discharges -- industrial (H) (35) Wastewater treatment plant discharges -- onsite systems (H) (36) Stormwater discharges (H) (37) Hazardous waste sites (H) (38) Small navigation projects (M)		

TABLE 4-12
AES Tiers for Actions Causing Beneficial Habitat Changes (HA)

RFFAs That Cause Beneficial Habitat Changes	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(1) Non-structural navigation improvements (H) (2) Non-structural measures (e.g., relocation) (H) (3) Modification of Corps structures for environmental improvements (Sec. 1135)(H) (4) Environmental restoration of aquatic ecosystems (Sec. 206)(H) (5) ERP projects - 5 categories (M) (6) Public lands acquisition and management (M) (7) Brownfields redevelopment (M) (8) Natural climatic effects - floods (H) (9) Natural climatic effects - droughts (H) (10) Natural climatic effects - severe storms (H) (11) Phase 1 and 2 NPDES program (H) (12) TMDLs (H) (13) Site remediation (H) (14) More stringent quality standards for environmental media (H) (15) Pollutant source control (H) (16) Wetland mitigation banking (H) (17) Farmland preservation (H) (18) Corps permitting programs (H) (19) ORSANCO monitoring program (M) (20) Spill response (M) (21) Endangered Species Act (H) (22) Environmental sustainability practices (H)	• Percent of Fish Populations with Abnormalities • Water Quality Measurements • Level of Disturbance from Biotic and Abiotic Stressors	• Amount of Adequate Habitat • Reproductive Viability • Diverse and Healthy Composition of Fish Communities

Fortunately, and as illustrated by the 22 RFFAs in **Table 4-12**, several ER and improvement programs are already underway or planned. Further, natural climatic events are expected to contribute to periodic, albeit temporary, movement of the basic measures to more normal environmental cycling and variability. Twelve of the RFFAs listed in **Table 4-12** relate to the regulatory environment and policies and programs that should minimize disturbances from stressors, enhance water quality, and reduce fish population abnormalities. Therefore, as these RFFAs are implemented, they should improve the ES of fish resources in the Ohio River mainstem.

The RFFAs that are anticipated to cause changes in disturbance regimes are summarized in **Tables 4-13 and 4-14**. **Table 4-13** highlights the 15 RFFAs that are anticipated to cause adverse changes in conditions to which species and ecosystems have adapted over a long period of time. Disturbances are anticipated from both biotic and abiotic stressors. Water quality parameters may experience transient changes as a result of construction or rehabilitation practices associated with many of the RFFAs. Such transient conditions can promote abnormalities in fish populations and disruptions to substrates, depths, currents, and food supplies for fish habitats. These changes would be expected to reduce the reproductive viability of fish populations in local areas and to cause temporary and local reductions in the diversity and health of fish communities.

Table 4-14 lists 15 RFFAs that are anticipated to improve conditions to which species and ecosystems have adapted over long periods of time. The first 6 listed actions, along with numbers 10 through 15, are related to restoration or land acquisition actions, or to preservation, protection, and sustainability actions that should reduce biotic and abiotic stressors and improve water quality, fish habitat, and fish reproductive viability. Actions 7 through 9 are associated with natural climatic effects that should mimic longer-term environmental conditions and regimes. As a composite result of these 15 RFFAs, the ES of fish resources would be expected to improve.

Tables 4-15 and 4-16, respectively, summarize 24 and 16 RFFAs that either adversely or beneficially affect hydrologic patterns. A key feature is that changes in these patterns include alterations to water connections that influence biodiversity and ecological integrity. Such connections can occur on tributaries, in the upstream to downstream flow patterns on the mainstem, and in runoff waters from adjacent urban and rural areas. Adverse changes to natural hydrologic connections can cause both changes in flow patterns and velocities as well as water quality. Disturbances to the quality and quantity of fish habitats, as well as fish behavioral patterns can result. The reproductive viability of various species can also be disrupted. As a consequence of the adverse changes to hydrologic patterns, the diverse and healthy composition of existing fish communities will be lowered, and the ES of fish resources will be reduced.

TABLE 4-13
AES Tiers for Actions Causing Adverse Changes in Disturbance Regimes

RFFAs That Cause Adverse Changes in Disturbance Regimes	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(1) Lock extensions, new locks, replacement or rehabilitation (M) (2) Lock and dam operation and maintenance (M) (3) Dam replacement and rehabilitation (H) (4) Levees/floodwalls (H) (5) Dry dams, other projects off mainstem (M) (6) Channel modifications (M) (7) Port development (Sec. 107) and maintenance dredging (M) (8) Pool maintenance (H) (9) Terminals (M) (10) Multi-modal sites (M) (11) Floodplain development -- residential (M) (12) Floodplain development -- commercial (M) (13) Floodplain development -- industrial (M) (14) Hazardous waste sites (H) (15) Small navigation projects (M)	• Percent of Fish Populations with Abnormalities • Water Quality Measurements • Level of Disturbance from Biotic and Abiotic Stressors	• Amount of Adequate Habitat • Reproductive Viability • Diverse and Healthy Composition of Fish Communities

TABLE 4-14
AES Tiers for Actions Causing Beneficial Changes in Disturbance Regimes

RFFAs That Cause Beneficial Changes in Disturbance Regimes	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(1) Non-structural measures (e.g., relocation) (H) (2) Modification of Corps structures for environmental improvements (Sec. 1135)(H) (3) Environmental restoration of aquatic ecosystems (Sec. 206)(H) (4) ERP projects - 5 categories (M) (5) Public lands acquisition and management (M) (6) Brownfields redevelopment (M) (7) Natural climatic effects - floods (H) (8) Natural climatic effects - droughts (H) (9) Natural climatic effects - severe storms (H) (10) Site remediation (H) (11) Wetland mitigation banking (H) (12) Farmland preservation (H) (13) COE permitting programs (H) (14) Endangered Species Act (H) (15) Environmental sustainability practices (H)	• Percent of Fish Populations with Abnormalities • Water Quality Measurements • Level of Disturbance from Biotic and Abiotic Stressors	• Amount of Adequate Habitat • Reproductive Viability • Diverse and Healthy Composition of Fish Communities

TABLE 4-15
AES Tiers for Actions Causing Adverse Changes to Hydrologic Patterns (Hy)

RFFAs That Cause Adverse Changes to Hydrologic Patterns (Hy)	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(1) Lock extensions, new locks, replacement or rehabilitation (M) (2) Lock and dam operation and maintenance (M) (3) Dam replacement and rehabilitation (H) (4) Channel dredging/dredged material disposal (H) (5) Levees/floodwalls (H) (6) Dry dams, other projects off mainstem (M) (7) Channel modifications (M) (8) Emergency streambank stabilization (Sec. 14) (M) (9) Port development (Sec. 107) and maintenance dredging (M) (10) Pool maintenance (H) (11) Terminals (M) (12) Multi-modal sites (M) (13) Instream sand and gravel mining (H) (14) Coal utilities (M) (15) Other coal industries (M) (16) Industrial users, excluding coal-related (M) (17) Floodplain development -- residential (M) (18) Floodplain development -- commercial (M) (19) Floodplain development -- industrial (M) (20) Crossings -- bridges (M) (21) Marina development and operation (M) (22) Agriculture (M) (23) Hazardous waste sites (H) (24) Small navigation projects (M)	• Percent of Fish Populations with Abnormalities • Water Quality Measurements • Level of Disturbance from Biotic and Abiotic Stressors	• Amount of Adequate Habitat • Reproductive Viability • Diverse and Healthy Composition of Fish Communities

Table 4-16 lists the16 RFFAs that could cause beneficial effects on hydrologic patterns, depending on specific locational and design features of the actions. Actions (1) through (4), (6), (11) and (12) are examples of restoration, remediation, or reclamation measures that could be designed with one purpose being to restore natural connectivity. Land acquisition and management measures, including management of hydrologic patterns, are included in actions (5) and (13), and possibly (16). The natural climatic events depicted in actions (7) through (9) are related to natural means for restoring altered connectivities. Finally, regulatory requirements for protecting hydrologic patterns can be imposed under actions (10), (14), and (15), along with action (16). In summary, the 16 RFFAs in **Table 4-16** would enhance the ES of fish resources in the Ohio River mainstem.

TABLE 4-16
AES Tiers for Actions Causing Beneficial Changes to Hydrologic Patterns

RFFAs That Cause Beneficial Changes to Hydrologic Patterns	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(1) Non-structural measures (e.g., relocation) (H) (2) Modification of Corps structures for environmental improvements (Sec. 1135)(H) (3) Environmental restoration of aquatic ecosystems (Sec. 206)(H) (4) ERP projects - 5 categories (M) (5) Public lands acquisition and management (M) (6) Brownfields redevelopment (M) (7) Natural climatic effects - floods (H) (8) Natural climatic effects - droughts (H) (9) Natural climatic effects - severe storms (H) (10) Phase 1 and 2 NPDES program (H) (11) Site remediation (H) (12) Wetland mitigation banking (H) (13) Farmland preservation (H) (14) COE permitting programs (H) (15) Endangered Species Act (H) (16) Environmental sustainability practices (H)	• Percent of Fish Populations with Abnormalities • Water Quality Measurements • Level of Disturbance from Biotic and Abiotic Stressors	• Amount of Adequate Habitat • Reproductive Viability • Diverse and Healthy Composition of Fish Communities

Table 4-17 displays 20 RFFAs that are expected to cause adverse effects on ecological services; examples of effects include those on nutrient cycling and purification services that break down toxins and transform soils and sediments. Many of the listed actions would cause adverse effects during their construction phases, and others would contribute to such effects during their operational phases. The effects would be manifested on both "basic measures" and "composite indicators." Accordingly, a decline in the ES of fish resources would be expected to occur, with the decline ultimately reflected in fewer diverse and healthy fish communities.

TABLE 4-17
AES Tiers for Actions Causing Adverse Effects on Ecological Services (EcS)

RFFAs That Cause Adverse Effects on Ecological Services	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(1) Lock and dam operation and maintenance (M) (2) Dam replacement and rehabilitation (H) (3) Channel dredging/dredged material disposal (H) (4) Levees/floodwalls (H) (5) Dry dams, other projects off mainstem (M) (6) Channel modifications (M) (7) Port development (Sec. 107) and maintenance dredging (M) (8) Pool maintenance (H) (9) Terminals (M) (10) Multi-modal sites (M) (11) Coal utilities (M) (12) Other coal industries (M) (13) Floodplain development -- residential (M) (14) Floodplain development -- commercial (M) (15) Floodplain development -- industrial (M) (16) Crossings -- bridges (M) (17) Marina development and operation (M) (18) Agriculture (M) (19) Hazardous waste sites (H) (20) Small navigation projects (M)	• Percent of Fish Populations with Abnormalities • Water Quality Measurements • Level of Disturbance from Biotic and Abiotic Stressors	• Amount of Adequate Habitat • Reproductive Viability • Diverse and Healthy Composition of Fish Communities

In contrast to adverse effects on ES, **Table 4-18** displays 21 RFFAs that are anticipated to cause beneficial effects on such services. The 21 RFFAs include those related to environmental improvements via the use of non-structural measures (no. 1), modifications and restoration efforts (nos. 2 through 4), land acquisition and management (nos. 5, 14, 15, and 16), natural climatic effects (nos. 7, 8, and 9), environmental controls, monitoring, and regulatory programs (nos. 10, 12, 13, 17, 18, 19, and 20), remediation efforts (nos. 5 and 11), and promotion and implementation of ES practices (no. 21). Some of these RFFAs reflect continuations of current measures, while others would be implemented at various times over the planning period. Overall beneficial effects are expected to occur from reduced pollutants released to the environment and less disruptions to natural biotic and abiotic processes.

TABLE 4-18
AES Tiers for Actions Causing Beneficial Effects on Ecological Services

RFFAs That Cause Beneficial Effects on Ecological Services	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(1) Non-structural measures (e.g., relocation) (H) (2) Modification of Corps structures for environmental improvements (Sec. 1135)(H)	• Percent of Fish Populations with Abnormalities	• Amount of Adequate Habitat • Reproductive

RFFAs That Cause Beneficial Effects on Ecological Services	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(3) Environmental restoration of aquatic ecosystems (Sec. 206)(H) (4) ERP projects - 5 categories (M) (5) Public lands acquisition and management (M) (6) Brownfields redevelopment (M) (7) Natural climatic effects - floods (H) (8) Natural climatic effects - droughts (H) (9) Natural climatic effects - severe storms (H) (10) Phase 1 and 2 NPDES program (H) (11) Site remediation (H) (12) More stringent quality standards for environmental media (H) (13) Pollutant source control (H) (14) Wetland mitigation banking (H) (15) Carbon sequestration (H) (16) Farmland preservation (H) (17) COE permitting programs (H) (18) ORSANCO monitoring program (M) (19) Spill response (M) (20) Endangered Species Act (H) (21) Environmental sustainability practices (H)	• Water Quality Measurements • Level of Disturbance from Biotic and Abiotic Stressors	Viability • Diverse and Healthy Composition of Fish Communities

Tables 4-19 and 4-20, respectively, address adverse and beneficial changes to fish populations resulting from RFFAs. Such changes include the impacts of exotic species, alterations in population dynamics, and modifications of genetic diversity. A total of 31 RFFAs that could have adverse effects are listed in **Table 4-19**, while 22 RFFAs that could cause beneficial effects are listed in **Table 4-20**. Examples of actions causing both types of effects are described in the earlier subsection entitled "Actions Contributing to Changes in Populations." The RFFAs listed in **Table 4-19** would be expected to decrease the ES of fish resources, while those in Table 20 would enhance the ES.

TABLE 4-19
AES Tiers for Actions Causing Adverse Changes to Fish Populations

RFFAs That Cause Adverse Changes to Fish Populations	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(1) Lock and dam operation and maintenance (M) (2) Dam replacement and rehabilitation (H) (3) Levees/floodwalls (H) (4) Dry dams, other projects off mainstem (M) (5) Channel modifications (M) (6) Port development (Sec. 107) and maintenance dredging (M) (7) Pool maintenance (H) (8) Barge queuing (M) (9) Terminals (M) (10) Multi-modal sites (M)	• Percent of Fish Populations with Abnormalities • Water Quality Measurements • Level of Disturbance from Biotic and Abiotic Stressors	• Amount of Adequate Habitat • Reproductive Viability • Diverse and Healthy Composition of Fish Communities

RFFAs That Cause Adverse Changes to Fish Populations	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(11) Increased traffic (H) (12) Dispersed barge traffic (M) (13) Accidents/spills (H) (14) Instream sand and gravel mining (H) (15) Coal utilities (M) (16) Other coal industries (M) (17) Hydropower on dams (M) (18) Industrial users, excluding coal-related (M) (19) Floodplain development -- residential (M) (20) Floodplain development -- commercial (M) (21) Floodplain development -- industrial (M) (22) Crossings -- bridges (M) (23) Marina development and operation (M) (24) Water-based recreation -- fishing (H) (25) Agriculture (M) (26) Wastewater treatment plant discharges -- municipal (H) (27) Wastewater treatment plant discharges -- industrial (H) (28) Wastewater treatment plant discharges -- onsite systems (H) (29) Stormwater discharges (H) (30) Hazardous waste sites (H) (31) Small navigation projects (M)		

TABLE 4-20
AES Tiers for Actions Causing Beneficial Changes to Fish Populations

RFFAs That Cause Beneficial Changes to Fish Populations	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(1) Non-structural measures (e.g., relocation) (H) (2) Modification of Corps structures for environmental improvements (Sec. 1135)(H) (3) Environmental restoration of aquatic ecosystems (Sec. 206)(H) (4) ERP projects - 5 categories (M) (5) Public lands acquisition and management (M) (6) Brownfields redevelopment (M) (7) Natural climatic effects - floods (H) (8) Natural climatic effects - droughts (H) (9) Natural climatic effects - severe storms (H) (10) Phase 1 and 2 NPDES program (H) (11) TMDLs (H) (12) Site remediation (H) (13) More stringent quality standards for environmental media (H) (14) Pollutant source control (H) (15) Wetland mitigation banking (H) (16) Carbon sequestration (H) (17) Farmland preservation (H)	• Percent of Fish Populations with Abnormalities • Water Quality Measurements • Level of Disturbance from Biotic and Abiotic Stressors	• Amount of Adequate Habitat • Reproductive Viability • Diverse and Healthy Composition of Fish Communities

RFFAs That Cause Beneficial Changes to Fish Populations	Basic Measures Related to Fish Resources	Composite Indicators of Fish Resources Sustainability
(18) COE permitting programs (H) (19) ORSANCO monitoring program (M) (20) Spill response (M) (21) Endangered Species Act (H) (22) Environmental sustainability practices (H)		

To summarize the overall AES, **Table 4-21** includes tabulations associated with the numbers and importance of RFFAs contributing to adverse and beneficial changes to the five categories of fish effects. Some general observations related to **Table 4-21** include:

- Adverse changes to the five categories of effects generally lead to declines in the ES of fish resources, while beneficial changes cause improvements in ES.

- RFFAs associated with adverse changes include a composite of construction and operational practices that will occur at various locations along the mainstem and at various times across the planning horizon. The majority of the RFFAs are associated with navigation investment actions by the Corps, other Corps actions, "but for" actions by others but related to presence of the navigation system, and general actions by others. The majority of the listed RFFAs anticipated to cause adverse changes are in the medium importance category.

- RFFAs associated with beneficial changes include a composite of restoration, protection, and remediation projects, along with natural climatic events, and permitting and environmental management programs associated with the regulatory environment. Some of these RFFAs represent continuations of past and present actions; however, the majority are dependent on future funding and new regulatory or management initiatives. Again, the beneficial changes from these actions are expected to occur at various locations along the mainstem and at various times across the planning horizon. Finally, the large majority of the listed RFFAs anticipated to cause beneficial changes are in the high importance category.

- The composite pattern indicated by **Tables 4-11 through 4-20**, as well as summarized in **Table 4-21**, is that in the short-term future (perhaps the next decade), the ES of fish resources would decline; however, in the longer-term future the beneficial changes would more than offset the adverse changes, thus the ES of fish resources would improve relative to the current conditions.

TABLE 4-21
Summary of Analysis of Environmental Sustainability

Effects on Fishes	RFFAs Causing Adverse Changes	RFFAs Causing Beneficial Changes
Habitat changes (HA)	Table 11 -- 38 RFFAs (14 H and 24M)	Table 12 -- 22 RFFAs (17 H and 5 M)
Changes in disturbance regimes (DR)	Table 13 -- 15 RFFAs (4H and 11M)	Table 14 -- 15 RFFAs (12H and 3M)

Effects on Fishes	RFFAs Causing Adverse Changes	RFFAs Causing Beneficial Changes
Changes in hydrologic patterns (Hy)	Table 14 -- 15 RFFAs (12H and 3M)	Table 16 -- 16 RFFAs (13H and 3M)
Effects on ecological services (EcS)	Table 17 -- 20 RFFAs (5H and 15M)	Table 18 -- 21 RFFAs (16H and 5M)
Changes related to fish populations (P)	Table 19 -- 31 RFFAs (14H and 17M)	Table 20 -- 22 RFFAs (17H and 5M)
Note: H denotes a high importance RFFA, and M denotes a medium importance RFFA		

4.12 SUMMARY AND CONCLUSIONS

The CE on Ohio River fishes from past, present, and reasonably foreseeable future actions have been addressed herein. Because of their importance to humans and their diversity, fish are a VEC in ORMSS. These resources further are valued because they serve as indicators of the quality and overall health of the aquatic ecosystem. Their indicator role is facilitated by their multiyear life spans and mobility, their wide range of species, trophic levels, and spawning conditions; their sensitivity to pollution, and their collection methods and relative ease of identification. Fish also are of interest and concern to society because of their potential for food and sport.

Fishes of the Ohio River interact with several other VECs including water and sediment quality, mussels, riparian/floodplain ecological resources, recreation, land use, and human health. Fish species composition, abundance and condition are all related to water and sediment quality. Fish and mussels generally have mutually beneficial interactions; mussels are an important food resource for certain bottom-dwelling fishes, including suckers and catfish. Conversely, fish are critical to mussel distribution because they serve as hosts for the immobile, glochidial (larval) stage of mussels. Riparian habitats, including wetlands and embayments, provide vital spawning areas for many fish species and their somewhat lower current velocities and higher temperatures offer refuges to fish during winter. Riparian habitats are important to processes for improving water quality and nutrient cycling providing benefits to fish, mussels, and other natural resources. Water quality improvements in recent decades have enhanced sports fishing which in turn has enhanced the perception of the river's recreational value. Despite improved water quality, fish consumption advisories remain in effect for a number of Ohio River species. Pollutants that affect fish are generated by an array of human activities, exacerbated by increased imperviousness and runoff from land.

The geographic boundaries for study of the fish VEC included the mainstem, the approximate 500-year floodplain zone along both sides of the river, and mouths of tributaries. More information is needed on the contribution of tributaries to the recruitment and sustaining of fish in the Ohio mainstem. The temporal boundaries of this study generally encompass 1920 to 2070, with the earlier date approximating the initiation of the Corps' lock and dam construction activities on the Ohio River and the latter date approximating the end of the 60-year planning horizon encompassed by ORMSS. However, some information prior or 1920 is included to establish an historic baseline.

Fish populations were identified in early study planning by the Corps and the IWG as an important topical issue to be addressed. This identification was confirmed via the number of comments and specific concerns expressed in 12 public scoping meetings. A total of 26 direct comments on fish were received, along with an additional 49 comments that have implications for fish and fishing. These comments have been addressed herein. Further, the Environmental Review Team has continued to express interest in, and provide information and advice on this VEC.

Several federal laws are related either directly or indirectly to fish in the mainstem. Biologically-focused laws include the Endangered Species Act, the Fish and Wildlife Coordination Act, National Invasive Species Act, and state fishing regulations. The ORFMT, composed of fisheries personnel for the six states bordering the river, has worked to facilitate fishing license reciprocity and standardize fishing regulations along the river. The CWA relates to water quality improvements; it also encompasses programs involving state water quality certification (Section 401), the Corps' Section 404 permitting of dredged and fill material, the NPDES program (Section 402) for point and nonpoint pollution sources, and the regulation of cooling water withdrawals and discharges (Sections 316 a & b). Monitoring of water quality, fish communities, and other related aquatic ecological components is routinely conducted by ORSANCO. Regulations applicable to wetlands and publicly-owned properties (e.g., federal and state wildlife refuges) also benefit fish habitat.

4.12.1 Describing the Affected Environment

Six indicators describing the essentials for diverse and ES fish communities in the mainstem were utilized in this CEA. They included: 1) composition of fish communities, including numbers of intolerant and nonnative species, abundance, and diversity; 2) amount of habitat with stable substrates, adequate depths, suitable currents, and sufficient food supplies; 3) reproductive viability as measured by amount of spawning habitat, genetic connectivity, numbers of gravid females, and larval individuals; 4) percent of the population with abnormalities such as parasites, tumors, ulcers, and fin erosion; 5) water quality measurements such as levels of DO, and pH; and 6) level of disturbance from biotic stressors, such as invasive species and from abiotic stressors, such as river traffic. The entire suite of indicators may be essential to adequately characterize and track Ohio River fish communities. In contrast to several other VECs, long-term data are available for several indicators of fish sustainability.

A total of 159 species of fish have been reported for the Ohio River main stem since the early 19th century. Reports prior to 1920 list 111 species; those from 1920-1969 list 121; and those from 1970-1988 list 140 species. Many human activities affected the river's environment before 1920, including clearing of forests and draining of wetlands leading to siltation, turbidity, and habitat loss. After about 1900, species tolerant of siltation and turbidity increased in numbers, including black bullhead, goldeye, skipjack herring, gizzard shad, and spotted bass. Before completion of the wicket dams in the early 20th century, large river species such as shovelnose sturgeon, paddlefish, muskellunge, and blue sucker had declined due to a variety of factors such as untreated municipal and industrial wastes, mine drainage, and unregulated modifications of aquatic and riparian zones. Rapid growth of human populations in the Ohio basin during the first half of the 20th century, led to larger inputs of domestic sewage, industrial effluents, and acid mine drainage. Historic

large river species continued to decline, and gizzard shad, emerald shiner, freshwater drum, and the introduced common carp became dominant. The fish fauna of the more populous, industrialized upper river became depauperate. Actions by ORSANCO and implementation of the CWA helped reverse these trends such that an upward trend in fish diversity in the upper Ohio has been documented in the last 20 years. Many species that disappeared from the upper river during the worst decades of pollution have returned to portions of the river approximating their historical ranges. Between 1984 and 1989, range extensions of mainstem fishes included 12 species in an upstream direction, 14 species in a downstream direction and six species both upstream and downstream. The availability, connectivity among, and access to complex habitat types that provide for spawning, nursery, feeding, and over-winter refugia is very dynamic.

The present system of high lift dams has altered aquatic habitats by converting the Ohio River from a free-flowing waterway to one of relatively constant width and a minimum maintained channel depth of 9 feet. The modern navigation system, combined with land use and flood control practices in the watershed, has resulted in the inundation and siltation of extensive areas of gravel substrate preferred by important fish species, particularly in the lower half of the river. High lift dams have also reduced connectivity of habitats and movements of riverine fishes. Concurrent with reductions in migratory species related to high-lift dams has been the creation of nearly 80 embayments in creek mouths adjacent to the mainstem in the upper half of the river. Such slow-moving waters offer important habitat for black basses and other sunfishes, species more typical of lake-like conditions. The importance of embayments has been documented, but many embayments in the lower river are not accessible to fishes when such habitat is most critical.

Eight historic Ohio River fish species not found since 1920 are the least brook lamprey, Alabama shad, hornyhead chub, Ozark minnow, and the mud, longhead, crystal, and gilt darters. Regarding Ohio River fishes listed under the federal Endangered Species Act, five species have been identified as species of special concern (SSC): the paddlefish (*Polyodon spathula*), blue sucker (*Cycleptus elongatus*), crystal darter (*Ammocrypta asprell*a), Eastern sand darter (*Ammocrypta pellucida*), and longhead darter *(Percina macrocephala*).

ORSANCO and other agencies have collaborated to develop an IBI specifically tailored to the distinctive ecological characteristics of the Ohio River. The resulting index, the ORFIn incorporates 13 attributes of Ohio River fish communities (see **Table 4-6** for additional details). ORFIn is sensitive to a wide range of habitat and water quality conditions and is being used to develop biological criteria for possible incorporation into ORSANCO's Pollution Control Standards. ORFIn scores, which range from 1 - 65 have been found to be lower at shallow sites with sand and fine substrates and higher at deeper sites with coarse substrates, clear water, and cooler temperatures, conditions favorable to gravel-spawning fish species typical of the preimpoundment Ohio River. Evaluation and refinement of ORFIn as a sustainability assessment tool will continue over the next several years.

Because of the conspicuousness, ecological, economic, and recreational importance of fish, many studies have been conducted to determine the effects of various human actions on fishes of the Ohio River. As discussed throughout this chapter, several studies

have considered the specific effects of navigation infrastructure (see Environmental Appendix, Volume 2), commercial transportation, and power generation (various published and unpublished literature sources). Some studies were specifically designed and conducted to address data gaps identified in the ORMSS scoping process. Key observations from these studies follow:

- A study on upstream fish passage at Ohio River dams was undertaken to examine the importance of longitudinal connectivity in sustaining the bioproduction and biodiversity of migratory fishes. The study related historical hydraulic conditions at the dams to swimming capabilities of 44 selected species to determine if dams are restricting upstream movements of fish. Targeted species were selected in consultation with the ORMSS IWG and through review of pertinent literature. The study findings suggest that upstream fish passage opportunities generally occur during open-river rather than controlled conditions at dams. An analysis of historical water elevation data at Ohio River mainstem dams revealed that the frequency of open river by calendar week (hence, the potential for fish passage) varied spatially along the river by dam and temporally with discharge. The general spatial pattern of open river indicated the potential for fish passage decreases from downstream to upstream as open river conditions are less likely and less frequent in the upper river compared to the lower river. Consequently, the potential for passage is low to high at dams in the Louisville District (Dam 53 through McAlpine – seven dams), low to moderate at Huntington District dams (Meldahl through Willow Island – six dams), and low at Pittsburgh District dams (Hannibal through Emsworth – six dams). In general, open-river conditions were more frequent during winter and spring and generally were nonexistent during summer and fall, coinciding with the low-flow period. The study suggests that because large river fish populations evolved under conditions less restrictive to longitudinal movement than presently exist, conditions created by mainstem dams probably affect the distribution, abundance, and productivity of migratory species by imposing limitations on life cycle completion and interactions among localized fish populations. The study recommends moving beyond species and site specific management towards more systemic considerations that could include both operational and structural measures to improve fish passage at mainstem dams on the river.

- Four additional studies undertaken for ORMSS related to fish movement and passage in the Ohio River and were conducted by the WVDNR in coordination with the ORFMT. These studies, which corroborate some findings of the upstream fish passage study, are briefly summarized below:

    1) The Fish Passage Direct Observations Study, conducted at Winfield L/D on the Kanawha River, showed that large river migratory fishes (e.g., white bass, skipjack herring, and sauger) were more common in tailwater areas than in the lock chambers, while species typical of more lentic (lakelike) conditions (e.g., channel catfish) were more common in the lock chambers. The findings support ORSANCO data indicating that fewer large river species are collected in traditional lock chamber surveys than expected based on their overall abundance in the river. Further, although flow attraction operations within lock chambers are part of lock chamber

sampling protocol, results of the direct observation study led to the reasoning that many migratory species are not attracted to flow conditions in lock chambers and, therefore, miss opportunities to pass through lock/dam complexes during typical navigational lockage operations.

2) The Fish Tagging and Recovery Study, conducted in nine tailwater areas along the Ohio River, supported the findings of the Fish Passage Direct Observations Study and indicated that migratory fishes' affinity for flowing waters inhibits them from gravitating to lock chambers. Instead, their interpool movement appears to be facilitated by more open river conditions, which occur more frequently at some L/Ds than at others.

3) The Recreational Fish Survey, conducted on more than 8,500 angler trips at eight tailwaters for at least a 12-month period covering all seasons, found that the number of anglers fishing for "any species" exceeded the number targeting a single species or group and totaled 33 percent of anglers on the river overall. Geographic differences also were observed in species sought; for example, percids were sought in more upstream tailwaters while catfish were sought more frequently in downstream tailwaters. Consumption advisories may explain that fewer fish were harvested (kept) by anglers in the more industrialized upper river than in the more rural lower river.

4) A Glochidial Infestation Study resulted in the collection of 31 fish species representing a wide range of behavioral and habitat guilds primarily from Ohio River tailwaters because of the potential presence of mussels in these more free-flowing sections of the river as well as the congregation of fish there. Of 536 fish examined for infestation with the mussel glochdial life stage, only four individuals were infested. Due to the low numbers of glochidia found, no conclusions could be made regarding fish hosts and interpool passage. A literature review for the study cited similar low infestation rates for fish from the Green River in Kentucky, a major tributary to the Ohio River.

- Studies on the effects of towboat operation on large rivers indicate that propellers of commercial towboats can cause abrupt changes in hydraulic patterns, including increased turbulence and water velocities with resulting injury or mortality of adult fish, eggs, and larval stages. Field investigations of these effects have been limited, in part because of the difficulty of sampling organisms in turbulent water behind large vessels. Two recent studies prepared for the Corps on the Upper Mississippi River-Illinois Waterway may be applicable to the Ohio mainstem. First, a study of larval shovelnose sturgeon, larval lake sturgeon, eggs and larvae of paddlefish, juvenile common carp, and larval blue sucker (all species recorded for the Ohio mainstem.) found that larval mortalities varied by size and species, with higher tolerances by larger individuals and by species adapted to higher velocity habitats. The study concluded that shear stress created by propellers can be a major source of larval fish mortality. Linear relationships between mortality and shear stress suggest that mortality can be predicted for different towboat configurations and extrapolated to approximate impacts of increased navigation traffic. The second study, conducted in Pool 26 of the Upper Mississippi and Alton Pool in the Illinois

River, concluded that with high annual tow traffic, even small entrainment mortality rates can yield high estimates of annual losses. Anecdotal evidence from Pool 26 also suggested that some fish are killed during acceleration of downbound tows as they exit locks.

- While ORMSS did not undertake a study on the effects of recreational boating on fish and habitat, a literature review by the North American Lake Management Society emphasizes that impacts of recreational boating on fish and other aquatic life are most pronounced in shallow waters and are compounded by the coinciding of peak boating activity with critical life stages of aquatic organisms during warmer months. Wave action by high-speed watercraft can disturb or destroy spawning nests, promote shoreline erosion, smother fish eggs and habitat, and lead to gill damage causing decreased growth rates and lower fish biomass overall. Most studies cited in the literature review focus on lakes and reservoirs and fish species that typically inhabit them. Because scant information exists on the effects of recreational boating on large rivers, it remains a topic ripe for additional research.

- A study of winter habitat used by fishes in the Ohio River, conducted during two winters in the Belleville and Smithland Pools, found that during both winters and in both pools, fish assemblages and abundances differed among the winter macrohabitats: In Smithland Pool, habitats adjacent to the main channel appeared to be important for fish during the winter, including island backwaters, submerged boulders at the channel border, and deep scours created by artificial structures. Tributary macrohabitats in Smithland Pool only appeared to provide important winter habitat when temperatures were low and when these areas were connected to the main channel. In Belleville Pool, tributaries and an embayment area appeared to play a critical role for wintering fishes, although such macrohabitats may cool more than the main channel during snow melt, necessitating movement of fish into warmer main channel areas. The unique opportunity to conduct parallel research projects in two Ohio River pools during the same winters provided several insights into the potential effects of increased navigation on fish assemblages: 1) Tributary habitats are clearly important to wintering fish; reduced connectivity of tributaries in Smithland Pool likely compromises the success of many species. 2) Artificial sites such as wing dikes in Smithland Pool create scours used by river fishes, although some concern about displacement by barges persists, requiring further exploration. 3) Island backwater areas appear particularly important for fishes during winter. In the Ohio mainstem, quantity and availability of winter refuge may well determine the relative survival and abundance of resident fish populations. Therefore, river habitat management that maintains or enhances accessibility to these areas should be beneficial to wintering fish in the Ohio River.

- Studies on the effects of cooling water intake structures on fish have been undertaken along the Ohio River since the 1970s in conformance with Section 316(b) of the Clean Water Act. In accordance with new and proposed regulations related to §316(b), USEPA recently evaluated entrainment and impingement rates at nine power plants on the Ohio mainstem between RM 53.9 and 560. The main fish species the study found to be at risk were emerald shiner, freshwater drum, gizzard shad, sauger, white bass, white crappie, and white sucker. Several of these species have floating (pelagic) eggs or larvae that make them more vulnerable to damage

from water intakes. Further §316(b) studies at several power plants along the Ohio River are anticipated as additional phases of the revised 316(b) program are implemented by USEPA in the coming years.

Finally, relative to describing the affected environment, the Navigation Predictive Analysis Technique (NAVPAT) model is a tool developed by the Corps – Louisville District to evaluate river traffic-induced impacts on habitat for fish and other aquatic life (see Environmental Appendix, Volume 2, NAVPAT Report). In general, NAVPAT links tow movements to possible biological effects. The NAVPAT model considers 15 life-stages of fishes selected to represent guilds of all major habitats and life stages in a river system. Although refinements to NAVPAT continue, the model has been used to evaluate environmental effects near Olmstead L/D and McAlpine L/D.

4.12.2 Assessing the Cumulative Effects of Past, Present, and Future Actions

Multiple past and present actions have affected the fish of the mainstem, and multiple future actions also are anticipated to contribute to the overall CE on the fish VEC. The systematic evaluation of 87 types of RFFAs indicated that 32 were ranked as having "high importance" for fish relative to CE, and 28 were designated as having "medium importance." One RFFA was ranked as both high and medium. The importance rankings for the actions reflect the composite consideration of the future time period of occurrence, likelihood of occurrence, potential for multiple locations along the river, the spatial and temporal extent of the anticipated effects, the level of knowledge about the effects, the relative contribution to the CE, and the possibilities for cost-effectively mitigating the negative consequences. The fact that 60 of the 87 RFFAs were ranked as having high or medium importance reflects several values, including the biological, economic, and recreational importance of fish.

The 60 ranked RFFAs have been divided into five categories based on their "common primary effects;" that is, actions contributing to habitat changes, actions causing changes in disturbance regimes, actions causing changes in hydrological patterns, actions affecting ecological services, and actions related to population changes. (It should be noted that some actions could have been listed for more than one category; however, the assignment was based on their "primary effects.") The first category includes actions that physically alter fish habitat, including changing its structural complexity, overall patterns, and connectivity. Many actions are listed in this category, including channel maintenance dredging, in-stream sand and gravel mining, construction of lock chamber extensions, barge queuing or barge fleeting and storage, periodic upkeep and maintenance of lock and dam facilities, major lock or dam rehabilitation projects, port development and maintenance, development of new terminals and multimodal sites, recreational boat marinas and launch ramps, industrial discharges, coal utilities and other coal-related industries, all types of floodplain development, the Phase 1 and 2 NPDES program, riverbed crossings, and Corps permitting programs. Examples of how these actions affect habitats were described earlier.

Actions that cause changes in disturbance regimes include altering conditions to which fish species and ecosystems have adapted over a long period of time. Examples of such actions include floods, droughts, severe storms and earthquakes; dry dams and other

off-mainstem flood control projects; and channel modifications designed to reduce flooding. Descriptions of how these actions indirectly affect habitat and instability were described earlier.

Actions that cause changes to hydrologic patterns are closely linked to changes in disturbance regimes and habitat and include alterations to water connections that influence biodiversity and ecological integrity. Examples of such actions include bridge construction, levees, ER projects, brownfields redevelopment, remediation of contaminated sites, and the Phase 1 and 2 NPDES programs. Again, descriptions of how these actions change hydrologic patterns were described earlier.

Actions affecting ecological services have impacts on nutrient cycling and purification services that break down toxins and transform soils and sediments. Although most of these actions occur in the floodplain, an exception is channel dredging, considered an action of high importance. Other examples of actions affecting ecological services are construction, repair, and maintenance of navigation structures; bridge construction, marina development and operation; all types of floodplain development, agriculture, and control of agricultural discharges; carbon sequestration, more stringent environmental standards; pollutant source control; ORSANCO's monitoring program; and spill response activities.

The last category, actions contributing to population changes, includes actions that inhibit or prevent normal reproduction or cause isolation of fish communities. Such actions with negative effects manifest themselves in the loss of species, populations, or genetic diversity. Examples in this category include operation and maintenance of locks and dams, lock extensions/rehabilitation, dam replacement/rehabilitation, barge queuing, dispersed barge traffic, increased barge traffic, in-stream sand and gravel dredging, operation of coal utilities, bridge construction, marina development and operation, nonstructural navigation improvements, and ORSANCO's monitoring program.

ES has been used as the "ultimate test" whereby the significance of CE from multiple past, present, and future actions on fish can be qualitatively evaluated. The analysis of ES (AES) involved "connecting" the five common effects from the 60 high and medium importance RFFAs to the six indicators of ES used to describe the historical situation, trends, and current conditions of the fish VEC. For purposes of this analysis, the indicators were divided into two tiers and re-grouped. The first tier included "basic measures related to fish resources" and encompassed the percent of population with abnormalities such as parasites, tumors, ulcers, and fin erosion; water quality measures such as levels of DO and pH; and level of disturbance from biotic stressors, such as invasive species and from abiotic stressors, such as river traffic. The second tier, called "composite indicators of fish resources sustainability," encompasses the three additional indicators: amount of habitat with stable substrates, adequate depths, suitable currents, and suitable food supplies; reproductive viability as measured by amount of spawning habitat, genetic connectivity, numbers of gravid females and larval individuals; and composition of fish communities, including numbers of intolerant and non-native species, abundance, and diversity. The qualitative discussion of the connections was based on available quantitative data, fundamental scientific information, and professional judgment.

After the connections were discussed, the conditions for the composite indicators were evaluated based on three categories of ES defined as follows:

- Not sustainable – the composite conditions for the selected indicators of ES for fish do not reflect conditions that would sustain diverse, healthy populations of fish in the Ohio River.

- Marginally sustainable – the composite conditions for the selected indicators of ES for fish are such that diverse populations of fish are occurring along some segments of the river; however, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of fish for the Ohio River).

- Sustainable – the composite conditions for the selected indicators of ES for fish are such that diverse, healthy populations of fish are occurring along the majority of the river; further, the conditions of the indicators exceed regulatory thresholds or other pertinent measures.

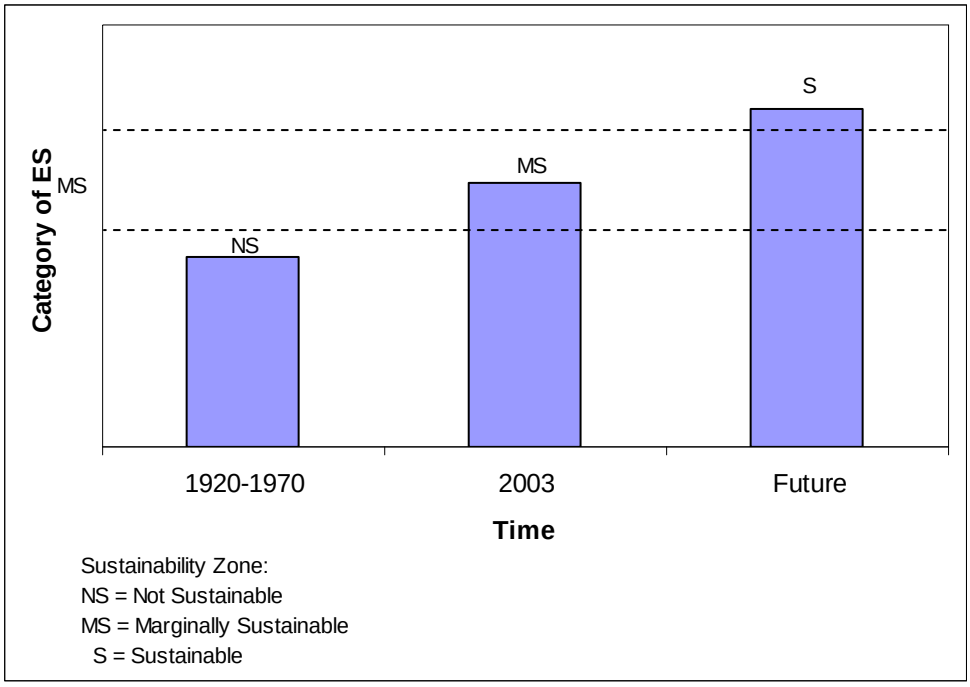
Based upon the above-described affected environment conditions, the consideration of multiple actions and their effects, the discussion of the connections with the two tiers of indicators, and the ES categories, the ES of the fish VEC of the mainstem of the Ohio River can be characterized and depicted in **Figure 4-2** as follows:

- In the time period prior to1920 and continuing well into the mid-20th century, fish communities became degraded, as reflected in the decline of many native river species and the increase in pollution tolerant species. This decline was particularly pronounced in the upper and middle river, where human populations grew rapidly during the first half of the 20th century, leading to increased inputs of domestic sewage, industrial effluent and acid mine drainage (especially in the upper river). Numerous other actions contributed to the degradation of fish communities, including, but not limited to, land clearing and sedimentation beginning in the 19th century, impoundment of the river by navigation dams that disrupted migrations of several important river fishes, in-stream sand and gravel dredging, development of new ports, terminals and marinas, the introduction of the common carp, and increasing quantities of stormwater runoff from urbanizing areas. Because these actions contributed to habitat loss, changes in species composition and abundances, and serious declines in necessary water quality conditions, the ES for this period is classified as "not sustainable." Further, until 1948, when a limited precursor of the Clean Water Act was passed and the ORSANCO interstate compact was signed, environmental and resource protection laws were limited. Accordingly, as a result of scientific data indicating changes in fish communities of the mainstem, as well as the recognition of multiple actions and factors causing such changes, it was concluded that the composite conditions for the selected indicators of ES for fish communities did not reflect conditions that would sustain diverse, healthy fish populations throughout the river.

- In the time period from the mid- 20th century until the present time, improvements in sustainability of the fish resource have been observed throughout the mainstem. Such improvements have resulted primarily from initiatives by ORSANCO, efforts of the six Ohio River states, and the requirements of the FWPCA and the amended

CWA. As municipal wastewater and industrial effluents to the river have decreased and other pollution control measures have increased pH and oxygen while reducing toxins, fish communities of the Ohio River have shown steady improvement, marked by the recovery of many native species. The common carp, while still significant in biomass and numbers, is no longer as dominant as in the past. Concurrent with improvements in water quality, however, has been the continued inundation of fish habitat not only from navigation structures constructed before 1950, but also from continuing construction and operation of additional high-lift dams (including Olmstead L/D at RM 964.6). The modern navigation system, combined with land use and flood control practices in the watershed, has caused the inundation and siltation of extensive areas with gravel substrate, preferred by many migratory fishes, especially in the lower river. Various studies on human impacts on Ohio River fishes, including studies on winter habitat and fish passage, underscore the need for additional research and development of resource management practices to gain a more comprehensive understanding of ES of the mainstem fish. Accordingly, the ES of the fish resource up to the present time is classified as "marginally sustainable." Two major uncertainties emerged during the last decade that may affect the fish resource into the future: first, the invasion of Asian carps upstream from the Mississippi River causing competition for feeding niches of native fishes and, second, the invasion and unknown population dynamics of zebra mussels, which seriously impact native mussels, an important food resource for many fish species.

FIGURE 4-2
ES of Fish Communities



- Regarding the long-term future, this study has identified 60 types of RFFAs ranked as having high or medium importance relative to CEs. These RFFAs include actions that change habitat, change disturbance regimes, change hydrological patterns, affect ecological services, and are related to population changes. During

recent decades, regulatory requirements and pollution control programs have been implemented that will benefit the fish resource, if continued into the future. Additional tools and studies that also should increase understanding of the ES of fish in the Ohio River mainstem include the NAVPAT habitat assessment model, the new ORFIn, and supplemental fish studies in accordance with proposed regulations related to §316(a & b) of the CWA. It is also expected that the ORFMT and USFWS Ohio River Valley Environmental Team will continue to be involved in fish resource monitoring and management. Given recent improvements in the resource, the development of new assessment tools, and the level of stakeholder interest, it is expected that fish communities of the Ohio River mainstem will attain a "sustainable" condition and may further improve with long-term elimination of combined sewer overflows (CSOs) and better control of nonpoint pollution, including regulation of stormwater runoff. The habitat effects of impoundment of the river are expected to persist into the future. However, adaptive management of the resource may produce measures that counteract such effects by benefiting habitat and enhancing interpool connectivity. An eminent concern is the invasion of Asian carps species moving upriver; however, effects on native fishes have yet to be demonstrated or quantified. Vigilance by ORSANCO and other resource agencies will be required to assess populations while potential measures to control these species are evaluated for the Ohio and other major river systems in the U.S.

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Chapter 5
MUSSELS

5.1 TABLE OF CONTENTS

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5.2 IMPORTANCE OF MUSSELS AS CUMULATIVE EFFECTS INDICATORS

Freshwater mussels or bivalves are valuable as indicators of environmental health, as a commercial resource in the cultured pearl industry, and as a major component of worldwide freshwater biodiversity (Williams et al. 1993). Mussels are the river's natural filter system, and they play an important role in the breakdown/compartmentalization of organic matter as well as provide habitat for other invertebrates. They also help stabilize the river substrate. Historically, one of the most diverse assemblages of freshwater mussels in the United States occurred in the Ohio River mainstem, with upwards of 80 species reported for the free-flowing river (USFWS 2000). Some positive trends towards mussel recolonization in the upper Ohio River have been observed since implementation of the Clean Water Act (CWA) in the 1970s, although the return of obligate big river riffle species has been less successful. There are currently at least 54 species (Ecological Specialists, Inc. 2000) of native freshwater mussels in the Ohio River. Tributaries with

viable mussel populations also have been important to recolonization and sustainment of the Ohio River mussel resource.

Unfortunately, in spite of such recent encouraging trends, freshwater mussels, in general, in the Ohio River mainstem have drastically declined in recent decades due to compounding factors, including habitat modification and destruction, as well as increasing competition from nonindigenous species, especially the zebra mussel. At least three species are extinct and many more have been extirpated (USFWS 2001). Today five native mussel species still occurring in the Ohio River mainstem are listed as federally endangered. The decline in both populations and species diversity of freshwater mussels of the Ohio River is likely occurring in other freshwater mollusks and aquatic organisms (Williams and Neves, not dated) and is underscoring the need for conservation and restoration on the ecosystem and watershed levels.

Freshwater mussels feed on organic particles, algae, and minute plants and animals, which they siphon out of the water. Because of their limited mobility, adult mussels are subject to a variety of environmental factors that can restrict their distribution and reproductive success. Both mussels' limited mobility and relatively long life spans make mussel populations good environmental indicators. This chapter considers how cumulative effects of human use of the Ohio River have influenced mussels inhabiting the river, what impacts to mussels may be anticipated in the foreseeable future, and what measures could be undertaken to mitigate potentially adverse impacts to this historically important, declining resource.

5.3 OBJECTIVES AND SCOPE OF THE MUSSEL STUDY

5.3.1 Objectives

This chapter assesses the system-wide cumulative impacts (including effects of mussels of all likely major navigation improvements) along the mainstem of the Ohio River during the planning period from 2000 to 2070. Impacts on mussels directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFAs) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFAs. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, non-governmental entities, and predictions of general economic expansion and development as well as regulatory changes.

The results of the Cumulative Effects Assessment (CEA) are intended to contribute to further discussion of:

1) the significance of the impacts of the RFFAs on the affected resources
2) the degree to which the proposed navigation improvements contribute to those outcomes, and
3) what constitutes sustainable conditions for freshwater mussels of the Ohio River mainstem

5.3.2 Geographic Scope

The geographic focus for mussel impacts includes the Ohio River mainstem, which is most directly impacted by operation and maintenance of the navigation system, and also includes lands along either bank of the Ohio River lying "between the bluffs." This "floodplain zone" is defined as the meander channel of the Ohio River and includes the 100 and 500 year floodplains as well as terraces of level land lying above these flood zones. Floodplain lands are considered in this assessment because mussel populations are affected by siltation and contaminants associated with construction, industry, agriculture, mining, and other land-based activities.

5.3.3 Time Frame

The established time frame for this project is 1920 to 2070. The earlier date approximates the initiation of the Corps' lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the Ohio River Mainstem Systems Study (ORMSS). Discussion of impacts on mussels requires some consideration of the condition of mussel populations prior to 1920. Freshwater mussels in the Ohio River had begun to decline as long ago as the late 1800s. Understanding factors that contributed to this decline over more than 100 years is important to discussion of how the lock and dam construction, operation, and maintenance activities contributed to subsequent changes in mussel populations.

5.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during the summer of 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or e-mail. A more detailed discussion of the scoping meetings is presented in Exhibits A and B of this report.

The meetings were attended by 185 persons and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Comments that directly or indirectly addressed mussels are presented in **Table 5-1**.

TABLE 5-1
Comments from Public Scoping Meetings

Direct Comments on Mussels	Relevance to Mussels	Total
Importance of including commercial dredging and associated permitting process in CEA	Elimination of mussels and habitat	2
Failure of barges to stay in designated shipping lanes	Potential damage to mussel beds by barge groundings	2
Increased spills and accidents potentially affecting aquatic life and impairing water quality	Potential loss of mussels and habitat	1

Direct Comments on Mussels	Relevance to Mussels	Total
Need to improve sediment and erosion control from public and private developments	Sediment blanketing of mussels and habitat	1
Need for long-term plan to address silt removal and prevent future sedimentation	Sediment blanketing of mussels and habitat	1
Damage/destruction of mussel beds and fish spawning areas	Reduction in mussel resources	4
Habitat damage caused by Corps permitted commercial sand and gravel dredging	Potential loss of mussels and habitat	1
Loss of unique sensitive species due to water quality problems and habitat modifications	Reduction in mussel resources	2
Need for Corps to coordinate with USFWS on threatened and endangered species issues	Preservation of sensitive mussel species	1
Effects related to 3 crayfish species, 2 fish species and 7 freshwater mussel species in IL	Preservation of sensitive mussel species	2
Need to prevent distribution of exotic/invasive plants and animals through USACE actions	Prevention of mussel reduction/elimination by exotic species, e.g., zebra mussels	1
Other Comments with Implications for Mussels	**Relevance to Mussels**	**Total**
Need for ongoing coordination and cooperation with concerned agencies and groups	Preservation of healthy freshwater mussel fauna	3
Need to consider Clean Water Act (CWA) Section 404 application approvals and resultant actions as direct USACE actions	Preservation of healthy freshwater mussel fauna	1
Importance of coordination of resources agencies in determining baseline conditions	Need to assess current mussel populations	2
Effects of Greenup L/D improvements on barge queuing	Potential reduction of damage to mussel beds	1
Cumulative effects of discharges to river may offset water quality improvements	Failure to attain water quality improvements to benefit mussel populations	4
Challenge to water quality presented by Combined Sewer Overflows (CSOs) and Sanitary Sewer Overflows (SSOs)	Failure to attain water quality improvements to benefit mussel populations	2
High levels of mercury, arsenic, fecal coliform bacteria and agri-chemicals in surface water	Failure to attain water quality improvements to benefit mussel populations	1
Need for more stringent discharge permitting procedures or moratorium on permits	Need for WQ improvements to benefit mussels	2
Possibility of implementing mechanical aeration in mainstem pools	Need for sufficient oxygen levels for mussels	1
Importance of continued water quality improvements as a high priority	Need for WQ improvements to benefit mussels	1
Mouths of tributaries silted in, impairing fish habitat, limiting access and damaging property	Elimination of habitat for mussels and their fish hosts	5
Impaired water quality and bioaccumulation in fish tissue of harmful substances stirred up by dredging	Uptake of toxic substances by mussels	2
Potential partnering with private enterprise to remove marketable aggregates when dredging	Continued elimination of mussels and habitat	1
Possible use of dredge spoils to improve riparian or island habitat or for upland filling	Potential creation of mussel habitat	2
Bank undercutting & failure caused by increased barge traffic, queuing and wave action	Sediment blanketing of mussels and habitat	7
Bank erosion caused by USACE-controlled pool fluctuations	Sediment blanketing of mussels and habitat	3
Development of floodplains and wetlands resulting in increased runoff and habitat loss	Failure to attain water quality improvements to benefit mussel populations	4

5.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

Indicators of Environmental Sustainability (ES), which vary by VEC, generally provide benchmarks for measuring CE on a given resource or VEC. The primary uses of indicators are to characterize the current status of a resource and to track or predict significant changes to the resource. It is desirable to select indicators that can be supported by data that are relatively straightforward to collect. Further, if an indicator is to be accepted and used to guide policy, the data upon which indicators are based must be available to a wide range of interested parties (CGER 2000).

ES indicators selected for mussels encompass the essentials for diverse communities of mussels to thrive and reproduce in the Ohio River. Key indicators, therefore, include:

- amount of habitat with stable substrates, suitable depths, currents, and connectivity to other mussel populations
- measures of water quality parameters important to mussel populations
- extent of food supplies to help ensure good growth rates and reproduction
- availability of fish hosts to ensure reproductive success and maintain species diversity
- extent of disturbance from biotic stressors, such as invasive zebra mussels and from abiotic stressors, such as river traffic.

The entire suite of indicators may be essential to adequately characterize and track freshwater mussels. Watters (1999) and others indicate that the basic biology of mussels is much more complex than previously known. Consequently, there is rarely a single causative agent for mussel decline.

Shifts in mussel abundance and community composition are measurable using community-level summary statistics such as diversity indices and species richness. Quantitative mussel surveys, including invasive species and distribution studies of endangered species, are also useful assessment methods.

The severe decline of native Ohio River mussels documented in the last decades of the 20th century coupled with the more recent invasion of zebra mussels has focused considerable research on freshwater mussels. Information to assess the selected indicators of mussels includes data from the Corps and from studies conducted by USFWS and ORSANCO.

5.6 LAWS, REGULATIONS, ORDINANCES, AND PROGRAMS

Several regulatory actions and related initiatives influence mussel populations in the study area. **Table 5-2** presents information on important regulations and established programs, which directly or indirectly influence mussels in the Ohio River.

TABLE 5-2
Laws, Regulations, Ordinances, And Programs Relevant to Mussels

Law/Program (Lead Agency)	Key Components	Relevance to Mussels
Clean Water Act (US Environmental Protection Agency)	• Section 402 establishes National Pollution Discharge Elimination System (NPDES) for regulating pollution discharges into U.S. waters • Gives EPA authority to implement pollution control programs • Requires establishment of water quality standards • Recognizes need to address nonpoint source pollution	Protects mussels within general context of water quality improvements
Endangered Species Act (US Fish & Wildlife Service)	• Provides various means of protection for endangered and threatened species and their critical habitats • Provides process for designation of such species and their habitats • Encourages development of related state programs	Has enabled endangered species designation for five Ohio River mussel species and addition of other species to candidate list. State endangered species status further supports protection of these endangered Ohio River mussels.
Fish and Wildlife Coordination Act (US Fish & Wildlife Service)	• Requires that whenever water bodies are modified by a federal agency, that agency first shall consult with the USFWS and with appropriate state agencies with a view toward wildlife conservation	Provides for equal consideration and coordination of mussel conservation with other aspects of water resources development
COE Permitting Statutes (US Army Corps of Engineers)	• Section 10 of Rivers and Harbors Act (1899) prohibits the unauthorized obstruction or alteration of any navigable water of the United States. • Section 404 of Clean Water Act authorizes the Corps to issue permits for the discharge of dredged and fill materials into U.S. waters.	Permits require assessment of impacts on water quality, mussels, and other aquatic resources and mandate mitigation of adverse impacts
State Water Quality Certification (Appropriate state or interstate pollution control agencies.)	Section 401 of Clean Water Act requires certification from state or interstate water control agencies that a project is in compliance with established effluent limits and water quality standards.	Provides opportunity for state or interstate scrutiny of impacts of such actions on mussels
Small Navigation Projects (US Army Corps of Engineers)	Section 107 of Rivers and Harbors Act (1960) authorizes COE to develop and construct small navigation projects for harbor protection	Provides opportunity for COE scrutiny of impacts of such actions on mussels
Site Remediation Statutes (US Environmental Protection Agency)	Includes CERCLA, RCRA, SARA and related state programs that focus on cleanup and restoration of contaminated sites	Potentially reduces soil and groundwater pollution sources which may adversely impact

Law/Program (Lead Agency)	Key Components	Relevance to Mussels
		mussels in the Ohio River
TMDL Program (US Environmental Protection Agency with ORSANCO)	Section 303 of Clean Water Act regulates the maximum load of a pollutant a water body can receive and still attain water quality standards	Presents a more holistic option to water quality management that may be more beneficial to mussels than traditional "command and control" approaches
Phase 1 & 2 NPDES Program (US Environmental Protection Agency)	Requires municipalities and certain industrial and construction sites to adopt BMPs to control nonpoint sources of pollution	Should reduce pollution characteristics of stormwater discharges from urban and industrial zones that may adversely affect mussels in the Ohio River
Spill Response (US Coast Guard, ORSANCO)	Includes emergency response activities for river-related spills and accidental discharges and is related to the Oil Pollution Act and Section 301 of the Clean Water Act	Minimizes adverse impacts of spills and discharges on mussels and other aquatic life and water quality
ORSANCO Monitoring (ORSANCO)	Encompasses ongoing water quality and aquatic ecology monitoring programs by the Ohio River Valley Water Sanitation Commission	Helps track changes in biological communities of relevance to mussels and provides database for environmental decision-making
Kentucky Mussel Refuges Act (KY Dept. of Fish & Wildlife Resources)	Establishes sanctuaries near KY islands within Ohio River Islands National Wildlife Refuge	Prohibits commercial mussel harvesting and collecting from these refuges

5.7 LIFE HISTORY OF FRESHWATER MUSSELS

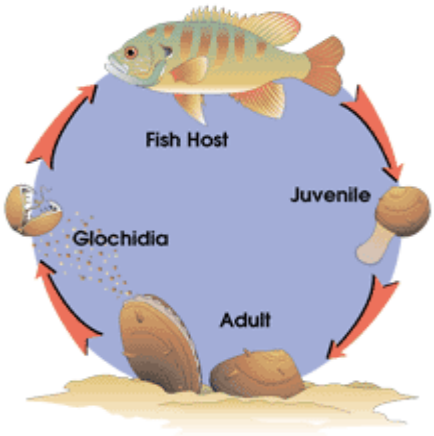
Important conditions must be met during each stage of the life history of mussels in order to sustain mussel populations in the Ohio River mainstem. Gametogenesis is stimulated by changes in water temperature. For fertilization to occur during the spawning season, sperm released by mature males must pass into the incurrent apertures of sexually mature females of the same species; therefore, a threshold density is required for reproductive success. After an egg is fertilized, it is transferred into the female's gill chamber where it undergoes metamorphosis from an embryo into the larval form known as the glochidium. Mature glochidia may be released after a few weeks or held in the brood chamber for months, depending upon the species. Bradytictic or long-term breeders hold

larvae until the following spring or summer. Tachytictic or short-term breeders release larvae later the same year, usually by July or August (Watters 1994).

The glochidia of almost all freshwater mussels are obligate parasites of fish and, consequently, must attach within 24 to 48 hours to the gills or fins of a suitable fish species to undergo another metamorphosis into free-living mussels. Fish may become infested with glochidia by coming into contact with them in the water column, on the substrate, or by attempting to ingest them, depending on the mussel species and where glochidia are released in the water column. Females of several mussel species mimic prey fish or insects to lure fish hosts before they release their glochidia. Other mussel species secrete a gelatinous matrix around the mature glochidia before they are released.

Once the glochidia have successfully attached to the fish host, they remain attached for a period of time that varies by species. While attached, the glochidia metamorphose into juvenile mussels, developing a true heart, gills, digestive tract, and muscular foot. When metamorphosis is complete, the juvenile mussel drops from the host and burrows into the substrate or attaches to a larger object by a byssal thread, secreted by a gland and later lost in adults. The buried juvenile stage may last for several years, according to several studies cited by Watters et al. 2003).

FIGURE 5-1
Life Cycle of the Freshwater Mussel



SOURCE : North Carolina Mussel Atlas http://www.ncwildlife.org.

An appropriate fish species must be present at the right time and place to serve as a mussel host. Some species, usually widespread and abundant, are able to parasitize many species of ecologically and phylogenetically interrelated fishes, including exotics. Other mussel species, usually localized and rare, rely on only a few fish hosts. Plans to conserve and manage rare and endangered mussels require specific knowledge of host-mussel associations. Hosts have been identified for most endangered mussel species in the Ohio River except for the orange-footed pimpleback (Watters, et al. 2003).

The extent to which navigation dams act as barriers to interpool movement of fish hosts is important in assessing cumulative effects on the Ohio River mussel resource. The

greatest factor affecting mussels in the mainstem Ohio River is habitat alteration resulting from impoundment by the high lift dams. Maintenance of the navigation pools creates year round slackwater habitat which has had and continues to have the most significant adverse affect on mussel resources. Much of the impounded habitat is no longer suitable for a diverse and healthy mussel community, nor will it become suitable in the foreseeable future. Watters (1999) indicates that inaccessibility of fish hosts to their respective glochidial parasites may cause otherwise healthy mussel populations to grow old and die without recruitment of enough juveniles to sustain these populations. Connectivity among mussel populations also is essential to maintain genetic diversity.

5.8 PAST TO CURRENT BASELINE CONDITIONS

5.8.1 Native Mussels

As long ago as the late 1800s, freshwater mussels had begun to decline in the Ohio River, primarily from direct habitat disturbances, as well as indirect effects of siltation, pollution, and contaminants associated with construction, industry, and agriculture (Taylor 1989). Harvesting of freshwater mussels for button manufacture began in the Ohio River in the 19th century and continued through the mid-20th century until the advent of plastic buttons which were less expensive and more easily manufactured. Mussel harvesting along the river, however, continued beyond the 1950s in response to the cultured pearl industry's demand for small mussel pellets to stimulate pearl growth. As late as the 1980s, 22 active commercial mussel harvesters were operating on the Ohio and Tennessee Rivers (Williams and Schuster 1989).

Because of limited mobility, mussels are subject to a variety of environmental factors that can restrict their distribution and reproductive success. Payne and Miller (1999) found that long-term stability of Ohio River mussel beds depends on clay, silt and sand deposited during seasonal low flows being removed by high flows without eroding underlying gravel and cobble. Changes in current velocity and direction associated with high-lift dams have had impacts on mussel beds. Deposition of silt as current velocity diminishes upstream of dams seems to particularly affect younger mussels, which are small enough to sink below the silt and suffocate. When lower level dams were in place, in many areas, the current followed the shoreline, washing mussel beds free of silt and mud. With the completion of high-lift dams, current positions changed, allowing greater deposition of silt (Williams and Schuster 1989).

Dams isolate upstream mussel populations from downstream ones and affect the distribution of fish hosts while also flooding habitat of many species typical of larger rivers. Numerous studies cited by Watters (1999) have shown that, almost without exception, rivers that have been impounded have lost or had changes in their mussel fauna. Mussels, in general, are most abundant in shallow water; relatively few species can tolerate impoundment depths. Inundated floodplains and tributary embayments created by impoundments typically have shallow mud or sand-mud substrates that support mussel species adapted to soft substrates instead of species better adapted to big river riffle habitat with coarser substrates. In recent decades, competition from the nonnative zebra mussel (*Dreissena polymorpha*) has further contributed to reductions in native Ohio River mussels. (See "Zebra Mussels and Other Invasive Species" below.)

Several federally-listed threatened or endangered species of freshwater mussels have not been recently found and are considered to be extirpated from the Ohio River mainstem. These include the white wartyback, cracking pearlymussel, rough pigtoe, winged mapleleaf, northern riffleshell, and catspaw. The ring pink may be present but no live specimens have been collected in recent years. The tuberculed-blossom pearlymussel once occurred in the Ohio River, but may be extinct. Also, although historical records indicate the dromedary pearlymussel once occurred in the Ohio River, definitive data are not available (USFWS 2000).

The five federally listed endangered native mussel species currently known to exist in the Ohio River mainstem are the fanshell, pink mucket, orangefoot pimpleback, clubshell, and fat pocketbook (see **Table 5-3** for scientific names and further information). Among the reasons for their decline listed in USFWS Recovery Plans are:

- Impoundment
- Channelization
- Habitat alterations (e.g., from channel maintenance dredging and sand and gravel mining)
- Nonpoint source pollution (e.g., agricultural and stormwater runoff)
- Point source pollution (e.g., from industrial sites and wastewater treatment plants) and
- Competition and damage from zebra mussels

Three additional historic Ohio River mussels are listed by the USFWS as candidate species – the sheepnose mussel (*Plethobasus cyphus*) found as recently as 1994 in the Newburgh and Markland pools, the spectaclecase (*Cumberlandia monodonta*) which may be extirpated from the Ohio River, and the rayed bean (*Villosa fabalis*). Candidate species are organisms for which the USFWS has sufficient information on their biological status and threats to propose them as endangered or threatened under the Endangered Species Act (http://endangerd.fws.gov/candidates/).

TABLE 5-3
Endangered Mussel Species Inhabiting the Ohio River

Scientific Name (Year listed as federally endangered)	Common Name	Preferred Habitat	Reproduction/ Fish Hosts Occurring in the Ohio River	OR States in which Species is Listed*
Cyprogenia stegaria (1990)	Fanshell	Gravel substrate in medium to large rivers	Breeding period unknown Hosts: greenside darter, banded darter, logperch	OH, WV, KY, IN, IL Once widely distributed
Lampsilis abrupta (1985)	Pink mucket pearly mussel	Medium to large rivers with fast-flowing water and depths of 0.5 to 0.8 m Various substrates including silt to boulders, rubble,	Spawns from August to September and releases glochidia the following year from May to July Hosts: smallmouth, largemouth and spotted basses,	WV, KY, IN, IL Once widely distributed, but always considered uncommon

Scientific Name (Year listed as federally endangered)	Common Name	Preferred Habitat	Reproduction/ Fish Hosts Occurring in the Ohio River	OR States in which Species is Listed*
		gravel and sand	walleye	or rare
Plethobasus cooperianus (1984)	Orangefoot (pimple back) pearly mussel	Medium to large rivers with fast-flowing water at depths of 12-29 ft. Only edge of shell & feed-ing siphons are exposed Clean silt-free rubble, sand or gravel	Requires stable, undisturbed habitat for reproduction. Adult may live up to 50 years.	KY, IN,IL
Pleurobema clava (1993)	Clubshell	Clean, coarse sand and gravel in runs often downstream of riffles; cannot tolerate slackwater conditions, burrows beneath substrate, very susceptible to siltation	Females gravid from May to July; glochidia released same year. Hosts: Unknown, possibly small minnow and darters	OH, WV, KY, IN, IL Once widespread and common; range reduced by 95%
Potamilus capax (1976)	Fat pocketbook	Large rivers with fast-flowing water and stable substrates Most likely prefers habitat of silt, sand and clay	Females reported gravid in June, July, August & October Glochidia released next spring or summer Only known host: freshwater drum	KY, IN, IL

* In addition to federal listing, these states along the Ohio River list the species as endangered.
SOURCES: USFWS (2000); individual USFWS Recovery Plans (listed in chapter references), http://midwest.fws.gov; and http://www. conservation.state.mo.us/documents/nathis/endangered/mucket.pdf

There are no recent records of live specimens of any federally-listed threatened or endangered species in the Ohio River mainstem upstream of Willow Island Dam, although Watters (2003) suggests the fanshell probably occurs in Dashields pool. Records of endangered mussels from Willow Island Pool downstream (including subfossil shells) are in **Table 5-4** below.

The Ohio State University Ohio River Mussel Database was queried to cross-reference pools where both endangered mussels and their fish hosts occurred. The coinciding data for the fanshell and pink mucket pearlymussel are presented in **Tables 5-5 and 5-6**. Also, the freshwater drum, a fish host for the fat pocketbook, has recently coincided with the presence of the fat pocketbook in the Myers and Olmsted Pools. The Mussel Database included no recent fish host/mussel coinciding pool data for the orange-foot pimpleback or clubshell. Four Ohio River fishes, however, have been recorded as hosts for clubshell glochidia – the central stoneroller, striped shiner, logperch, and blackside darter (Watters, et al. 2003).

TABLE 5-4
Records of Endangered Mussels in the Ohio River by Pool

	Cyprogenia stegaria (Fanshell)	*Lampsilis abrupta (Pink mucket)*	*Plethobasus cooperianus (Orange-foot pimpleback)*	*Pleurobema clava (Clubshell)*	*Potamilus capax (Fat pocketbook)*
Ohio River Pool					
Willow Island				SF[1]	
Belleville	1997[2] 1[3]	1991 1			
Racine	1998 4	SF	SF	SF	
Byrd		1993 1			
Greenup		1995 5			
Meldahl	1929	1914			
Markland	1997	1846		1846	
McAlpine				SF	
Cannelton	2000			1994	
Newburgh					
Myers					Since 1980
Smithland				SF	1994
Olmsted (including L/D 52 & 53)			2002		1991

[1]SF = sub-fossil shell
[2]Most recent year for sample reported in "good condition" (live or fresh dead).
[3]Total live organisms found in all samples, Meldahl Pool and above, 1969-1999.

SOURCES: Clarke (1995), ESI (2000), Payne and Miller (2002) and Watters (2003)

Table 5-5
Known Fish Hosts of the Fanshell (*Cyptogenia stegaria*) by Ohio River Pool

	Greenside darter	**Banded darter**	**Logperch**	**Blackside darter**	**Central stoneroller**
Ohio River Pool					
Belleville	1997*	1993	2000		
Racine	2001	2001	2001		
Meldahl	2001	1992	2001		
Markland	2000	2000	2001		
McAlpine			2001		
Cannelton			2001		
Smithland			2001	1969	1997

*All dates indicate most recent record.
SOURCE: Master Ohio River Mussel Database, Ohio State University (Watters 2003).

Table 5- 6
Known Fish Hosts of Pink Mucket Pearlymussel (*Lampsilis abrupta*) by Ohio River Pool

	Smallmouth bass	Spotted bass	Largemouth bass	Walleye
Ohio River Pool				
Belleville	2001	2001	2000	2000
Racine	2001	2001	2001	1999
Byrd	2001	1995	1995	2001
Greenup	2001	2001	1999	1999
Meldahl	2001	2001	2001	2001
Markland	2001	2001	2001	2001
McAlpine	2001	2001	2001	1968

*All dates indicate most recent record.
SOURCE: Master Ohio River Mussel Database, Ohio State University (Watters 2003)

5.8.2 Mussel Studies in the Upper Mainstem River Reaches

A total of 117 studies between Pittsburgh (RM 0) and Meldahl Lock and Dam (RM 436) have recently been compiled into a database that can be used by river users and managers (ESI 2000). Most of the studies (99 of 117) were conducted post-1990 and are dive studies. Prior to 1987, studies were limited to bank searches and brailing (dragging a brail along the river bottom for a given time or area). Diving yields more accurate samples in large, deep rivers such as the Ohio River mainstem.

Studies conducted since 1991 indicate that some species of mussels are colonizing the upper to middle Ohio River mainstem, reflecting in large part the revitalization the river has undergone in recent years due to more stringent water quality standards (ESI 2000, Cavanaugh and Mitsch 1989). Patterns in the ESI data suggest that recolonization is occurring primarily from downstream as evidenced by:

- decreasing species richness and abundance in more upstream pools, and
- opportunistic habitat use in upstream pools.

Mussels were completely extirpated from the upper portion of the Ohio River during the early 20th century. Ortmann (1919), in his classic monograph of the *Naiades* of Pennsylvania, reported the total demise of the mussel fauna of many tributaries of the upper Ohio River, mostly from the impacts of acid drainage from bituminous coal mining. However, in 1919 he was still able to document either the presence, or relatively recent occurrence, of a diverse assemblage of at least 39 species of mussels in the Pennsylvania portion of the mainstem Ohio River. As recently as 1980, Taylor found only subfossil shells and no living mussels in the Pennsylvania reach of the Ohio River. The recolonization of Dashields and Montgomery Pools by mussels as reported by Watters et al. (2003), therefore, is a very recent phenomenon.

The degree, extent, and duration of previous water quality conditions limiting to the survival of mussels along the upper Ohio River cannot be precisely determined from

historical data. However, as early as 1914, the U.S. Public Health Service documented episodic acidification of the Ohio River extending as far as 170 miles downstream of Pittsburgh (U.S. Public Health Service 1924). Data collected by the U.S. Geological Survey and the Pennsylvania Department of Forests and Waters (White 1951) provide a good picture of Ohio River water quality conditions (at a station 17 miles downstream of Pittsburgh) during the late 1940s. Cross-section measurements of total acidity between October 1947 and September 1949 ranged from 5 to 86 mg/l $CaCO_3$ and averaged 30 mg/l as $CaCO_3$ (N=24). The pH of the Ohio River ranged from 3.65 to 6.6 and averaged 5.3 (N=110).

Mussel beds (defined as areas where mussels are consistently found in greater abundance than in surrounding areas and where several species and young animals are present) occur as far upstream as Willow Island Pool (ESI 2000). However, recruitment in recent years was only apparent in a few areas in Willow Island Pool and density was low (<5 mussels /m^2). Density was still low to moderate (<10 mussels /m^2) between Belleville and Meldahl Pools, but species richness increased and recruitment was good in many areas sampled.

Table 5-7 includes the locations of mussel beds and other low-density areas in the upper river. Individual beds ranged from <0.5 mile to 5.3 miles long. Numbers of mussel beds generally increased from upstream to downstream pools. The larger number of beds in Meldahl Pool, however, may reflect the greater sampling effort there, especially relative to the Byrd (Gallipolis) and Greenup Pools.

ESI (2000) concluded that the present fauna of the upper Ohio River appears to be a mix of historical species and species that have recently colonized the study area from tributaries and downstream pools. Evidence of 54 species was found, including 35 species that appear to be part of the historical fauna and 19 species that have recently become established in the upper river. This considerably expands the number of species reported for the upper Ohio River by Taylor (1989). Of the 54 species for which evidence was recovered (including weathered and subfossil shells), one species is presumed extinct, eight species are considered extirpated from the study area and the status of two species is unknown. Ten species thought extirpated from the upper river, however, were found live or as freshly dead shells. Indications of recent recruitment were observed for 15 species, including five species previously thought extirpated. Increasing trends of total mussel species and rare mussel species (those species comprising <1% of the total collected) from upstream to downstream pools in the upper river are shown in **Figure 5-2**, further illustrating the downstream to upstream recolonization of the Ohio River mussel fauna.

Unfortunately, the invasion of zebra mussels (discussed in greater detail below) has occurred simultaneously with mussel recolonization of the upper river; and the full impacts of the invasion remain unknown. ESI (2000) concluded that without zebra mussel infestation, mussel communities would continue the trend of expanding distribution and increasing abundance, although species composition in the future may differ considerably from the historic fauna.

Table 5-7
Mussel beds and areas with scattered mussels in the upper Ohio River.

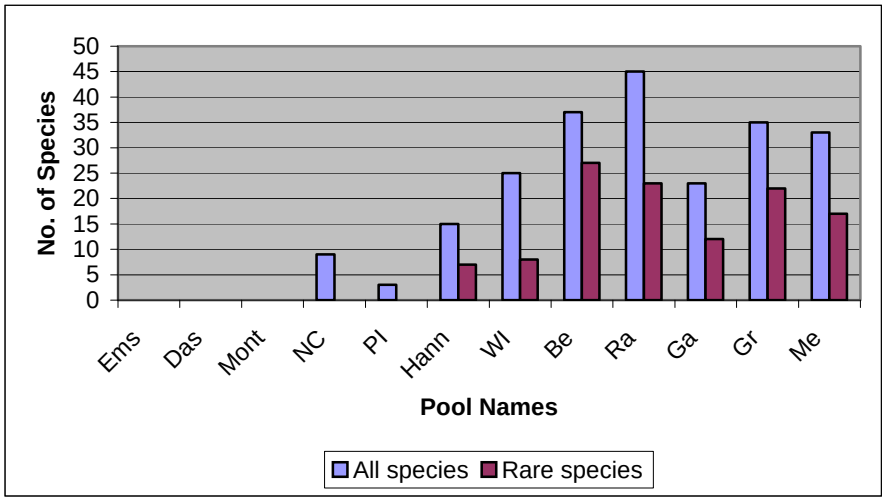
Pool	Bed no.[1]	Bank	Up. RM	Dn. RM	No. species in mussel bed	Density [2]	Recruit. [3]
Elmsworth							
Dashields							
Montgomery							
New Cumberland	A	LEFT	32.0	32.3	2	ND	ND
	B	IS LEFT	35.0	36.0	5	ND	ND
Pike Island	A	BOTH	55.0	57.5	1	ND	ND
	B	RIGHT	75.5	78.0	3	ND	ND
Hannibal	A	IS HEAD	89.0	89.5	1	ND	ND
	B	LEFT	96.7	97.3	1	ND	ND
Willow Island	1	LEFT	128.5	130.5	7	ND	Y
	A	RIGHT	128.5	130.5	3	ND	ND
	2	ISLAND	131.8	133.2	16	Low	0
	3	ISLAND	133.8	135.8	11	Low	Y
	B	LEFT/ISL	138.2	139.6	7	ND	ND
	4	LEFT/ISL	140.0	142.0	11	ND	ND
	5	RIGHT	140.0	141.0	6	ND	ND
	6	BOTH	150.0	151.0	9	Low	0
	C	ISLAND	151.5	152.0	8	ND	ND
	7	ISLAND	152.7	155.3	14	ND	ND
	8	BOTH	155.8	158.0	9	Low	ND
	D	ISLAND	158.3	158.5	1	ND	ND
Belleville	A	BOTH	162.0	168.0	4	ND	ND
	1	ISLAND	168.5	172.8	16	ND	Y
	2	ISLAND	175.0	177.5	30	Moderate	9 to 53
	3	RIGHT	179.0	180.0	18	ND	ND
	4	ISLAND	181.0	182.5	18	Low	37
	B	BOTH	183.0	183.7	11	Low	2
	C	ISL	186.0	189.5	14	Low	20
	5	RIGHT	192.8	193.3	15	Low	24
Racine	1	LEFT	204.4	208.8	25	Low	33 to 52
	2	RIGHT	204.5	207.7	23	Low	33 to 54
	A	BOTH	208.0	218.0			
	3	RIGHT	208.5	209.7	10	ND	Y
	4	RIGHT	210.6	215.9	20	Low	57
	5	LEFT	213.3	215.6	9	ND	ND
	6	LEFT	216.0	218.0	12	ND	ND
	B	LEFT	229.5	230.0	1	ND	ND
	7	ISLAND	234.9	235.0	9	ND	ND
Gallipolis	1	RIGHT	238.5	238.9	8	ND	ND
	A	BOTH	248.0	249.0	1	ND	ND

Table 5-7
Mussel beds and areas with scattered mussels in the upper Ohio River.

Pool	Bed no.[1]	Bank	Up. RM	Dn. RM	No. species in mussel bed	Density [2]	Recruit. [3]
	2	LEFT	252.3	252.8	16	Low	50
	3	RIGHT	253.8	254.1	15	Low	50
	4	RIGHT	254.5	255.5	18	Moderate	18 to 63
	B	RIGHT	256.5	258.4	4	ND	ND
	5	LEFT	257.4	258.0	17	Low	17 to 28
	C	BOTH	260.0	265.0	7	ND	ND
	D	LEFT	277.2	278.0	1	ND	ND
Greenup	1	RIGHT	282.5	282.7	9	Low	11
	2	LEFT	282.5	284.5	30	Low	20 to 30
	3	LEFT	286.4	288.8	26	Moderate	Y
	4	RIGHT	288.5	290.5	22	Low	Y
	5	RIGHT	292.0	292.8	21	Abundant	Y
	6	LEFT	299.8	301.0	16	ND	ND
	A	RIGHT	326.9	327.1	1	ND	ND
	7	RIGHT	332.0	332.3	13	ND	ND
Meldahl	1	BOTH	341.0	343.5	22	ND	Y
	2	LEFT	344.2	344.9	12	ND	ND
	3	LEFT	354.7	355.9	15	Low	56
	A	RIGHT	355.5	355.7	1	<Low	100
	B	RIGHT	358.0	358.2	8	ND	ND
	4	RIGHT	362.9	363.5	9	ND	ND
	5	LEFT	366.1	368.0	10	ND	ND
	6	RIGHT	370.0	370.3	9	ND	ND
	7	LEFT	371.2	372.2	11	ND	ND
	8	RIGHT	372.6	373.5	9	ND	ND
	9	LEFT	376.4	377.0	9	ND	ND
	10	RIGHT	383.4	386.5	10	ND	ND
	C	ISL HEAD	387.8	388.0	6	ND	ND
	11	RIGHT	391.0	394.5	14	ND	ND
	D	ISL HEAD	395.0	395.1	7	ND	ND
	E	ISLAND	395.0	396.5	5	ND	ND
	12	ISL TOE	396.7	397.1	19	Low	14 to 55
	13	RIGHT	396.7	397.1	19	Moderate	16 to 22
	14	RIGHT	397.5	399.1	8	ND	ND
	15	LEFT	401.5	403.0	3	ND	ND
	16	RIGHT	406.0	408.0	5	ND	ND
	17	LEFT	409.0	410.7	8	ND	ND
	18	RIGHT	412.1	413.0	10	ND	ND
	19	LEFT	415.0	415.9	9	ND	ND
	20	RIGHT	417.1	419.1	27	Moderate	2
	21	LEFT	422.2	423.0	7	ND	ND
	22	LEFT	430.5	431.1	7	ND	ND

[1]Numbers designate beds (>0.4/m2), letters designate areas with density <0.4/m2, but more unionids than the surrounding area.
[2]Abundant, >10/m2; moderate, 5 to 10/m2; low, 0.4 to 5/m2; ND=no density data
[3]Range of % of individuals ≤5 years or ≤40mm, based on quantitative samples; if no quantitative samples then
Y=individuals ≤5 years or ≤40mm collected, N=individuals ≤5 years or ≤40mm not collected. ND=no data available.
SOURCE: Upper Ohio River Mussel Database compiled by Ecological Specialists, Inc (2000).

FIGURE 5-2
Total and Rare (<1% of total) Mussels Species by Pool



5.8.3 Mussel Studies in the Lower Mainstem River Reach

The most comprehensive studies of mussels of the lower Ohio River mainstem have been conducted by Williams during 1967-1968, Williams and Schuster (1989), and Clarke (1995). During the last decades of the 20th century, several factors converged that stimulated these studies and underscored the importance of knowing the geographical locations of still-extant mussel beds in the lower Ohio mainstem. These converging factors included: 1) barge traffic on the river and the channel maintenance required to support it, 2) needs of the sand and gravel industry for in-stream areas to dredge, 3) heightened interest in conservation of native mussels, and 4) the increased importance of the mussel fishing industry (Clarke 1995). Further, these converging factors stimulated more site-specific mussel studies, including mussel research that has been conducted since 1983 in relation to the planning and construction of Olmsted L/D at RM 964.4.

Williams and Schuster (1989), whose studies during 1982 somewhat geographically overlap the ESI database discussed in the previous section, reported a net loss of 18.6 linear miles of mussel beds between RM 317 and RM 981 in the 15 years between 1967 and 1982. The most drastic change was the complete absence of mussel beds in 51.8 miles of the Ohio River above McAlpine L/D. According to Clarke (1995), Williams and Schuster found 78 mussel beds between RM 438.1 and 981 in 1976, but only 48 in 1982. Species composition also shifted during that time with the largest change occurring in the abundance of the ebony shell (*Fusconaia ebena*); this species comprised 16 percent of all mussels collected in 1967 and 26 percent in 1982. Between 1967 and 1982, four new high-lift dams within the study area (Cannelton, Newburgh, John T. Myers, and Smithland) replaced wicket dams while other high-lift dams completed during the 1960s had been operational for nearly 20 years. Williams and Schuster directly related decline in mussel bed area and species composition to the construction and operation of high-lift dams, concluding the two most important conditions impacting lower Ohio River mussels communities were:

- diminished current velocity from upstream to downstream portions of pools, causing silt deposition near dams that is especially detrimental to younger mussels and
- changes in current velocity and position relative to the main channel, contributing to silt deposition on mussel beds in quantities sufficient to decrease their areas or to eliminate them.

Clarke's 1993-1994 survey encompassed the lower reach sampled by Williams and Schuster more than decade earlier, but sampling conditions were different because of the invasion of zebra mussels in the interim. Clarke found only 40 of the 48 mussels beds reported by Williams and Schuster (1989) for the same reach, but delineated an additional five mussel beds not previously recorded in the literature. Clarke encountered heavy infestation of native mussels and bottom substrates by zebra mussels that severely interfered with sampling using wooden bottom brails and suggested these conditions accounted for failure to locate some of previously reported beds, especially in the Cannelton Pool. Of the missing beds, local informants told Clarke that one had been covered by sand and two others were overharvested to the extent that they no longer existed. Clarke found a total of 31 mussel species compared to 32 species found by Williams and Schuster. (See **Table 5-4** for locations where Clarke found the endangered clubshell and fat pocketbook and the sheepnose, a candidate species.) Because of sampling complications related to the zebra mussels, Clarke did not conclude that mussel beds were poorer in number of species or diversity in 1994 than in 1982.

Table 5-8 includes information on the beds located by Clarke (1995). The richest mussel bed in the lower river occurred near Owensboro, Kentucky, and contained 22 species including the candidate sheepnose mussel and rare rabbit's foot (*Quadrula cylindrica*). Clarke recommended designation of the bed as a nature preserve.

TABLE 5- 8
Mussel Beds in the Lower Ohio River between RM 438.1 – RM 981

Ohio River Pool	Bed Name	Upstream RM	Down-Stream RM	No. Species Present[1]	Notes/Comments[2]
Markland	Moscow North Bend	443.4	445.1	NA	
	California	446.7	447.3	NA	
	Melbourne	455.5	458+	NA	
	Little Sugar Cr.	522.2	522.7	NA	
	Bryant Creek	526.1	526.6	NA	
McAlpine	Vevay	537.7	540.0	NA	
	Brooksburg	549.5	554.7	NA	
Cannelton	Floyd-Harrison County	613.5	617.4	8	Expansion of nearby sand and gravel (s&g) dredging into bed would drive bed to extinction. In August 1994, zebra mussel invasion was well underway with an average of 40 zebra mussels attached to each

Ohio River Pool	Bed Name	Upstream RM	Down-Stream RM	No. Species Present[1]	Notes/Comments[2]
					unionid.
	Rosewood	625.5	627.6	6	Not near s&g dredging areas. In August 1994, zebra mussel invasion was well underway with an average of 5 zebra mussels attached to each unionid.
Cannelton (cont'd)	Haunted Hollow	650.9	Uncertain	11	Small bed of unknown shape. Not near s & g dredging areas. In 1994, contained Pleurobema clava (clubshell), a federal endangered species. In August 1994, zebra mussel invasion was well underway with an average of 50 zebra mussels attached to each unionid.
	Richardson Landing	652.7	Uncertain	10	Small bed of unknown shape. Not near s & g dredging areas. In August 1994, zebra mussel invasion was well underway with an average of 50 zebra mussels attached to each unionid.
	Leavenworth	664.3	665.0	16	Not near s &g dredging areas. Rich bed. In July 1994, on average 250 zebra mussels were attached to each unionid.
	Alton	679.2	679.7	5	Not near s &g dredging areas. Crowded zebra mussels with an average of 300 were attached to each live unionid.
	Cloverport	711.3	712.3	3	S & g dredging operations across river and upstream. Crowded zebra mussels with an average of 300 were attached to each unionid. Encrustation by zebra mussels com-plicated brail sampling.
	Millstone Creek	717.5	Uncertain	7	Not near s & g dredging areas.

Ohio River Pool	Bed Name	Upstream RM	Down-Stream RM	No. Species Present[1]	Notes/Comments[2]
					Bed being devastated by zebra mussels in summer 1994, with hundreds on each unionid.
Newburgh	(Town of) Cannelton	724.5	725.8	10	Across river from Fulton Bar, an area designated for s & g dredging. No zebra mussels observed in 1993, but present on nearby bed in October 1994.
	Hawesville	724.6	726.8	NA	Along opposite bank as Cannelton Bed. Located within Fulton Bar, an area designated for s & g dredging. In October 1994, on average about 30 zebra mussels were attached to each unionid.
	Troy	731.6	731.9	NA	
	Anderson Is.	734.2	735.4	NA	
	Lewisport	738.7	741.2	NA	
	Grandview-Rockport	742.2	747.1	NA	
	Puppy Creek	749.1	749.8	6	Downstream end of bed overlaps s & g dredging area. Another s & g area is across the river. In September 1994, on average 150 zebra mussels were attached to each unionid.
	Owensboro North	759.3	763.2	22	Richest bed in lower Ohio River, although located 300 ft. downstr. from s & g dredging area. Designation as a nature preserve recommended by Clarke. Very few zebra mussels observed in 1993; somewhat higher number (mean of 10) found in nearby area in 1994.
	Yankeetown	769.7	770.1	5	Downstream from s & g dredging area around French island and across river from such an area. Only one zebra mussel observed in 1993.
Myers	Green River East	783.0	783.1	6	Meets but does not overlap area where s & g dredging is permitted. No zebra mussels found

Ohio River Pool	Bed Name	Upstream RM	Down-Stream RM	No. Species Present[1]	Notes/Comments[2]
					in 1993.
	Green River West	784.8	785.0	7	Not close to s & g dredging area. Local fishermen describe bed as over-exploited for mussels. No zebra mussels seen in 1993.
	Dutch Island	796.7	798.2	14	Upstream and across river from s & g dredging area. In September 1993, only three zebra mussels were observed, one on each of three unionids.
	Henderson North	801.1	801.5	11	Not close to any s & g dredging areas. In August 1993, only one zebra mussel was observed.
	Henderson	803.7	805.4	9	Lies across river from long, narrow area where dredging is permitted. No zebra mussels observed in August 1993.
	Cypress Bend	813.0	815.1	11	Lies across river from s & g dredging area. No zebra mussels observed in August 1993.
Myers (cont'd)	Mount Vernon	852.2	852.2		Small bed is in shallow pools on Mount Vernon Towhead. Only juvenile mussels in 1-2 year classes found. Therefore, these pools may dry out some years. Not close to s & g dredging area.
	Uniontown	843.0	843.4	7	Not close to s & g dredging area. Remnant of much more widely distributed resource and biological assemblage. In September 1993, on average 22 zebra mussels were attached to each unionid.
Smithland	Old Shawneetown East	855.9	856.0	6	Does not overlap s & g dredging area, but about 1 mi. downstream from such an area. No zebra mussels observed in July 1993.
	Old Shawneetown	859.2	859.7	8	Parallels area of river where

Ohio River Pool	Bed Name	Upstream RM	Down-Stream RM	No. Species Present[1]	Notes/Comments[2]
	South				s & g dredging occurs. Bed described 10 years earlier by Williams & Schuster as >1 mi. long.
	Upper Cave-in-Rock	879.1	879.9	NA	Opposite Cave-in-Rock Island.
	Rosiclare-Elizabethtown	888.5	891.9	NA	
	Carrsville	893.0	894.2	6	Near s & g dredging area. No zebra mussels observed in July 1993.
	Shelterville	896.0	897.0	6	Does not intersect any s & g dredging areas, but located across river from such an area. No zebra mussels observed in July 1993.
	Rondeau Island	898.8	902.1	9	Does not intersect any s & g dredging areas. No zebra mussels observed in July 1993.
	Sisters' Island	909.3	909.5	3	Not near any areas where s & g dredging is permitted. No zebra mussels observed in summer 1993.
	Birdsville	913.9	914.1	6	Does not intersect any s & g dredging areas. Local fishermen describe bed as over-exploited for mussels for cultured pearl industry. In June 1993, up to 75 zebra mussels observed on specimens of *Megalonaias giantea* (washboard), but numbers on other species not noted.
L/D 52	Cumberland Towhead	Opposite RM 922.6 & Cumber-land RM 0.3	923.4	6	Does not intersect any s & g dredging areas, although large dredging area is located 0.5 mi. downstream. Only slightly impacted by zebra mussels as of October 1994 (average of 0.4 per unionid).
	Kinkaid Landing	930.5	930.5	4	Densities relatively low, but qualifies as bed. Across river from area dredged for decades. Only one zebra mussel found.
	Brookport	936.8	938.8	9	Does not intersect any s

Ohio River Pool	Bed Name	Upstream RM	Down-Stream RM	No. Species Present[1]	Notes/Comments[2]
					& g dredging areas. Zebra mussel invasion well underway by June 1994, with averages of 3 adults and 40 juveniles on each unionid.
L/D 53	Metropolis East	940.5	942.1	11	Does not intersect any s & g dredging areas. Zebra mussel invasion well underway by June 1994, with 1 or 2 adults and an average of 25 juveniles on each unionid.
	Metropolis	944.0	944.8	5	Does not intersect any s & g dredging areas. Zebra mussel invasion had begun by June 1994 with an average of 6.8 juveniles on each unionid.
	Little Chain	947.5	948.1	7	Does not intersect any s & g dredging areas. Possibly over-harvested. Zebra mussel invasion underway by summer 1994 with an average of 50 juveniles on each unionid.
Below L/D 53	Olmstead-America	965.0	971.9	6	Does not intersect any s & g dredging areas. Zebra mussel invasion underway by summer 1994 with an average of 50 juveniles on each unionid.
	Mound City	972.1	974.1		Confined to mid-river. Important to local fishing and mussel harvesting activities. Zebra mussel invasion just beginning in September 1994 –only one zebra mussel found.

[1] NA = data not available on number of species in mussel bed
[2] Notes and comments extracted from bed descriptions provided by Clarke (see below).
SOURCE: Clarke, A.H. 1995. Survey of mussel beds in the lower Ohio River. Prepared for the U.S. Army Corps of Engineers, Louisville District by Ecosearch, Inc.

On a site specific level, intensive mussel surveys have been conducted since 1983 in the lower Ohio River near Olmsted, Illinois, to assess the ecological effects of construction and operation of a new lock and dam at RM 964.4 that will replace existing Locks and Dams 52 and 53. Upon completion, the new Olmsted Dam will increase water levels by a maximum of 10 ft. in the pool above the dam for approximately 42 percent of the year (i.e., during periods of normal and low flow). In addition to upstream changes, navigation traffic patterns and hydraulics immediately downstream of the new dam will be altered.

These projected changes are of special interest with respect to their possible impacts on a dense, diverse mussel bed that occurs from approximately RM 966.7 to 969 and includes the federally endangered orangefoot pimple back mussel (*Plethobasus cooperianus*). A second mussel bed has been sampled upstream of Olmsted Dam near the Post Creek outlet at RM 956.5 (Payne and Miller 2002).

In contrast to Williams and Schuster (1989) and Clarke (1995), who reported 17 and 6 mussel species from the Olmsted bed, respectively, the intensive multi-year efforts of Payne and Miller (1997) have documented 32 species. As with other studies, Payne and Miller reported that *Fusconaia ebena* (ebony shell*)* heavily dominates mussels in stable shoals of the lower Ohio River. Despite being a species-rich mussel community, the Olmsted bed has low species diversity because of the high relative abundance of *F. ebena*. The mussel community at Post Creek outlet is similarly species-rich, but *F. ebena* is less dominant. Consequently, diversity indices for the Post Creek community are more moderate.

Good recruitment of juvenile mussels occurs at both Post Creek and Olmsted and appears to be correlated with river discharge conditions. Years with strong recruitment, including 1981, 1990 and 1998, have had remarkably similar hydraulic conditions that may have enhanced both the probability of successful attachment of glochidia to the gills of their fish host and the subsequent settlement of juveniles from fish (Payne and Miller 2002). The combined conditions of spring temperature rise and a marked rise in discharge from a lower than average seasonal value are appropriate signals for spawning migrations of skipjack herring, the host fish of ebony shell glochidia.

Mussel studies near Olmsted Lock and Dam are anticipated to continue until the completed navigation project has operated for several years.

5.8.4 Zebra Mussels and Other Invasive Species Affecting Native Ohio River Mussels

The progress of the zebra mussel invasion in the Ohio River has been studied since its first appearance in 1991. Zebra mussels most likely spread throughout the Ohio River by barge traffic (www.lrd.usace.army.mil/gl/wq_or.htm#zebra). Zebra mussels negatively affect native mussels primarily by smothering siphons, preventing valve opening and closure, and interfering with normal feeding and burrowing. Further, studies indicate living freshwater mussels are a preferred substrate for zebra mussels (Ricciardi et al. 1995). These adverse effects have been compounded in the Upper Mississippi River system when the shorter-lived zebra mussels die and rot creating sustained anoxic bottom conditions that are intolerable to native mussels and their fish hosts (USACE 2002). Within a short time, zebra mussels have critically impaired native mussels already threatened by habitat degradation, such that by 1998 native mussel mortality was approaching 40 percent at lower Ohio River monitoring sites (Morrison 1998).

A model developed by Ricciardi et al. (1995) predicted severe mortality (>90 %) of freshwater mussels within 4 to 5 years after the establishment of habitats that support zebra mussel densities of at least 6,000 /m^2. A cooperative of state, federal and private partners have tracked impacts of zebra mussels on the Ohio River since 1995. Data from the cooperative's fall 2001 survey approached Ricciardi et al.'s prediction of 90 percent or higher mortality of the native species at sampling stations near Aurora, Indiana (near RM

497) and Rosewood, Indiana (near RM 627) (Morrison, personal communication). The USACE (2002), however, reports that native mussels continue to successfully recruit in mussel beds in the lower Ohio River, despite occasional high densities of adult zebra mussels. The persistence of native mussels in the lower river appears to be related to substrate scouring which prevents extensive buildup of zebra mussel debris.

Population dynamics of zebra mussels in the Ohio River are yet to be determined, but are under continuing study by the cooperative team mentioned in the preceding paragraph. After high densities were observed in the late 1990s, zebra mussels markedly declined in the last few years. However, photos of Belleville and Meldahl L/Ds recently provided by Morrison and others indicate that zebra mussels again are on the rise.

Long-term measures to protect native mussels include hatchery rearing and subsequent reintroduction of presently endangered species, and efforts to add at least one more mainstem mussel to the federal endangered species candidate list. Additions to the candidate list also may include two Ohio River snails (*Lithasia* spp.), whose populations have been damaged by zebra mussel infestation.

Experiments on fish predation of zebra mussels in the Mississippi and Ohio Rivers indicate that although fish can reduce numbers of zebra mussels in the two rivers, current levels of fish predation seem insufficient to regulate zebra mussel densities because of their great reproductive capacity (Thorp et al. 1998). Similar findings were reported from experiments in Lake Dardanelle, Arkansas (Magoulick and Lewis 2002).

Zebra mussels also have colonized concrete, metal, rope and other materials at Ohio River locks and dams, but complications by zebra mussels in navigation operations have been minimal, in part because of proactive measures taken by the Corps. Such measures have included physical and chemical treatments to protect locks and dams, navigation vessels and water quality monitors; use of high power hoses and other similar equipment and scheduling of additional time to remove zebra mussels prior to diving inspections (www.lrd.usace.army.mil/gl/wq_or.htm#zebra).

A Biological Opinion (BO) issued by USFWS in 2000 for the upper Mississippi determined that operation and maintenance of navigation pool and project-dependent commercial barge transportation would facilitate continued existence of zebra mussels and impede the recovery and survival of the federally endangered Higgins' eye pearly mussel. Alterations to dam operations and substrates offer potential for managing zebra mussel infestations in the upper Mississippi and creating habitat for native mussels that is less susceptible to accumulation of zebra mussel debris. Some evidence suggests that native mussels adapted to riverine conditions have a competitive advantage over zebra mussels, which are adapted to more lake-like conditions (USACE 2002).

Native mussels of the lower Ohio have been resilient to invasions of the nonindigenous Asian clam (*Corbicula fluminea*). The high densities and complex age structure of the Asiatic clam appeared to have no adverse effects on native mussels in the Olmsted bed from 1983 to 1993. Since 1993, Asian clam populations have greatly declined and zebra mussels, which first appeared in the Ohio River in 1991, have replaced Asiatic clams as the nonindigenous bivalve of primary concern. The zebra mussel density near Olmsted L/D was 49,000 individuals per square meter in 1994, but was reduced to

5,000 per square meter in 1995. High zebra mussel densities in 1994 resulted in reduced growth of native mussels, but did not cause major declines in density of native mussels such as have occurred in the Great Lakes. It remains to be seen if zebra mussels can occur in sustained abundance in the lower Ohio at a density sufficiently high to have drastic effects on native mussels (Payne and Miller 1999).

Black carp (*Mylopharyngodon piceus*) is another serious threat to native Ohio River mussels. This Asian species escaped into the Mississippi River system during flooding in the 1990s and now threatens the Ohio River system. Black carp are molluscivores (mussel and snail feeders) which are likely to negatively affect native mussel and snail populations. Native fish, turtles, birds, raccoons, otters, and muskrats also are likely to be affected through competition for food. The USFWS is in the process of listing black carp as an injurious wildlife species, but this listing will only apply to future importation and interstate transportation of the species (http://southeast.fws.gov/hotissues/Black_Carp_FS.pdf). Additional information on exotic fish species of the Ohio River is found in Chapter 4, Fish Resources.

5.9 INTERACTIONS WITH OTHER VECS

Recent drastic declines in native mussel populations have contributed to increased scrutiny of numerous human activities that affect them. Several VECs influence the sustainability of mussel populations in the Ohio River, primarily in connection with mussel habitat.

Water quality improvements in various chemical and bacteriological parameters over the last half-century have generally been beneficial to mussels. As indicated in Chapter 3, "**Water Quality.**" dramatic increases in the number of river miles fully supporting the warmwater aquatic life use designation have occurred in the past 20 years, as water quality has continued to improve. At the same time, changes in sediment patterns near high-lift dams and continuing sediment input from land development, agricultural activities, and dredging have resulted in siltation that has impaired respiration, feeding, and reproduction of mussels throughout the Ohio River. The transformation of the free-flowing Ohio River into a series of more lake-like pools has influenced current patterns and distributions of mussels, extirpation of some species, and extinctions of some big river riffle species. The dams themselves may form barriers to fish movement, which might inhibit the distribution of mussel-specific fish hosts that are necessary to complete the mussels' life cycle.

River transportation and recreational boating have facilitated spread of the invasive zebra mussel. After large infestations of zebra mussels in the mid- to late 1990s, zebra mussels have declined in the Ohio River. The long-term effects of this exotic invader remain to be seen. Barge transportation with associated fleeting and mooring areas, terminals, and ports potentially damages mussel beds through groundings, spills, and wave action that cause bank erosion.

Declines in freshwater mussel populations also underscore the need to maximize the effectiveness of regulations and programs to protect mussels. Concerns about mussel declines have:

- influenced lock operation and maintenance (including zebra mussel control) and commercial navigation to mitigate the impacts of barge queuing, fleeting and storage, and dispersed traffic,
- heightened the need to identify mussel beds and potential bed sites and develop protection plans before new developments such as lock extensions, bridges, marinas, and floodplain conversions are initiated,
- influenced channel maintenance dredging practices and increased interest in using dredged materials to create new islands and sandbars and to restore eroded riparian areas,
- helped promote ecosystem restoration (ER) and other initiatives aimed at habitat conservation and restoration.

The Ohio River navigation system itself can be viewed as a potential tool for management of native mussels and other aquatic resources. In concert with management of upstream flood control reservoirs, navigation dams may offer some possibilities for manipulating river flows to minimize damage and improve aquatic habitats. Further studies may be warranted, as no studies on flow manipulation of the Ohio River have occurred to date.

5.10 RELEVANT ACTIONS AFFECTING MUSSELS

Of 73 ranked RFFAs, only seven were not ranked "high" or "medium" with respect to their potential importance to freshwater mussels. These high numbers of important actions seem to reflect both the precariousness of the mussel resource and recently enhanced efforts to protect it. In essence, the high importance placed on such a large number of RFFAs communicates that resource managers who ranked the RFFAs perceive any adverse impacts to freshwater mussels as important. Comments that accompanied many RFFA rankings indicated that it was the actual or potential proximity of the activity to mussel beds or other mussel populations that generated the importance rankings. **Table 5-9** presents the matrix of RFFAs that were ranked as high or medium importance to Ohio River mussels.

The relatively complex and somewhat obscure biology and ecology of mussels makes it challenging to comprehensively discuss relevant actions affecting them. Because mussels respond to multiple interrelated factors, it is difficult to examine any action in isolation or even groups of actions. Although this section considers RFFAs according to their primary effects, it should be understood that most actions have cumulative and/or synergistic effects. Bearing grouping limitations in mind, RFFAs affecting mussels are discussed below in the context of:

- Actions directly contributing to habitat degradation and instability
- Actions indirectly contributing to habitat degradation and instability
- Actions affecting reproductive success and community connectivity and
- Actions beneficial to mussels.

TABLE 5-9
Cumulative Effects Matrix for Mussels

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Mussels	Importance[5]
Navigation Investment Actions					
Lock Extensions/New Locks/Replacement or Rehabilitation	A	H	SL, E	x	H
L&D operation and maintenance	A	H	SL,E	x	H
Non-structural navigation improvements	A	H	SL,E	x	H
Dam replacement and rehabilitation	A	H	SL, E	x	H
Other Corps Actions					
Channel dredging/dredged material disposal	A	H	SL, E	x	H
Navigation aids - Construction & O&M	A	H	SL, E	x	M
Flood damage reduction projects					
dry dams, other projects off mainstem	A	M	E	x	M
channel modifications	A	H	E	x	H
nonstructural (e.g., relocation)	A	H	E	x	H
Emergency streambank stabilization (Sec. 14)	A	H	SL, E	x	H
Modification of Corps structures for envt. improvements (Sec. 1135)	A	H	E	x	H
Ecosystem restoration of aquatic ecosystems (Sec. 206)	1,2	H	E	x	H
ERP Projects - 5 categories	A	H	E	x	H
Port development (Sec. 107) and maintenance dredging	A	H	SL, E	x	H
Pool maintenance	A	H	E	x	H
"But for Actions"					
Commercial Navigation					
barge queuing	A	H	SL,E	x	H
fleeting areas/barge storage	A	H	SL, E	x	H
terminals	A	H	SL, E	x	H
multi-modal sites	A	H	SL, E	x	H
increased traffic	A	H	E	x	H
dispersed barge traffic	A	H	E	x	H
barge/tow tech/"green" design	A	H	E	x	H
accidents/spills	A	H	E	x	H
Coast Guard Nav. Aids - Construction, O&M	A	H	E	x	M

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Mussels	Importance[5]
Instream sand and gravel mining	A	H	SL, E	x	H
Floodplain sand and gravel mining	A	H	SL, E	x	H
Limestone aggregates mining	A	H	SL, E	x	M
Coal utilities	A	M	SL, E	x	H
Other coal industries	A	M	SL, E	x	H
Hydropower on dams	A	M	SL, E	x	H
Water intakes	A	H	SL, E	x	M
Industrial users, excluding coal-related	A	H	SL, E	x	M
Recreation facilities - Construction and O&M	A	H	SL, E	x	M
Actions by Others					
Public lands acquisition and management	A	H	SL, E	x	M
Floodplain development					
residential	A	H	E	x	H
commercial	A	H	E	x	H
industrial	A	H	E	x	H
Crossings					
bridges	A	H	SL, E	x	H
utility	A	H	SL, E	x	H
industrial	A	H	SL, E	x	H
Riverbed crossings	A	H	SL, E	x	H
Marina development & operation	A	H	SL, E	x	M
Silviculture	A	H	R	x	H
Agriculture	A	H	R	x	H
WWTP discharges					
municipal	A	H	U	x	H
industrial	A	H	U,R	x	H
onsite systems	A	H	U,R	x	H
Stormwater discharges	A	H	U,R	x	H
Casinos	A	M	SL	x	L,M,H
Hazardous waste sites	A	M	SL	x	M
Regulatory Environment					
Phase I & 2 NPDES program	A	H	SL,E	x	H
TMDLs	A	H	E	x	H
Site remediation	A	H	SL,E	x	M,H
More stringent quality standards for environmental media	A	H	E	x	H

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Mussels	Importance[5]
Pollutant source control	A	H	E	x	H
Carbon sequestration	A	M	R	x	H
Farmland preservation	A	M	R	x	H
Effluent trading	A	H	SL,E	x	H
Agricultural discharges	A	H	R	x	H
Pollution Prevention	A	H	E	x	H
Emissions trading	A	H	SL,E	x	H
Corps permitting programs	A	H	SL,E	x	H
Small navigation projects	A	H	SL,E	x	H
ORSANCO monitoring program	A	H	E	x	M
Spill response	A	H	E	x	M
Environmental Awareness Education	A	H	E	x	H
ESA (Endangered Species Act)	A	H	E	x	H
Environmental sustainability practices	A	M	E	x	H

[1] Reasonably Foreseeable Future Actions
[2] Time period in which the RFFA may occur: 1 = within 10 years. 2 = in 10 - 25 years. 3 = in 25 - 60 years. A = applicable to all time periods
[3] Occurrence probability or likelihood RFFA will happen: H = high M = medium L = low
[4] Location or setting on river where RFFA is expected to occur:
U = upper (Pittsburgh - Huntington), M = middle (below Huntington - Louisville),
L = lower ((below Louisville - mouth), E = along entire length of river,
SL = specific location, e.g., locks and dams, U = urban setting, R = rural setting
[5] Importance of RFFA: H = high M = medium L = low

5.10.1 Actions Directly Contributing to Habitat Degradation and Instability

This group includes actions that physically alter mussels and their habitats by direct damage or removal of mussels. Such actions also may indirectly alter habitats. Channel maintenance dredging and in-stream sand and gravel mining exemplify actions with both direct and indirect impacts.

Channel maintenance dredging (H) involves the removal and disposal of sand and gravel deposits from the navigation channel of the Ohio River to maintain a nine-foot depth. Mussels and other bottom-dwelling aquatic organisms may also be removed during dredging. Land disposal has been used for dredged materials in the upper 120 miles of the river, but past practices in the remainder of the river have generally utilized in-stream disposal (Rieger, personal communication). In-stream disposal of dredged materials potentially results in the disturbance of mussel beds through the redistribution of sediments, which may cover mussels and interfere with respiration and feeding. Sediments from dredging also may resuspend contaminants, increase concentrations of plant nutrients, lower or increase photosynthesis and increase biological oxygen demand (Watters 1999). The elimination of suitable habitat, destabilization of bottom substrates

and the creation of deep pools can inhibit recolonization of dredged areas (Kanehl and Lyons 1992). Recommendations for mitigating the adverse impacts of channel dredging include:

- Restricting dredged areas to the minimum required to maintain the navigation channel,
- Conducting long-term monitoring of mussel habitats where dredging has occurred and/or continues, and
- Disposing of dredged materials in a manner least harmful to mussels (e.g., land disposal, deep channel), and
- Creating new islands or riparian habitat (e.g., using structural fill for ER streambank restoration projects).

Potential future constraints on in-stream disposal may encourage land disposal of these dredged materials. In some cases, dredged materials may be utilized to create new sandbars or islands that would provide more sheltered habitat for mussels. For most extended reaches of the Ohio River, channel maintenance dredging is an ongoing activity.

Ongoing in-stream sand and gravel mining (H) also involves the removal of sand and gravel deposits from the river and their subsequent transport to land. Like channel maintenance dredging, this activity potentially results in disturbance and/or destruction of mussel beds and redistribution of sediments, which may cover mussels and interfere with metabolic processes. Further, a process called headcutting may occur following dredging, leading to the loss of habitat and mussels upstream from the dredged site. Headcutting occurs when the upper boundaries of a modified area collapse, moving the disturbance upstream in a zipper-like fashion (Watters 1999). Prohibiting instream mining activity in or nearby, known, well-marked mussel beds would help protect the Ohio mainstem's limited mussel resources and enhance their recovery.

Construction of lock chamber extensions (H) could require dredging and excavation in the Ohio River which could result in destruction, partial loss, or siltation of existing mussel beds or potentially suitable mussel habitat in proximity to the construction area. As described above, dredging would temporarily increase turbidity and suspended solids and might release any contaminants found in the sediments, though elutions of worst case contaminated sediments from the upper Ohio River failed to release priority pollutants (USACE 1982 and 1989). Increased sediments in the water column would harm benthic organisms, including mussels that are filter feeders. Construction also would require placement around the foundations of extended walls of fill consisting of concrete, rock, and earth (removed from the existing structure during demolition). Dewatering of auxiliary lock chambers to install additional filling/emptying systems would temporarily increase turbidity in the water column.

Construction of lock chamber extensions also could require establishment of parking and maintenance areas for equipment, a lay-down yard for materials, an onsite-disposal area for excavated materials and some earthwork where portions of the lock chamber connect with the riverbank. These activities would require clearing of vegetation with potential surface runoff and soil erosion that could lead to siltation of mussel beds.

Barge queuing upstream and downstream of locks and dams is expected to increase during temporary closures of main and/or auxiliary chambers, if lock chambers are extended. Queuing (H) would create turbidity and potential damage to mussel beds, as well as to fish spawning beds and other shoreline habitats while barges await lock passage.

The potential extent of impacts during all aspects of lock extension would vary at construction locations and in queuing areas depending upon their proximity to mussel beds. Several actions, however, could be taken to minimize or mitigate impacts including:

- Installing markers around shallow mussel beds in the vicinity of lock chamber construction areas.
- Installing mooring facilities that restrict queuing tows to the navigation channels, thus avoiding direct physical damage to mussel beds.
- Keeping barges away from sensitive mussel beds by utilizing various traffic management measures that would reduce queuing (e.g., use of helper boats, lock scheduling with remote mooring, queuing fees/penalties, etc.).
- Installing turbidity curtains to surround construction areas.
- Using environmentally acceptable fill materials.
- Scheduling construction to minimize in-river activities.
- Scheduling construction to avoid mussel breeding periods.
- Using dewatering techniques that minimize suspended solids in the water column.
- Implementing erosion control plans that emphasize phased clearing, containment of soils, water detention, and temporary reseeding of cleared sites along with timely permanent revegetation.
- Creating new side channel habitats with continuous flow and suitable substrate below dams.
- Disposing of dredged materials in a way that either does not affect mussels or creates new aquatic habitat.

Barge queuing during normal commercial navigation and its attendant turbidity effects and potential physical damage to mussel beds would be reduced during normal navigation operations, as a result of increased lock capacity and decreased lock maintenance events. However, barge fleeting and storage (H), which also may cause direct damage to mussels, would not be relieved by lock expansions and, in fact, would be expected to increase in proportion to growth of commercial traffic. Prohibiting fleeting and storage near mussel beds would help mitigate physical damage. Enhanced knowledge of mussel beds and good cautionary signage would be essential to restricting traffic in sensitive mussel areas, particularly in the absence of wildlife enforcement officers. An example of such an effort is the Biologist on Board program, a cooperative initiative between the USFWS and the towing industry, designed to promote communication among the participants and enhance education regarding aquatic habitats in and along the Ohio River.

Ongoing commercial use of lock and dam facilities requires periodic upkeep and maintenance, which includes major and minor repairs of both primary and auxiliary locks. As existing locks age, the need for such repairs will become more frequent. The frequency of repairs will generally increase as locks age and in proportion to increases in commercial traffic (and resultant use of the lock chambers) on the Ohio River. For the 60-year study

period, scheduled repair events are expected to occur on an average of once every five years for each lock and dam project (USACE 2000).

Impacts on mussels will vary depending upon the location and extent of each lock repair event. Dewatering of lock chambers, establishment of areas for equipment, parking and materials, and barge queuing as a result of delays at locks would all potentially impact mussels in the work area. These impacts could be lessened through the corresponding actions listed under lock chamber extension in the previous section.

Unlike lock extensions, maintenance and repair activities are not expected to require disposal of significant quantities of dredged or excavated materials. Also, zebra mussel control is expected to be part of lock maintenance and can lengthen a repair event.

Maintenance and repair events will occur with or without lock extensions. Completion of lock extensions or lock additions, however, can reduce repair activities and associated impacts to mussels in three ways:

- It may be feasible to schedule each construction project to eliminate one complete auxiliary chamber repair event or major rehabilitation that would have otherwise been necessary.
- Each extension creates a lock in new condition, allowing for a longer time interval between the auxiliary chamber repair events.
- Finally, the original full-sized lock will be used less, since total lockages can be shared equally between the two full sized locks allowing for a longer time between the main chamber repair events (USACE. 2000).

Fewer repair activities lead to reductions in queuing, especially important in the more ecologically sensitive tailwater areas subject to queuing of tows bound upstream. If locks are extended, impacts on mussels directly attributable to maintenance and repair activities will be reduced in proportion to the expected reduction in repair activity.

Effects from major lock rehabilitation (H) would be similar to those of repairs, but would likely occur over longer time periods.

Regardless of whether or not locks are extended, continuing operation of existing locks and dams (H) along the Ohio River and related pool maintenance (H) will have ongoing effects on mussels. These effects include siltation, modification of current direction and velocities, increased depth, downstream scour that may preclude recolonization, colonization of locks by zebra mussels, and restrictions on movements of fishes that host the glochidial stages of freshwater mussels.

An infrequent action with potentially significant impacts on mussels is major rehabilitation of the dams (H) (as opposed to rehabilitation of lock chambers). While the timing of rehabilitation projects is subject to numerous variables, this activity primarily corresponds to the useful life cycle of the dam. Of the 20 dams currently on the river, 6 have been rehabilitated in the past two decades, at an average age of 60 years following their initial construction. Assuming a life cycle of 60 years, all of the dams currently on the Ohio River may require major rehabilitation during the 60-year cycle of the study period.

Impacts related to mussels from dam rehabilitation projects would be similar to construction site impacts described previously for lock extension projects. The activities would require similar temporary impacts for construction parking and lay down yards and would likely entail similar needs for the disposal of dredged materials.

Port development and maintenance (H) is another activity with potentially adverse direct impacts on mussels. Awareness of the location of mussel beds, care in avoiding them, and use of turbidity curtains to limit downstream siltation are among measures that can mitigate such impacts. Development of new terminals and multimodal sites associated with commercial traffic would be expected to similarly impact mussel resources of the Ohio River. Avoidance of important mussel habitat at new sites and careful adherence to the Corps' permitting procedures (Section 10, and 404 and corresponding state 401 certification in connection with the Corps permit) would help to minimize these impacts.

Recreational activities, especially development and maintenance of marinas and boat launch ramps (H) and other support facilities, also can directly impact mussel resources of the Ohio River. Potential impacts of marina development include direct elimination or encroachment on mussel habitats and erosion and resultant sediment damage to mussel beds, unless turbidity curtains or other containment procedures are used during construction. Marinas tend to be located in embayments and can be found throughout the floodplain, although they concentrate somewhat in proximity to urban areas. The embayments in which marinas and related facilities concentrate comprise a very limited resource within the Ohio River floodplain. Additionally, dredging activity within these embayments is generally required to maintain accessibility to the marinas and/or launch ramps. The expected continued growth of marinas and dredging of embayments will likely compete with or displace other resource values of the embayments, including known or potential mussel habitat and other aquatic resources. Other facilities supporting boating and non-boating activities include riverfront parks, riverfront hotel/restaurant complexes, and casino boat/resort complexes. Virtually all recreation infrastructure has been built in relation to and is dependent upon continued maintenance of the existing system of navigation pools. Careful recreational facilities siting and other protective measures would help prevent further habitat loss to mussels in proximity.

Dispersed barge traffic (H) outside of designated shipping lanes is not frequent, but also may result in direct damage to mussel beds.

5.10.2 Actions Indirectly Contributing to Habitat Degradation and Stability

This group includes actions that indirectly alter and destabilize mussel habitat. Such actions also may affect reproductive success and community connectivity. As Watters (2003) explains in more detail, impoundment necessary for continued operation of locks and dams along the Ohio River dramatically reduces mussel habitat heterogeneity and buries the original channel under deeper water. Suspended sediments reduce light penetration and associated algal production that provides food for mussels and leads to oxygen depletion and reductions in growth. After impoundment, sediment deposition impacts the original mussel fauna which may be eliminated or greatly reduced in favor of invading species are better adapted to softer substrates.

Channel modifications designed to reduce flooding (H) also affect flow patterns, which in turn may cause changes in species composition of mussel beds either through sediment deposition or natural scouring. Existing and increased barge traffic (H) creates another type of scouring – propeller-induced scouring (prop scour) from large vessels. Further, barge traffic continues to spread zebra mussels and has the potential to destroy juvenile mussels, thereby limiting reproductive success. Watters' (1999) review of the effects of hydrologic and instream habitat alterations on mussels, however, included conflicting results and suggests that further studies are warranted. Aldridge et al. (1987), as cited by Watters, concluded that frequent turbulence (once every 0.5 hr) and high concentrations of suspended solids (600-750 mg/L) significantly changed the food clearance rates, oxygen uptake, and nitrogen elimination of mussels. In contrast, Miller and Payne (1995, as cited by Watters 1999) concluded that changes in velocity associated with barge passage were too small and too short in duration to affect mussels.

Floodplain sand and gravel mining (H) and limestone aggregate mining (M) do not involve direct riverbed extractions that could damage mussel beds. These mining activities, however, benefit directly from the availability of barge transport along the Ohio River and may entail the construction and maintenance of port/docking facilities with potential impacts on mussels. As with general terminal construction discussed in the previous section, facility siting to avoid mussel beds and compliance with associated Corps permits is important in reducing construction and operation impacts.

Well-documented improvements in water quality in the Ohio mainstem since the mid-20th century have benefited mussels and other aquatic life, but some pollution threats remain. For example, spills of hazardous materials during navigation and product transfer (H) can threaten mussel beds and other aquatic resources, although advanced spill notification systems, Coast Guard spill reporting procedures, and improved containment and recovery techniques have ameliorated these impacts in recent years.

Another potential future mining related impact to mussels along the upper Ohio River is acid mine drainage (AMD) from abandoned coal mines. As discussed earlier in this chapter, along with uncontrolled industrial and domestic waste pollution for most of the 20th century AMD totally eliminated mussels from the upper Ohio River. For the past three decades, drainage from both active deep mines and associated interconnected abandoned mines has been pumped and treated. This pumping and treatment has resulted in highly improved water quality and previously extirpated mussel species, and other aquatic life, have made progress in recolonizing the upper river. At present, however, a series of huge underground mines in the Pittsburgh Coal Seam are facing bankruptcies and closures. Unless actions are taken to mitigate this problem, these mines will soon flood and discharge enormous quantities of untreated AMD. The mines with the greatest potential to degrade the Ohio River will discharge along a 100-mile reach of the left descending bank of the Monongahela River. Of special concern will be the extremely degraded first flush from each mine complex. First flush discharges could be months or years in duration for each mine. As of this time, there is no well-developed plan, authority, or source of funding to address this problem.

Industrial discharges to the Ohio River are highly regulated under the NPDES permitting program of the CWA, but spills, NPDES violations, and discharges of unregulated substances may still occur with potentially harmful effects on mussels and

other aquatic life. Other potential mussel impacts related to industrial activities (M) along the river primarily focus on transfer of potentially harmful materials and maintenance of port/docking facilities. Coal transport alone currently accounts for more than 55% of all barge traffic on the Ohio River and is projected to account for a large percentage of traffic for the foreseeable future. Because of the coal industry's prominence, potential impacts on mussels from barge activities and spillage of coal fines and other harmful substances are particularly important. Contaminated sediments from past industrial pollution or landfill materials can impede mussel recovery wherever such sediments occur, but they are more prevalent in the heavily industrialized upper river.

Floodplain ordinances, government programs and other constraints have limited **residential, commercial, and industrial development (all H)** in the Ohio River floodplain in recent years; however, some floodplain development is expected to continue throughout the study period. Possible impacts related to mussel populations include increased erosion and attendant siltation during construction and increased stormwater runoff and associated pollutants as impervious surfaces, such as driveways, parking lots, and roof tops increase. Phase 1 and 2 stormwater programs over time, however, should decrease stormwater impacts. (See Exhibit D, Land Use, for additional details.)

Bridge construction, redesign, or replacement (H) is expected to be a relatively infrequent occurrence during the time frame of this study. Bridges can potentially affect mussel beds because of erosion and siltation during construction and possible long-term alterations of flow patterns, which in turn can cause velocity changes and silt deposition on mussel beds. Drastic flow alterations can even lead to disappearance of entire habitats as occurred at Baker Island (formerly located at RM 49.5) (USFWS 2001). A comparison of 1987 and 2003 Pittsburgh District navigation charts documented the scouring away of Hughey Island (formerly at RM 9.0 near Neville Island) following construction of the Interstate 79 bridge piers just upstream. Available GIS data on mussel beds should be consulted during bridge planning to determine if mussel beds are present and to ensure that necessary preventive measures are undertaken. Additionally, bridge design can determine if materials spilled on the bridge will enter the river directly or be diverted to the shore where they might be contained more easily.

Other utility, industrial, and riverbed crossings (H) will occur more frequently during the study period than bridge construction. Such crossings may involve suspending aerial lines or burying lines beneath the river bottom. As with bridges, care in avoiding mussel beds in proximity to the crossing and measures to limit turbidity and siltation would limit potentially adverse impacts. Another pertinent aspect of riverbed utility crossings is that, along with buffer zones, they are protected from commercial sand and gravel dredging activities. Thus, some older utility crossings may inadvertently serve as mussel refuges.

Agriculture (H) and silviculture (M) constitute the largest land use activities by area within or adjacent to the Ohio River floodplain. These activities potentially impact mussels primarily through erosion and runoff, which carries sediments and associated pesticides and herbicides. Voluntary implementation of BMPs promoted through the USDA helps mitigate these impacts, but such BMPs are not uniformly used. Most future conversions of land use in the Ohio River corridor will occur on land currently in agriculture or in forests with potential impacts to mussels as described under floodplain development.

5.10.3 Actions Affecting Reproductive Success and Community Connectivity

This group includes actions that inhibit or prevent normal reproduction and actions that cause isolation of mussel communities.

As previously mentioned, impoundment associated with the Ohio River navigation system has lead to siltation of the river channel that not only has interfered with feeding and respiration, but impoundment may also reduce or stop reproduction and growth (Watters et al. 2003) and downstream scour that may preclude recolonization. A 1993 study cited by Watters (1994) noted that fertilization success may be related to population density, with a threshold density required for any reproductive success.

Already declining Ohio River mussel communities were further weakened and isolated after the arrival of zebra mussels in the mainstem in 1991. Because watercraft provide attachment sites for zebra mussels, the rapid spread of this invasive species has been facilitated by the movement of commercial barges, power boats, and personal watercraft (PWCs) throughout the system. Barges are the major vector because of their large surface areas and time in the river.

Numerous studies have shown that even low level dams may affect movement of fish hosts and thus restrict the ranges of some mussels. Under high flow conditions, some fish hosts may be able to traverse dams, but unless high flows occur in late spring or summer when glochidia are released, high flow fish passage will not help interpool mussel dispersal. Watters et al. (2003) indicated that declining mussel populations in the Ohio River mainstem do not seem to be attributable to loss of fish hosts. While several host fish species were extirpated in the upper river, most pools have a wide variety of fishes that could act as hosts, particularly in the middle and lower river pools. In fact, the number of fish species by pool has increased as water quality has improved since the mid-20th century. Watters et al. (2003) concluded that while it is possible that some very specific mussels, perhaps now extinct, may have been affected by the loss of proper fish hosts, those are probably exceptions.

5.10.4 Actions Beneficial to Mussels

This group includes traffic management and regulatory actions that directly or indirectly benefit mussels and their habitats and act as countermeasures to the cumulative effects of many previous listed RFFAs.

Within this grouping, nonstructural navigation improvements (H) constitute non-regulatory actions perceived as having high importance to mussel resources. Nonstructural navigation improvements refer to traffic management alternatives that do not involve modifications of lock and dam infrastructure. Because these nonstructural measures can facilitate passage of barge traffic, barge queuing and related siltation and physical damage to mussel beds are reduced. Nonstructural navigation improvements include efficiency measures, such as vessel scheduling and prioritization and self-help coordination among towboat coordinators. Related structural measures, such as expanded mooring facilities near locks and dams, may result in modest, temporary riverbed and/or land-based impacts during construction and installation. Using BMPs for sediment and erosion control and

avoiding construction of mooring facilities within or adjacent to existing mussel beds or potentially suitable habitats should help minimize impacts. Other nonstructural measures such as vessel scheduling may require improved communication and position tracking system, which are expected to have no direct environmental impacts. Further information on nonstructural measures is found in Chapter 10, Transportation.

Table 5-1 (in the section titled Laws, Regulations, Ordinances, and Programs) presents ten regulatory actions relevant to freshwater mussels. The federal Endangered Species Act (ESA) (H) and Kentucky Mussel Refuges pertain to direct protection of mussel habitat. With varying degrees of protection, permitting statutes (Sections 10, 404, and state 401 certification) also regulate activities that can directly benefit mussels and their habitats. The remaining actions listed in **Table 5-1** benefit mussels by potentially eliminating, reducing, and/or monitoring sources of pollution.

To a lesser extent, the Freedom of Information Act (FOIA) and enhanced environmental education, in general, should promote more responsible environmental decision-making that consequently will benefit mussels and other aquatic resources. Several other initiatives, including carbon sequestration, wetland mitigation banking, farmland preservation, effluent trading, pollution prevention, and environmental sustainability are relatively recent programs or concepts with potentially high, but unknown, benefits to mussels. These activities would need significant expansion from current funding levels to produce measurable impacts within the Ohio River corridor.

5.11 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

Native freshwater mussels are a uniquely rich component of the Ohio River's bottom fauna. Changes in current velocity and direction and resulting silt deposition associated with high-lift dams have compounded a decline in Ohio River mussels that began more than a century ago. Ohio River mussels have been resilient to invasions of Asiatic clams, but have been more severely threatened by the nonindigenous zebra mussel. Interest in protecting the remaining native mussel populations in the Ohio River is high. Coordinated monitoring and protection strategies have been undertaken and others are proposed, but the long-term outlook for native mussels is uncertain.

One of the seven environmental operating principles of the Corps is to strive to achieve ES. ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of cumulative effects can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An Analysis of Environmental Sustainability (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps: (1) identification of "common effects" on mussels from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix; (2) selection of indicators for ES for mussels, and their

grouping, as appropriate; and (3) consideration of the "connections" between the common effects and the indicator groups. The output of the AES consists of a qualitative (descriptive) discussion of the "connections," with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for mussels, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – the composite conditions for the selected indicators of ES for mussels do not reflect conditions that would sustain diverse, healthy populations of freshwater mussels in the Ohio River.

- Marginally sustainable – the composite conditions for the selected indicators of ES for mussels are such that diverse populations of freshwater mussels are occurring along some segments of the river; however, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of freshwater mussels for the Ohio River).

- Sustainable – the composite conditions for the selected indicators of ES for mussels are such that diverse, healthy populations of freshwater mussels are occurring along the majority of the river; further, the conditions of the indicators exceed regulatory thresholds or other pertinent measures.

Four common effects of multiple actions have been previously discussed in the section entitled "Relevant Actions Affecting Mussels"; they include actions directly contributing to habitat degradation and instability, actions indirectly contributing to habitat degradation and instability, actions affecting reproductive success and community connectivity, and actions beneficial to mussels.

Five indicators of ES were identified earlier in the section entitled "Indicators of Environmental Sustainability," and relevant information on them have been presented in the section entitled "Past to Current Baseline Conditions." Regarding their relevance for ES, the following rationale is appropriate:

- suitable habitat with stable substrates, adequate depths and currents, and connectivity to other mussel populations – these indicators are related to the physical habitat requirements associated with a sustainable mussel population; specific research studies are available to support the importance of these characteristics of the physical habitat

- adequate water quality – pollutional stresses can cause degradation of various physical, chemical, and bacteriological parameters of water quality; degraded conditions are a deterrent to a robust and sustainable mussel population

- sufficient food supplies to help ensure good growth rates and reproduction – adequate food supplies are needed to support a sustainable mussel population; degraded conditions can result from habitat impacts and instability, and other interferences associated with the life cycle of freshwater mussels

- availability of fish hosts to ensure reproductive success and maintain species diversity – as described in the earlier section on life history, the glochidia of most freshwater mussels are obligate parasites of fish, thus they must quickly attach to suitable fish species in order to metamorphose into free-living mussels; therefore, appropriate fish hosts are necessary in the life cycle of freshwater mussels

- minimal disturbance from biotic stressors, such as invasive Asian clams and zebra mussels, and from abiotic stressors, such as river traffic – biotic and abiotic disturbances disrupt the life cycle of mussels, and are a deterrent to the maintenance of a sustainable population of mussels

For the purposes of this analysis, the five indicators are grouped into three tiers for conducting the AES. The three tiers are as follows:

- first tier – "physical measures of an adequate habitat and related biotic and abiotic stressors"

  (1) suitable habitat with stable substrates, adequate depths and currents, and connectivity to other mussel populations

  (2) minimal disturbance from biotic stressors, such as invasive Asian clams and zebra mussels, and from abiotic stressors, such as river traffic

- second tier – "biological and other requirements for the life cycle of freshwater mussels"

  (1) adequate water quality

  (2) sufficient food supplies to help ensure good growth rates and reproduction

  (3) availability of fish hosts to ensure reproductive success and maintain species diversity

- third tier – "composite indicator of mussel sustainability" - sustain diverse, healthy populations of freshwater mussels (this indicator reflects the collective consideration of the five indicators in the first two tiers)

Finally, the indicators and tiers are displayed in four tables, with each table coinciding with the four groups of actions with common effects. **Tables 5-10 through 5-13** are on the following pages. **Table 5-10** relates to RFFAs that directly contribute to degradation and instability of mussel habitat, accordingly, they would cause reductions in the physical measures of adequate habitat and greater habitat disturbances due to biotic and abiotic stresses. However, as noted in the above subsection entitled "Actions Directly Contributing to Habitat Degradation and Instability," mitigation measures for several of the 13 listed RFFAs are identified, thus providing the opportunity to minimize mussel habitat degradation and instability and to minimize the decline in mussel sustainability.

Table 5-11 relates to RFFAs that indirectly contribute to the degradation and instability of mussel habitat via undesirable changes in substrates, depths and currents, and connectivity; and potential increases in biotic and abiotic stressors. However, careful examination of the 10 listed RFFAs can lead to the identification of numerous mitigation measures which could be used to minimize future declines in mussel sustainability. Implementation of such measures may require development of governmental programs or requirements and related permits and inspections.

Table 5-12 focuses on RFFAs that can affect mussel reproductive success and community connectivity. As such, the 3 listed RFFAs primarily impact biological and other requirements. For example, they may contribute to changes in water quality, disrupt food supplies, and obstruct the movement and availability of fish hosts. Mitigation measures would appear to be the most promising for movement of commercial barges, power boats, and PWCs. Better management of all forms of river traffic could help in promoting mussel sustainability.

Finally, **Table 5-13** lists 4 RFFAs that are beneficial to mussels. One relates to better management of navigation traffic, one to a federal protection law and state program, and two to enhanced education and information dissemination. These RFFAs are expected to reduce disruptions to mussel habitat, help to minimize biotic and abiotic stresses, and enhance necessary biological and other requirements. As a result, more diverse and healthy populations of freshwater mussels should occur, and ES would be promoted.

TABLE 5-10
AES Tiers for Actions Directly Contributing to Habitat Degradation and Instability

Actions Directly Contributing to Habitat Degradation and Instability	Physical Measures of an Adequate Habitat and Related Stressors	Biological and Other Requirements	Composite Indicator of Mussel Sustainability
• Channel maintenance dredging (H) • Ongoing instream sand and gravel mining (H) • Construction of lock chamber extensions (H) • Barge queuing (H) • Barge floating and storage (H) • Periodic upkeep and maintenance of locks and dams (H) • Major lock rehabilitation (H) • Continuing operation of existing locks and dams (H) • Major rehabilitation of dams (H) • Pool maintenance (H) • Port development and maintenance (H)	• Suitable Habitat Regarding Substrates, Depths and Currents, and Connectivity to Other Populations • Minimal Disturbance from Biotic and Abiotic Stressors	• Adequate Water Quality • Sufficient Food Supplies • Availability and Mobility of Fish Hosts	• Sustain Diverse, Healthy Populations of Freshwater Mussels

Actions Directly Contributing to Habitat Degradation and Instability	Physical Measures of an Adequate Habitat and Related Stressors	Biological and Other Requirements	Composite Indicator of Mussel Sustainability
• Recreational activities, especially the development and maintenance of marinas and boat launch ramps (M) • Dispersed barge traffic (H)			

TABLE 5-11
AES Tiers for Actions Indirectly Contributing to Habitat Degradation and Instability

Actions Indirectly Contributing to Habitat Degradation and Instability	Physical Measures of an Adequate Habitat and Related Stressors	Biological and Other Requirements	Composite Indicator of Mussel Sustainability
• Operation of the existing navigation system (H) • Channel modifications designed to reduce flooding (H) • Floodplain sand and gravel mining (H) and limestone aggregate mining (M) • Spills of hazardous materials (H) • Acid mine drainage (H) • Industrial activities (H) • Residential, commercial, and industrial development in the floodplain (H) • Bridge construction, redesign, or replacement (H) • Other utility, industrial, and riverbed crossings (H) • Agriculture and silviculture (H)	• Suitable Habitat Regarding Substrates, Depths and Currents, and Connectivity to Other Populations • Minimal Disturbance from Biotic and Abiotic Stressors	• Adequate Water Quality • Sufficient Food Supplies • Availability and Mobility of Fish Hosts	• Sustain Diverse, Healthy Populations of Freshwater Mussels

TABLE 5-12.
AES Tiers for Actions Affecting Reproductive Success and Community Connectivity

Actions Affecting Reproductive Success and Community Connectivity	Physical Measures of an Adequate Habitat and Related Stressors	Biological and Other Requirements	Composite Indicator of Mussel Sustainability
• Impoundments (H) • Movement of commercial barges, power boats, and PWCs (H to M) • Dams obstructing the movement of fish hosts (H)	• Suitable Habitat Regarding Substrates, Depths and Currents, and Connectivity to Other Populations • Minimal Disturbance from Biotic and Abiotic Stressors	• Adequate Water Quality • Sufficient Food Supplies • Availability and Mobility of Fish Hosts	• Sustain Diverse, Healthy Populations of Freshwater Mussels

TABLE 5-13
AES Tiers for Actions Beneficial to Mussels

Actions Beneficial to Mussels	Physical Measures of an Adequate Habitat and Related Stressors	Biological and Other Requirements	Composite Indicator of Mussel Sustainability
• Nonstructural navigation improvements (H) • Endangered Species Act and Kentucky Mussel Refuges (H) • Freedom of Information Act (FOIA) (H) • Enhanced environmental education (H)	• Suitable Habitat Regarding Substrates, Depths and Currents, and Connectivity to Other Populations • Minimal Disturbance from Biotic and Abiotic Stressors	• Adequate Water Quality • Sufficient Food Supplies • Availability and Mobility of Fish Hosts	• Sustain Diverse, Healthy Populations of Freshwater Mussels

5.12 SUMMARY AND CONCLUSIONS

The cumulative effects on Ohio River native mussels from past, present, and reasonably foreseeable future actions have been addressed herein. Mussels are the river's natural filter system, and they play an important role in the breakdown/compartmentalization of organic matter as well as provide habitat for other invertebrates. They also help stabilize the substrate. Freshwater mussels feed on organic particles, algae, and minute plants and animals, thus they are important biological components in aquatic ecosystems. Not only are mussels valued ecologically, but they also serve as indicators of the quality and overall health of the aquatic ecosystem. This indicator role is facilitated by their sensitivity to stress, limited mobility, and long life span. Some species also have value as a commercial resource in the cultured pearl industry, and serve as a major component of freshwater biodiversity.

Mussels are highly dependent on other VECs during their life cycle. Proper flow regimes are essential for sustaining healthy and diverse mussel communities. The reproductive cycle of mussels is stimulated by changes in water temperature. The glochidia of most species are obligate parasites of fish and must be attached to their fish hosts within 24 to 48 hours of their release. Further, influences on benthic substrates that may result from floodplain/riparian sources can also influence the sustainability of mussel populations. Introduction and proliferation of nonindigenous zebra mussels and other invasive species is a primary concern in considering the future well being of native mussels.

The greatest factor affecting mussels in the mainstem Ohio River is habitat alteration resulting from impoundment by the high lift dams. Maintenance of the navigation pools creates year round slackwater habitat which has had and continues to have the most significant adverse effect on mussel resources. Much of the impounded habitat is no longer suitable for a diverse and healthy mussel community, nor will it become suitable in the foreseeable future. However, this is not to imply that nothing can be done within the context of this highly modified system to improve sustainability of mussel resources. The overall challenge is determining how to manage the remaining suitable riverine habitat to maintain it and optimize its utilization by mussels, while continuing to develop and evaluate a variety of methods that could be applied to expand suitable habitat and to encourage recolonization by mussels. Further, a basic concern related to the sustainability of native mussel populations in the mainstem is associated with life cycle disruptions from changes in fish movement patterns due to the navigation system and disturbances to mussel beds and bottom habitats from sediments and chemical pollution, barge traffic, and recreational boating in specific areas.

5.12.1 Describing the Affected Environment

In the latter part of the 1800s, when the Ohio River was still free flowing, upwards of 80 species of native freshwater mussels were reported for the mainstem. However in the late 1800s, declines in mussels began to occur, with contributing factors including direct habitat disturbances and indirect effects from siltation (turbidity) and organic and inorganic pollution. The lower portion of the river was not as severely affected by water quality degradation as the upper river. As a result, the lower river typically had and continues to support more diverse mussel populations and generally higher densities than the upper river. Commercial harvesting of freshwater mussels for button manufacturing, from the late nineteenth to the mid-twentieth century, also contributed to declines in the resource, as did mussel harvesting for the cultured pearl industry from the 1950s to the late 1980s. As noted earlier, in addition to directly eliminating much of the habitat suitable for mussels, the system of high-lift locks and dams also contributed to disruptions in the life cycle of the mussels by interfering with fish aided dispersion of mussels.

Concern continues to exist about the impacts of nonindigenous species such as zebra mussels and the latest indication that the black carp has been recorded in the Ohio River. It is not at all clear that levels and impacts of zebra mussels have stabilized to the point that native mussels' sustainability is possible. It should be noted there are still many uncertainties as to the life cycle requirements of freshwater mussels, the long-term effects of invasive species including zebra mussels and black carp, the specific effectiveness of

conceptually sound mitigation measures, and the ability of mussels to colonize more areas or habitat than those currently available.

Six previously designated endangered species have not been recently found in the mainstem; however, five others have been recorded fairly recently in the mainstem (mainly as very old individuals or single individuals). This trend of apparent loss and/or diminishment of listed mussel species does not bode well for sustainability of mussels in the future. In addition to already listed species, three other mussel species (spectacle case, rayed bean, and sheepnose) are currently candidate species in line to be added to this list. The spectacle case is already generally considered extirpated from the mainstem. Further, the rabbitsfoot mussel has undergone a status review and is currently being evaluated for candidate species status.

5.12.2 Assessing the Cumulative Effects of Past, Present, and Future Actions

Multiple past and present actions have affected the freshwater mussel resource of the mainstem, and multiple future actions are also anticipated to contribute to the overall CEs on mussels. The systematic evaluation of 87 types of RFFAs indicated that 56 were ranked as having "high importance" relative to CEs, and 14 were designated as having "medium importance." The fact that 70 of the 87 RFFAs were ranked as having high or medium importance is a reflection of several issues, including the large numbers of mussel beds spatially distributed in the mainstem, the interactions of mussels with other components of the aquatic and riparian environment (i.e., being sessile, nearly everything in the water and coming off the land affects mussels), the current precariousness of the mussel resource, the fairly low level of knowledge about mussels and their life cycle requirements and fragility, and the necessity for implementing a variety of resource protection measures.

Actions that physically alter mussel beds and individual mussels include channel maintenance dredging, in-stream sand and gravel mining, construction of lock chamber extensions, barge queuing or barge fleeting and storage in the vicinity of mussel beds, periodic upkeep and maintenance of lock and dam facilities, major lock or dam rehabilitation projects, port development and maintenance, recreational boat marinas and launch ramps, and barge traffic outside of designated shipping lanes (dispersed traffic).

Actions that indirectly contribute to habitat degradation or instability include those that alter water depths and velocities, composition of bottom substrates at specific locations, and/or the physical, chemical, or biological parameters of water quality. A major contributor in this category is the impoundment that resulted from construction of the high lift dams on the system. Other examples include tributary channel modifications designed to reduce flooding, increased barge traffic close to mussel beds, nearby floodplain sand and gravel mining and limestone aggregate mining, spills of hazardous materials, acid mine drainage, wastewater discharges from various municipalities and industries, floodplain development activities (residential, commercial, and industrial), bridge projects and various riverbed crossings, and stormwater runoff from urban, agricultural, and silvicultural areas. Barge traffic, recreational boats, and personal watercraft are in this category because their underwater surfaces provide attachment sites for zebra mussels.

Actions that inhibit or prevent normal mussel reproductive cycles, or actions that cause isolation of mussel bed communities were classified as affecting reproductive success and community connectivity. Impoundment of the Ohio River via high-lift locks and dams has isolated previously connected beds and affected movements of both mussels and fish hosts.

Actions beneficial to mussels include navigation traffic management via the use of nonstructural and structural measures to reduce queuing in tailwaters; continued implementation of regulatory programs such as NPDES permits for municipal and industrial point sources, along with Phase 1 and 2 programs for stormwater runoff; pollution prevention efforts; locational sensitivity associated with the Section 10 and 404 regulatory permit programs; and implementation of the requirements of the Endangered Species Act and various state laws and programs encompassing protection of mussels. While these actions collectively will not reverse the habitat loss that has occurred, they should be of some help in recolonization and restoration of mussel populations in the remaining suitable habitat.

ES has been used as the "ultimate test" whereby the significance of CEs from multiple past, present, and future actions on mussels can be qualitatively evaluated. The Analysis of ES (AES) involved "connecting" the four common effects from the 70 high and medium importance RFFAs to the five indicators of ES used to describe the historical situation, trends, and current conditions of the mussel resource. For purposes of this analysis, the indicators were divided into three tiers: 1) physical measures of adequate habitat and related biotic and abiotic stressors, 2) biological and other requirements for the life cycle of freshwater mussels, and 3) composite indicators of mussel sustainability

After the connections were determined, the conditions for the composite indicator were evaluated based on three categories of ES defined as follows:

- Not sustainable – the composite conditions for the selected indicators of ES for mussels do not reflect conditions that would sustain diverse, healthy populations of freshwater mussels in the Ohio River.

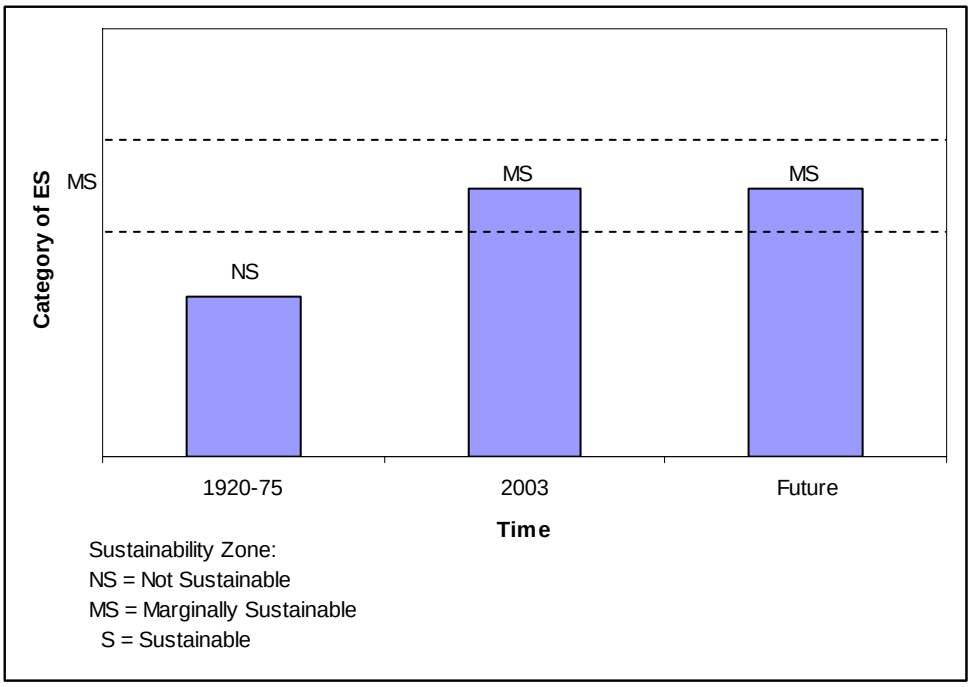
- Marginally sustainable – the composite conditions for the selected indicators of ES for mussels are such that diverse populations of freshwater mussels are occurring along some segments of the river; however, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of freshwater mussels for the Ohio River).

- Sustainable – the composite conditions for the selected indicators of ES for mussels are such that diverse, healthy populations of freshwater mussels are occurring along the majority of the river; further, the conditions of the indicators exceed regulatory thresholds or other pertinent measures.

Based upon the above-described conditions of the affected environment, the consideration of multiple actions and their effects, the discussion of the connections with the three tiers of indicators, and the ES categories, the ES of mussels of the mainstem of the Ohio River can be characterized and depicted in Figure 3 as follows:

In the time period from 1920, and continuing up to the mid-point of the last half of the 20th century, the ES of freshwater mussels in the mainstem was classified as "not sustainable." Analysis of the scientific data indicated substantial declines in various mussel populations in the mainstem, along with the recognition of multiple actions and factors causing such declines. Further, it was concluded that the composite conditions for the selected indicators of ES for mussels did not reflect conditions that would sustain diverse, healthy populations of freshwater mussels throughout the river.

FIGURE 5-3
ES of Freshwater Mussels



In the time period from 1975 up to 2003, some improvements in sustainability of the mussel resource in the mainstem were noted, although improvements were typically localized and exhibited frequent fluctuations. Improvements that have occurred resulted from: 1) reduced acid mine drainage in the upper river, 2) enhanced treatment requirements for municipal and industrial wastewater treatment plant discharges, 3) consideration of mussel bed locations in river-related permitting programs (e.g., Section 404 and Section 10 permits) and navigation system operational features (location of queuing and barge fleeting/storage areas and placement of dredged material), and 4) protection provided through designation of several mussel species as threatened or endangered under the ESA and similar state protective mechanisms.

Conversely, there has also been a general reduction in number of mussel beds since about 1975. Concern continues to exist about the impacts of nonindigenous species such as zebra mussels and black carp. It is not at all clear that levels and impacts of zebra mussels have stabilized to the point that native mussel sustainability is possible. Further, barge traffic is a primary vector for dispersion and continued re-infestation of zebra mussels. It should be noted there are still many uncertainties as to the life cycle requirements of freshwater mussels, the long-term effects of invasive species including zebra mussels and black carp, the specific effectiveness

of conceptually sound mitigation measures, and the ability of mussels to colonize more areas or habitat than what is currently available.

Recent fish movement research indicates evidence of some inter-pool movement (see fish resources chapter); however, it is not clear if sufficient host fish are able to move successfully from a mussel assemblage in one pool to another mussel assemblage in another pool, particularly during seasons when host fish could be expected to be carrying mussel glochidia.

Six previously designated endangered species have not been recently found in the Mainstem. However, five others continue to exist in the river, but it is not evident that these are in the recovery phase.

Based on the above, it is concluded that the current ES classification for the mussel resource is "marginally sustainable." This "marginally sustainable" classification is appropriate since the composite conditions for the selected ES indicators are such that diverse mussel populations are occurring only along some segments and in some pools of the river and that the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrence, with the conditions reflecting a continuing level of uncertainty regarding appropriate quantitative measures of the ES of freshwater mussels.

Examination of past and present conditions and an examination of the 70 RFFAs of high and medium importance to freshwater mussels resulted in the conclusion that future sustainability of mussels in the mainstem will continue to be marginal. This assessment of future marginal sustainability acknowledges that many unknowns remain and that recovery of Ohio River mainstem native mussel populations will be a long-term process involving many years of collaborative efforts and monitoring. A primary concern is that loss of mussel habitat is and will continue to be a limiting factor influencing the long-term sustainability of mussels. Development, especially river based, if not carefully planned could cause mussel resources to become unsustainable in the future. Evidence of recruitment and population stability is necessary to validate viability of mussel resources. To illustrate the many uncertainties, the following tasks to effect recovery have been selected from a more extensive list from Watters (1994) and supplemented by the ORMSS Interagency Working Group:

- Identify other resource values associated with mussel populations, including fish hosts, key food organisms, and habitat elements.
- Protect and manage mussel populations and their habitat on a site-specific basis to avoid future net loss of available habitat or populations.
- Characterize the habitat that best supports species of concern, including historically important sites.
- Restore habitats and reintroduce mussel species to suitable areas.
- Conduct searches for additional populations.
- Enforce all laws and regulations pertaining to collection of specimens and protection of habitat.
- Enhance knowledge of life histories for species of concern, including life histories of host fishes.
- Identify the potential effects and responses to zebra mussel and Asian carp invasions and their control measures.
- Evaluate the efficacy of removing zebra mussels from vessels to prevent re-infesting areas.
- Increase public and agency awareness of existing laws that protect mussels.
- Use media opportunities to reach the general public and encourage involvement in the recovery process.
- Restore and protect direct connections to tributary populations.

- Restore mobility of fish hosts through dams at appropriate times of the year needed for mussel reproduction.

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Chapter 6

RIPARIAN/FLOODPLAIN RESOURCES

6.1 TABLE OF CONTENTS

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6.2 DEFINITION AND IMPORTANCE OF RIPARIAN/FLOODPLAIN TERRESTRIAL RESOURCES

This chapter considers how Cumulative Effects (CE) of human use of the Ohio River and other factors have influenced Riparian/Floodplain Resources (RFR) and what impacts to these resources may be anticipated in the foreseeable future. In the Ohio River Mainstem Systems Study (ORMSS), RFR include terrestrial habitats, wetlands, soils and geology, islands, and floodplain hydrology.

The National Research Council (NRC) (2002) has identified the lack of a consistent definition for "riparian" as a major problem of federal and state programs that might manage and protect riparian areas. To address that concern, the NRC has developed the following working definition:

> Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients of biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface

> hydrology connect water-bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines (NRC 2002).

Further, riparian areas include portions of the channel system and associated features (gravel bars, islands, and wood debris); a vegetated zone of varying successional states influenced by floods, sediment deposition, soil-formation processes, and water availability; and a transitional zone to the uplands of the valley wall - all underlain by alluvial aquifers. Although they occupy only a small proportion of the total land base in most watersheds, riparian areas are regional hot spots for biodiversity and exhibit high rates of biological productivity in contrast to larger landscapes (NRC 2002).

The varied components of RFR add to the difficulty of precisely defining them. For example, several habitat types occur within riparian areas, including wetlands, bottomland hardwood forests, prime and other agricultural land, and transitional/upland habitats. Also included in this riparian chapter are islands, which represent a unique and limited habitat type. Concerns related to riparian habitat include loss due to development, habitat conversion and fragmentation, and changes in habitat quality due to natural occurrences and human actions.

Wetlands are transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water (USFWS 2001). This study considers wetlands that exist within the 500-year floodplain of the Ohio River mainstem and slackwater zones of its tributaries. Construction of dams on the Ohio River inundated many mainstem wetlands while creating conditions conducive to formation of wetlands in embayments of the tributaries. Concerns related to wetland resources include wetland loss due to conversion for agricultural use or development projects, decline in quality due to modifications on adjacent lands, inappropriate and unauthorized filling, long-term changes resulting from refuge and wildlife management programs, and fragmentation.

Agricultural and forested lands along the mainstem to some extent provide habitat for a variety of species. They also can act as important buffer areas between mainland development and the Ohio River, with buffering efficiency varying with type and extent of vegetation. The amount of undisturbed terrestrial and wetland habitat remaining is one measure of the health of riparian resources along the Ohio River.

Hydrological processes since impoundment have created a few small islands in the Ohio River. Islands in general, however, typify a dynamic and diminishing resource in the mainstem. Human disturbances and an island's unique underlying geology are among factors influencing its vulnerability or persistence.

Several physical parameters related to the Ohio River also can affect riparian resources, including flow velocity, sediment transport, fluctuating pool levels, large woody debris, and manmade modifications (jetties, pipelines, marinas, etc.). Further, complex interrelationships among the various components of riparian areas, as well as interactions between riparian areas and other Valued Environmental Components (VECs) affect the

health and sustainability of riparian resources. This chapter discusses physical parameters under the general headings of floodplain hydrology and soils and geological features.

Floodplain hydrology includes factors that influence the physical characteristics and variability of water flow within a given river system and the resulting physical and biological characteristics of the riparian zone influenced by the flow regime. Factors influencing floodplain hydrology include varying combinations of climatic, geomorphic, and hydrologic processes, for example:

- Climate heavily influences watershed vegetation communities, streamflow magnitude and timing, water temperature, and many other key watershed characteristics.
- Geomorphology refers specifically to the study of the landforms on the earth and the processes that change them over time. Fluvial geomorphology, which refers to structure and dynamics of stream and river corridors, is especially important to understanding the formation and alteration of the stream or river channel, as well as the floodplain and associated upland transitional zone.
- Finally, the hydrologic cycle is a natural, solar-driven process of evaporation, condensation, precipitation, and runoff (from *Introduction to Watershed Ecology;* http://www.epa.gov/watertrain/ecology/index.html).

Compounding the influence of natural processes are changed floodplain hydrology and characteristics resulting from development projects or other human induced changes in land use. These influences include dams and other instream developments, activities along the riverbank or within the riparian zone, and upstream activities throughout the watershed.

The floodplain hydrology resulting from the combination of natural and human influences, subsequently, affects the full spectrum of riparian features. It also significantly affects the suitability of the riparian zone for various human activities such as agriculture, recreation, transportation, housing, and commerce.

Soils and geological features of lands near the mainstem are of concern for several reasons, including the land's use/eligibility as prime farmland. Further, groundwater characteristics, including flow and quality, can be disrupted by various human activities. In addition, groundwater flow can influence the movement of contaminants from waste disposal sites to the river. Soil characteristics also can be of concern due to potential erosion and contribution to non-point source water pollution. Bank instability can occur due to fluctuating water levels, propeller "wash," and inappropriate barge "toe-ins".

6.3 OBJECTIVES AND SCOPE OF THE RIPARIAN/FLOODPLAIN ECOLOGICAL RESOURCES STUDY

6.3.1 Objectives

This chapter assesses the system-wide CEs on RFR of all likely major navigation improvements along the mainstem of the Ohio River during the planning period from 2000 to 2070. Impacts directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFAs) by the Corps and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFAs. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, actions by non-government entities, and predictions of general economic expansion and development as well as regulatory changes.

Results of the CEA will lead to further consideration of:

1) the acceptability of the impacts of the RFFAs on the affected resources
2) how the proposed navigation improvements contribute to those impacts, and
3) what constitutes a sustainable system for RFR of the Ohio River mainstem.

6.3.2 Geographic Scope

The geographic focus for RFR includes the 500-year floodplain, which encompasses an area that has a 0.2 percent annual chance of flooding. In addition to the Ohio River mainstem, the area of focus includes the 500-year floodplain of tributaries and embayments that are influenced by pool elevations of the mainstem lock and dam projects.

6.3.3 Time Frame

The established time frame for this project is 1920 to 2070. The earlier date approximates the initiation of the Corps' long-term 20th century lock and dam construction activities on the Ohio River while the latter date approximates the end of the 60-year planning horizon encompassed by ORMSS. Discussion of impacts on RFR requires consideration of conditions before 1920 in order to understand how lock and dam construction and operation have interacted with other events to influence RFR.

6.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. A more detailed discussion of the scoping meetings is presented in Exhibits A and B of this report.

The meetings were attended by 185 persons and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted.

Riparian/floodplain protection was a major focus of the meetings. **Table 6-1** presents comments that directly and indirectly addressed RFR.

TABLE 6-1
Comments from Public Scoping Meetings

Direct Comments on Riparian/Floodplain Resources	Relevance to Riparian/Floodplain Resources	Total Comments
Need to consider 404 application approvals and resultant actions as direct USACE actions	Potential damage to riparian areas without Corps oversight	1
Loss of shoreline trees and river property caused by barge activity	Damage to riparian vegetation by navigation activities	7
Failure of barges to stay in designated shipping lanes	Erosion and damage to riparian habitat	2
Increased spills & accidents potentially affecting aquatic life & impairing water quality	Potential loss of riparian wildlife and habitat	1
Overall effects of navigation structures & activity on groundwater levels	Changes to hydrological connections affecting groundwater	1
Need to protect public groundwater supplies	Potential groundwater pollution from floodplain activities	1
Mouths of tributaries silted in, impairing fish habitat, limiting access & damaging property	Loss of riparian habitat and economic losses due to pool maintenance	5
Need to improve sediment & erosion control from public & private developments	Protection of riparian vegetation/habitats	1
Possible use of dredge spoils to improve riparian or island habitat or for upland filling	Creation of new wildlife habitat in riparian areas; mitigation for impacts of pool maintenance	2
Habitat damage caused by Corps' permitted sand & gravel dredging	Loss or damage to riparian habitat from materials disposal	1
Bank undercutting & failure caused by increased barge traffic & queuing & wave action	Erosion and damage to riparian habitat by navigation activities	7
Bank erosion caused by Corps controlled pool fluctuations	Bank failure and damage to riparian habitat	3
Shoreline instability threatening costly restoration projects in wildlife management areas	Economic loss and physical damage to restored riparian areas	1
Need for elevation management to prevent water levels from exceeding flood stage	Protection of riparian vegetation/habitats	1
Loss of green space & wildlife habitat with development of marina facilities	Preservation of existing riparian vegetation/habitats	5
Development of floodplains & wetlands resulting in increased runoff & habitat loss	Preservation of existing riparian vegetation/habitats	4
Need for coordination with community floodplain coordinators along river	Better riparian protection through more uniform floodplain regulations	1
Loss of wildlife corridors as shoreline develops	Preservation of existing riparian vegetation/habitats	2
Need to focus on riparian corridors & green space near power plants	Lessening of aesthetic and runoff impacts	1
Clarification of differences between floodway and floodplain	Enhanced understanding of riparian areas	1
Other Comments with Implications for Riparian/Floodplain Resources	**Relevance to Riparian/Floodplain Resources**	**Total Comments**
Importance of including commercial dredging & associated permitting process in CEA	Potential impacts of these activities on riparian areas	2
Complaints received by Ohio Division of Watercraft about barges damaging shoreline	Potential impacts of this activity on riparian areas	1

Direct Comments on Riparian/Floodplain Resources	Relevance to Riparian/Floodplain Resources	Total Comments
near Greenup L/D		
Need for long-term plan to address silt removal & prevent future sedimentation	Protection of riparian vegetation/habitats	1
Damage/destruction of mussel beds & fish spawning areas	Related to embayments that are aquatic nursery areas	4
Severe erosion occurring at Slough Wildlife Management Area near Henderson, KY	Economic loss and physical damage to restored riparian area	1
Pools maintained at higher levels than agreed on in flowage easement contracts with property owners	Protection of riparian vegetation/habitats & property	2
Loss of significant farmland to urban development along river corridor	Loss of associated wildlife areas & groundwater connections	3
Need to develop comprehensive plans for development along river	Protection of riparian vegetation/habitats	3
Danger to recreational users of submerged trees toppled by bank erosion	Safety concerns related to riparian erosion damage	1
Increased development of scenic byways & bikeways	Enhanced use and appreciation of riparian areas	2
Loss of unique, sensitive species due to water quality problems & habitat modifications	Preservation of existing riparian vegetation/habitats	2
Riverfront development constraints related to endangered species	Concern related legislation will inhibit development	1
Need for stricter litter laws	Relates to riparian area aesthetics	1

6.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

Indicators of Environmental Sustainability (ES), which vary by VEC, generally provide benchmarks for measuring CEs on a given resource or VEC. The primary uses of indicators are to characterize the current status of a resource and to track or predict significant changes to the resource.

The ES indicators selected for RFR include:

- adequacy of hydrologic connections between riparian areas and
- adjacent water bodies and uplands
- capacity for water storage in floodplain
- quality of soil structures
- adequacy of water table and groundwater recharge
- sustainability of sediment dynamics
- capacity of riparian areas to intercept pollution
- integrity of riparian habitats, and
- measures of biodiversity

An important feature of the definition of riparian areas quoted at the beginning of this chapter is the concept of riparian areas having gradients in environmental conditions and functions between upland and aquatic ecosystems (NRC 2002). The eight indicators listed above were developed within the context of functionality because a resource cannot be sustainable if its functions are impaired. Environmental services performed by riparian areas generally fall into three major functional categories: 1) hydrology and sediment

dynamics, 2) biogeochemistry and nutrient cycling, and 3) habitat and food web maintenance.

The following text from NRC (2002) makes connections between riparian functions and the indicators listed above:

> Functions related to hydrology and sediment dynamics include storage of surface water and sediment, which reduces damage from floods downstream from the riparian area. Riparian areas intercept, cycle and accumulate chemical constituents in shallow subsurface flow to varying degrees, with the societal benefit of removing pollutants from overland flow and shallow groundwater that might otherwise contaminate nearby waterbodies.
>
> Maintaining biodiversity is one of the most important functions of riparian areas and is the basis for many valued fisheries, in addition to birds and other wildlife habitat. The benefits of functioning riparian areas to fish stem directly from the role of vegetation in controlling temperatures, stream structure, and sedimentation. Riparian areas themselves are home to an abundance of animal life, including invertebrates, almost all amphibian species and many reptiles, the majority of bird species (particularly in the semi-arid West) and many mammal species with semiaquatic habitats. In addition to being characterized by unique assemblages of plants compared to wetlands and uplands, riparian areas frequently harbor rare plant species.

6.6 LAWS, REGULATIONS, ORDINANCES, AND PROGRAMS

Legal strategies to manage and protect riparian areas have only begun to be developed in the past decade. Most frequently, riparian protection is an indirect consequence of other environmental objectives, such as improving water quality or protecting wetlands. **Table 6-2** illustrates the broad spectrum of federal regulations and established programs that directly or indirectly influence RFR associated with the Ohio River mainstem.

TABLE 6-2
Laws, Regulations, Ordinances and Programs Relevant to RFR

Law/Program	Key Components	Relevance to RFR
Clean Water Act (CWA) (U.S. Environmental Protection Agency)	• Establishes structure for regulating pollution discharges into U.S. waters (NPDES permits) • Gives EPA authority to implement pollution control programs • Requires establishment of water quality standards • Recognizes need to address nonpoint source pollution	Implementation plans to achieve water quality standards in impaired waterbodies can involve riparian management strategies. Specific provisions of the CWA (e.g., §319) provide for demonstration projects in riparian areas.
National Environmental Policy Act (NEPA)	• Requires preparation of environmental impact	Includes water quality & habitat impacts of new

Law/Program	Key Components	Relevance to RFR
(Council on Environmental Quality & other agencies)	assessments for new construction projects by private and governmental agencies.	projects along the Ohio River such as power plants, Corps projects and riverfront developments.
Water Resources Development Act (U.S. Army Corps of Engineers)	• Authorizes Corps' port development, navigation, flood control and erosion control projects through the 1986 act and subsequent amendments	Contains provisions for environmental assessment and mitigation
National Flood Insurance Act (Federal Emergency Management Agency)	• Encourages adoption of state & local floodplain regulations restricting certain types of development within floodplains.	Limits development impacts in riparian areas.
Safe Drinking Water Act (SDWA) (USEPA)	• Provides for establishment of primary regulations for the protection of public health and secondary regulations related to taste, odor and appearance of drinking water	Helps protect public water supplies for approximately three million people who use Ohio River as their source of drinking water
Oil Pollution Act (USEPA & U.S. Coast Guard)	• Strengthened EPA's ability to prevent & respond to catastrophic oil spills	Protects RFR from pollution & damage from oil spills.
Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (USEPA)	• Provides for liability, compensation, cleanup and emergency response for hazardous substances released into the environment and cleanup of inactive hazardous waste sites	Includes abandoned hazardous waste sites in the floodplain.
Emergency Wetlands Resources Act (U.S. Fish & Wildlife Service)	• Authorizes purchase of wetlands from Land and Water Conservation fund • Requires states to include wetlands in Comprehensive Outdoor Recreation Plans • Provides funding for the Migratory Bird Conservation Fund	Encourages federal-state cooperation in wetlands protection and outlines funding mechanisms
Endangered Species Act (USFWS)	• Authorizes determination & listing of threatened & endangered species • Prohibits unauthorized taking, possession, sale & transport of endangered species • Provides for land acquisition to protect endangered species	Establishes framework for protection of threatened & endangered riparian species
Fish & Wildlife Act (USFWS)	• Section 7(a) requires USDI to take steps required for management & protection of fish & wildlife resources through research, acquisition of land & water & other means.	Establishes a comprehensive national fish & wildlife policy applicable to RFR
Fish & Wildlife Coordination Act (USFWS)	• Requires that whenever water bodies are modified by federal agency, that agency first shall consult with the USFWS and with appropriate state agencies with a view toward wildlife conservation	Provides for equal consideration and coordination of RFR wildlife conservation with other aspects of water resources development

Law/Program	Key Components	Relevance to RFR
Migratory Bird Conservation Act (U.S. Dept. of Interior)	• Provides for the acquisition and maintenance of public land for habitat preservation of migratory birds	Applies to land, water and transitional areas, e.g., riparian areas
Migratory Bird Treaty Act (U.S. Dept. of Interior)	• Implements various treaties and conventions between the U.S., Canada, Mexico, Japan and the former Soviet Union for the protection of migratory birds. Prohibits taking, killing and possession.	Protects migratory birds utilizing RFR.
National Wildlife Refuge System Administration Act & National Wildlife Refuge System Improvement Act (USFWS)	• Provides guidance for management and public use of refuge system, including development of comprehensive conservation plan for each refuge	Guide management & public use of Ohio River Islands National Wildlife Refuge
North American Wetlands Conservation Act (USFWS with North American Wetlands Conservation Council)	• Provides funding and implementation of the North American Waterfowl Management Plan & North American nations wetlands agreement	Provides funding support for migratory bird conservation in the Ohio River valley
National Invasive Species Act (U.S. Dept. of Trans-portation and Aquatic Nuisance Species Task Force)	• Requires all vessels operating in US waters that are equipped with ballast tanks to comply with guidelines designed to prevent and reduce the dispersal of aquatic nuisance species	Helps reduce the further introduction and dispersal of invasive species that can disrupt riparian ecosystems
Refuge Recreation Act (U.S. Dept. of Interior)	• Authorizes USDI to administer conservation areas for recreational use when such uses do not interfere with areas' primary purpose	Allows recreational use of Ohio River Islands National Wildlife Refuge
Farm Security and Rural Investment Act of 2002 (a.k.a. Farm Bill) (USDA Natural Resources Conservation Service)	• Includes various incentive programs to promote installation of riparian buffers. • Swampbuster provisions withhold certain USDA benefits from farmers who convert or modify wetlands • Offers opportunities for wetlands mitigation	Helps improve and/or preserve environmental functions & value of riparian areas in the Ohio River floodplain
Executive Order 11988, Floodplain Management & Executive Order 11990 (Both in 1977) (Executive Branch)	• Prevents federal agencies from contributing to the adverse impacts of floodplain development & modification	Restricts federal development in Ohio River floodplain wherever there are practicable alternatives
Executive Order 13112, Invasive Species (1999) Multi-agency National Invasive Species Council)	• Requires federal agencies to prevent the introduction of invasive species and provide for their control and to minimize their economic, ecological and human health impacts.	Helps to maintain and/or restore the ecological integrity of riparian areas.

Law/Program	Key Components	Relevance to RFR
Corps Permitting Statutes (U.S. Army Corps of Engineers)	• Section 10 of Rivers and Harbors Act (1899) prohibits the unauthorized obstruction or alteration of any navigable water of the United States. • Section 404 of Clean Water Act authorizes the Corps to issue permits for the discharge or dredged and fill materials into U.S. waters.	Permits require assessment of impacts on water quality and aquatic ecological resources and mandate mitigation of adverse impacts
Small Navigation Projects (USACE)	• Section 107 of Rivers and Harbor Act (1960) authorizes COE to develop and construct small navigation projects for harbor protection.	Includes impacts of such actions on riparian/floodplain resources
State Water Quality Certification (Appropriate state or interstate pollution control agencies)	• Section 401 of the Clean Water Act (CWA) requires certification from state or interstate water control agencies that a project is in compliance with established effluent limits and water quality standards.	Provides opportunity for state or interstate scrutiny of such actions on riparian and other aquatic resources
Site Remediation Statutes (USEPA)	• Includes CERCLA, RCRA, SARA and related state programs that focus on cleanup and restoration of contaminated sites.	Potentially reduces groundwater and soil pollution sources and contributions to pollution loads in the Ohio River
TMDL Program (USEPA)	• Increasingly important section (§303) of CWA; regulates maximum pollutant load a water body can receive and still attain water quality standards.	Many TMDL implementation plans require restoration of riparian areas as a management measure to achieve nonpoint source pollution reductions.
Phase 1 & 2 NPDES Program (USEPA)	• Also developed within the CWA, requires municipalities and certain industrial and construction sites to adopt BMPs to control nonpoint sources of pollution.	Should reduce pollution characteristics of stormwater discharges from urban and industrial zones along the Ohio River
National CSO Control Policy (USEPA)	• Published by USEPA, calls for communities to implement long-term plan for combined sewer overflows (CSOs) to comply with the CWA. •	Should reduce pollution to RFR from a major urban source
Spill Response (U.S. Coast Guard, ORSANCO)	• Includes emergency response activities for river-related spills and accidental discharges and is related to the Oil Pollution Act and Section 301 of the Clean Water Act.	Minimizes adverse impacts of spills and discharges on RFR and on water quality
ORSANCO Monitoring (ORSANCO)	• Encompasses ongoing water quality and aquatic ecology monitoring programs by the Ohio River Valley Water Sanitation Commission.	Helps track trends in water quality and biological communities and provides database that can inform env.decision-making

6.7 PAST TO CURRENT BASELINE CONDITIONS

In *Riparian Areas: Functions and Strategies for Management*, the NRC underscores the profound lack of information on riparian land status and trends in the United States (NRC 2002). Before riparian functions began to be understood, the majority of riparian areas in the U.S. were converted or degraded such that their functions were greatly diminished in comparison to what occurred historically. Limited landscape level assessments indicate that the spatial extent of riparian forest has been substantially reduced, plant communities on floodplains have been converted to other land uses or replaced by developments, and the area of both woody and non-woody riparian communities has decreased. These nationwide trends are applicable to Ohio River riparian areas.

Wetland components of riparian areas have received greater attention historically and provide some information about trends in riparian acreage and condition. Four of the seven states that have experienced the greatest wetland losses nationally are in the Ohio River basin -- Ohio, Kentucky, Indiana and Illinois.

The following baseline information on the Ohio River mainstem RFR focuses on terrestrial habitats; including wetlands, and the underlying geology; soils; and floodplain hydrology which have influenced their composition and which sustain RFR. Limited information on trends in riparian areas over time is included later in this section.

6.7.1 Physiography and Geomorphic Considerations

Based on average annual discharge, the Ohio River is the second largest river in the United States, surpassed only by the Mississippi River, below its confluence with the Ohio (USGS streamflow data, cited in USEPA 2000). The Ohio River is formed by the confluence of the Allegheny and Monongahela Rivers at Pittsburgh, Pennsylvania, and flows 981 miles in a southwesterly direction to join the Mississippi River at Cairo, Illinois. The elevation of the Ohio's riverbed drops 429 feet from the headwaters to its confluence with the Mississippi River (USEPA 2000). The mainstem's major tributaries, from upstream to downstream, include the Allegheny, Monongahela, Beaver, Muskingum, Kanawha, Guyandotte, Big Sandy, Scioto, Licking, Great Miami, Kentucky, Green, Wabash, Cumberland, and Tennessee rivers**.** The 203,940 sq.-mi. Ohio River basin encompasses several physiographic provinces, but the Ohio mainstem is primarily influenced by the four provinces described in **Table 6-3**.

TABLE 6-3
Physiographic Provinces Associated with the Ohio River Mainstem

Physical Features	Appalachian Plateau	Central Lowlands	Interior Low Plateau	Coastal Plain
Location relative to mainstem	Pittsburgh (RM 0) to Vanceburg KY (RM 380)	North of Ohio River from central Ohio through Indiana and Illinois	Vanceburg, KY (RM 380) to New Liberty, IL (RM 928)	Approx. New Liberty, IL (RM 928) to Cairo, IL (RM 981)
Topography	Moderate to strong relief Steep stream gradients	Flat to slightly rolling due to glaciation	Rolling hills underlain by limestone to lower plateaus with silt-filled valleys	Undulating plains of reconsolidated sediments and highly dissected loess capped bluffs
Floodplain	Well-developed alluvial floodplain with numerous meanders Narrow valley	Not included in Ohio River floodplain*	Floodplain flattens from upstream to downstream; very broad in places (up to 7.5 mi. wide)	Extensive floodplain with sandy ridges forming natural levees, numerous swamps, islands and sandbars Lowest 11 miles to river are composed of Mississippi River delta and its bottomlands Remnant of higher floodplains exist as terraces
Groundwater supplies	Moderate supplies in permeable sand & gravel	Extensive supplies in some areas with buried pre-glacial streams	Variability typical of limestone areas	
Soils	Poor quality	Till Plains include some of basin's richest agricultural land	Good agricultural soils to thin forested soils	Sandy; some unstable loess
*Natural features and human activities within the Central Lowlands influence the Ohio River mainstem, but do not overlap with the river. This is consistent with glaciation of the Till Plains and the role of glaciation in determining the present-day course of the Ohio River south of the glacial boundary.				
SOURCES: U.S. Army Corps of Engineers, 2000. ORMSS Integrated Decision Document and Environmental Assessment, Ohio River Ecosystem Restoration Program, Appendix C, and U.S. Fish & Wildlife Service, Ohio River Valley Ecosystem Team, 1999. Strategic Plan for Conservation of Fish and Wildlife Service Trust Resources in the Ohio River Valley Ecosystem.				

6.7.2 Floodplain Description

Thorp (1992) noted that the Ohio River has a constricted channel upstream of Louisville, Kentucky (RM606); however, small floodplains are common within portions of this area. Downstream from Louisville, Thorp describes the Ohio River as a floodplain river. While this description is generally true, the dimensions of the Ohio River floodplain in various river reaches are influenced by the erodibility of the rocks forming the valley (USACE 2000). The floodplain is narrow upstream (e.g., 0.8 mi. at Pittsburgh) as it flows

through a relatively flat-lying sequence of sedimentary rocks. By Vanceburg, KY (RM 380) the floodplain has broadened to 1.6 miles, but then remains fairly narrow almost to Louisville, because the valley walls are formed by relatively resistant shaly limestone. From above Louisville to West Point, KY (RM 630), the floodplain widens where more erodible soft shales form the valley walls. Downstream from West Point, however, the river enters an area of more resistant limestone and the valley narrows for approximately 90 miles. Near Hawesville, KY (RM 724), the valley enters soft shale and sandstone and, consequently, broadens. The valley narrows again near Shawneetown, IL (RM 858) where more resistant sandstones occur, then broadens near the confluence with the Cumberland River (RM 920), where the floodplain consists of soft unconsolidated sediments of the Mississippi Valley (USACE 2000). Land use data and National Land Cover maps for the Ohio River floodplain are included in Exhibit D, Land Use.

Although the drainage area for the Ohio River Basin totals 203,940 square miles, the drainage area encompassed by Ohio River tributaries with watersheds of 1,000 square miles or greater is 182,370 square miles, or 89.4 percent of the total drainage area (USACE 2000). Consequently, less than 11 percent of the entire Ohio River drainage basin contributes directly to the mainstem.

The *Ohio River Restoration Program Environmental Assessment* (USACE 2000) describes the Ohio mainstem as a relatively stable river when compared with other systems of similar size and type. This is verified by considering the hydraulic relations for a variety of rivers and comparing conditions that occur on the average for other alluvial river systems. The Ohio River is narrower than alluvial channels commonly studied. Also, the depth is greater and the width-depth ratio is smaller.

6.7.3 Soils and Sedimentation

Riparian soils are highly variable in structure, particle size distribution, and other factors that occur not only horizontally across a riparian area but also vertically within a soil profile. Such variability results from interactions between streamflow patterns and sediment transport in conjunction with variations in local geology, channel morphology, and streamside vegetation. Sediments deposited on floodplains undergo biogeochemical changes that over time transform flood-deposited sediment into riparian soils. Because of their high levels of nutrient and organic matter, floodplain soils are some of the most productive agricultural soils in the nation (NRC 2002).

The alluvial sediments on the upper Ohio River Valley consist of glaciofluvial fill or medium to coarse-grained sand and gravel of Wisconsin Stage and post-glacial terrace deposits mainly of the “point-bar” type of river sediment. These glaciofluvial deposits are as much as 125 feet thick and are composed of 45 to 83 percent locally derived pebbles of Pennsylvanian and Permian rock derivation, and foreign pebbles. Granite, quartzite, vein quartz, and chert pebbles comprise the foreign material that has been introduced into the watershed by glaciation. The sedimentary structures are predominately the cut and fill type that is characteristic of aggrading streams. The individual beds are highly lenticular and there are abrupt changes in particle size, both horizontally and vertically. The floodplains commonly consist of thick sections of sand, silt, and clay that are commonly referred to as loams. Eolian deposits, known as loess, occur as a blanket deposit along the Ohio River in

the Purchase and Western Coal Field regions. Away from the river, these deposits grade into loams. East of mile point 785 and the Green River, there is very little typical loess.

In the area of the Ohio River Islands National Wildlife Refuge (RM 0 - RM 437), most soils on floodplains and islands are classified as fine sandy or silt loams of the Huntington, Chagrin, and Linside series. The Huntington and Chagrin soils are very well drained while the Linside series are classified as moderately well drained and somewhat poorly drained soils. A small amount of poorly drained Melvin silt loam is located primarily on Blennerhassett and Grape Islands (USFWS 2000b).

Table 6-4 summarizes the primary soil types bordering the Ohio River, following USDA taxonomy.

TABLE 6-4
Soil Types Bordering the Ohio River

River Segment	Predominant Soil Type	Description	Water Storage Erodibility
RM 0-25	Order-Ultisols, suborder-Udalts, great group - Hapludult.	Strongly leached acid forest soils with relatively low native fertility. Found in humid temperate and tropical areas of the world, typically on older, stable landscapes. Ultisols have a subsurface horizon in which clays have accumulated, often with strong yellowish or reddish color due to the presence of Fe oxides, such as in the 'red clay' soils of the southeastern United States. Support productive forests, but are poorly suited for continuous agriculture without the use of fertilizer and lime.	High water-holding capacity Heavily weathered and erodible
RM 25-330	Inceptisols>Onchrepts> Dystrochrepts	**Inceptisols** exhibit minimal horizon development and lack features that are characteristic of more developed soil orders. They are widely distributed, occur under a wide range of ecological settings and are often found on fairly steep slopes, young geomorphic surfaces, and on resistant parent materials. Land use varies considerably. Inceptisols are often found in mountainous areas and are used for forestry, recreation, and watershed. **Dystrochrepts** soils are generally thin and weakly developed with a large percentage of rock fragments. Forest productivity is dependent on availability of water due to low water holding capacity of these soils.	Water holding capacity varies with amount of rock fragments**.**
RM 330-410	Alfisol>Udalf	**Alfisols** are moderately leached forest soils that have relatively high native fertility. These soils are well developed and contain a subsurface horizon in which clays have accumulated. Mostly found in temperate humid and subhumid regions of the world.	

River Segment	Predominant Soil Type	Description	Water Storage Erodibility
		The combination of generally favorable climate and high native fertility promotes very productive soils for both agricultural and silvicultural use.	
RM 410-580	Inceptisols>Onchrepts> Eutrochrepts	**Eutrochrepts** form in glacial till, have low water holding capacity due to the large percentage of rock fragments in the subsoil, and are most suitable for pasture and grazing.	
RM 580-610	Alfisol>Udalf	See above.	
RM 640-710	Order-Ultisols, suborder-Udalts	See above.	
RM 710-981	Mollisol>Aquolls	**Mollisols** form in grassland ecosystems and are characterized by a thick, dark surface horizon. This fertile surface horizon, known as a mollic epipedon, results from the long-term addition of organic materials derived from plant roots. Poorly drained Aquolls occupy lower-lying landscape positions.	Aquolls have high water-holding capacity. May require tile drainage to make crop production possible.
SOURCE: Natural Resources Conservation Service. 1999. *Soil Taxonomy, A Basic System of* Soil Classification for Making and Interpreting Soil Surveys. 2nd ed.			

6.7.4 Hydrological Considerations

In addition to precipitation, riparian areas along the Ohio River mainstem receive water from three main sources: 1) groundwater discharge, 2) overland and shallow subsurface flow from adjacent uplands, and 3) flow from the Ohio River by various pathways. General functions related to riparian hydrology include storage of water and sediment, which reduces flood damage to areas downstream. Riparian areas also intercept, cycle and accumulate chemical constituents in shallow subsurface flow, with the environmental benefit of removing pollutants from overland flow and shallow groundwater that might otherwise contaminate nearby waterbodies (NRC 2002).

Groundwater is available from three sources along the Ohio River mainstem:

1) Most groundwater along the mainstem's length is recovered by induced river discharge from the predominantly Pleistocene glacial-outwash sediments over which the Ohio River flows. These sediments, consisting of unconsolidated sand, gravel, silt, and clay deposits, can yield large volumes of water to industrial, municipal, and domestic wells. An ORSANCO groundwater publication from 1984 includes an estimate of 4,500 billion gallons of water stored in the Ohio River mainstem aquifer. Because aquifer volume increases with downstream distance, more than 70 % of the storage is in the lower river, as indicated in **Table 6-5**:

TABLE 6-5
Water Stored in the Ohio River Aquifer

River Reach	Groundwater Stored (billions of gallons	% of Total
Upper Third	371	8.2
Middle Third	875	19.4
Lower Third	3,255	72.3
Total	4,501	
SOURCE: ORSANCO 1984		

Because surface contaminants can migrate quickly through coarser sediments, the Ohio River alluvium is sensitive to pollution. In fact, the Kentucky groundwater sensitivity map depicts the Ohio River aquifer as highly sensitive to contamination (http://kgsweb.uky.edu/download/wrs/sensitivity.pdf).

2) Groundwater is also associated with the Coastal Plain at the confluence with the Mississippi River in southwestern Kentucky and extreme southern Illinois. Semi-consolidated Cretaceous-age and younger sand, silt, gravel and clay deposits underlie this area. The coarser sediments are prolific aquifers for multiple uses, but are sensitive to pollution, especially at shallow depths. In general, however, the relatively low flow velocity within deeper saturation zones provides significant protection from contamination. Consequently, the Kentucky groundwater map rates groundwater contamination sensitivity as slight to moderate.

3) Groundwater also is found in the bedrock beneath the alluvial deposits and soils along the mainstem, but has less influence on riparian areas than the alluvial sources.

Groundwater adjacent to the Ohio River contains varying amounts of calcium, magnesium, iron, and other ions that contribute to water hardness, expressed as parts per million (ppm) of dissolved solids. Salt brines, with dissolved solids concentration exceeding 1,000 ppm occur at depths of less than 150 feet below the ground surface along many parts of the Ohio (USACE 2000).

Many ecological functions along the Ohio River have been lost, as riparian areas have become hydrologically disconnected from their adjacent stream channels. Such disconnections occur, for example, when local topography and soils are altered by agricultural activities or by development and its associated infrastructure. Floodplain and instream sand and gravel mining also potentially modify riparian hydrology, influencing groundwater levels, overbank flow, bank stability, and the character of riparian vegetation. Impoundment of the river for navigation has elevated the water table and has significantly affected RFR. Deepwater habitats of navigation pools have replaced the varied habitats of islands, gravel bars, riffles, and channel wetlands, while some new habitats have been created in embayments. The CE of these and other activities on Ohio River hydrology are discussed later in this chapter (USFWS 2001).

6.7.5 Extent of Floodplain and Riparian Corridors

One method to assess the health of riparian areas is to observe or estimate trends in riparian and floodplain acreage over time. The resulting data may be less straightforward and useful than appears at first because riparian areas are difficult to assess along larger river corridors and their extent varies with water levels. Further, acreage alone does not reveal the quality of riparian areas in terms of such important indicators as biodiversity and hydrological connections. Only limited data exist on acreage of riparian areas associated with the Ohio River mainstem. As expected, measurements of riparian and floodplain

areas have varied. The Ohio River Basin Comprehensive Survey (USACE 1968) indicated that the area of Ohio River mainstem flooded during the floods of record in the upper, middle and lower river reaches totaled 1,840,803 acres. Only 11 years later, a photo analysis by the Ohio River Basin Commission (ORBC) (1978) indicated that the Ohio River floodplain encompassed 846,700 acres. Flow/flood stages at the time of the latter analysis were not indicated.

The ORBC study provided area estimates of floodplain, floodplain wetlands and embayment wetlands for the upper, middle and lower reaches of the Ohio River, as shown in **Table 6-6**.

TABLE 6-6
Area of Floodplains and Wetlands for Ohio River Mainstem

	Total River	**Lower River (RM546-981)**	**Middle River (RM 266-546)**	**Upper River (RM 0-266)**
Floodplain (acres)	846,700	602,100	144,700	99,900
Floodplain Wetlands	19,500 ac. (2.3% of floodplain)	18,000[1] (3.0%)	640[1] (0.4%)	860 (0.87%)
Embayment Wetlands[2]	13,500 ac.	6,000 ac.	4560	2940

[1]Much of the remaining floodplain (584,000 acres on lower river and 144,700 on middle river) was previously wetlands which have been cleared of timber and drained or filled for agriculture and other uses.
[2]Represents all of embayment areas associated with navigation pool slackwater, prior to completion of Smithland Lock and Dam.

SOURCE: ORBC 1978.

More recently, the USWFS (2000a) analyzed aerial photos to estimate the miles of riparian habitat remaining along the Ohio River. The analysis used 1800 as a benchmark year and assumed that at that time, the entire river corridor was forested, therefore, encompassing 1,962 linear miles on both banks of the river. The length of the remaining intact riparian forested areas along each riverbank was calculated by examining aerial photographs from randomly selected 20-mile stretches of river in the Pittsburgh, Huntington and Louisville Corps' Districts. Intact riparian forested areas were defined as having stable, undeveloped banks that support mature native riparian vegetation of sufficient width to provide some habitat value and/or provide buffering from mainland development. The percent forested riparian areas for each evaluated reach was calculated and extrapolated to determine the total number of riparian habitat miles remaining, as shown in **Table 6-7**:

This analysis indicates that slightly more than 50 percent of all types of riparian habitat along the Ohio River has been lost since 1800. Additionally, disproportionate losses in the upper and middle river are consistent with historic patterns of settlement and development.

TABLE 6-7
Riparian Habitat Remaining along Ohio River Mainstem
Based on Aerial Photography Analysis

Corps District	Date of Photos	Total River Miles (Both banks)	% Riparian Habitat Remaining	Miles of Riparian Habitat Lost
Pittsburgh	1995	254.4	29	180.6
Huntington	1984	621.6	34	410.2
Louisville	1995	1086.0	62.4	408.3
TOTAL		1962.0		**999.1**
SOURCE: USACE 2000a.				

Habitat values are enhanced when long stretches of riparian corridor remain intact. Such corridors may provide connectivity between patches of upland habitat for land-based wildlife. On the Ohio River, as along other rivers, long segments of riparian corridor support annual movements of migratory birds and also supply good habitat for mammals.

6.7.6 Riparian Habitats

Many studies have indicated that the contributions of riparian areas in maintaining biodiversity far exceed the proportion of the landscape they occupy (NRC 2002). The structural diversity of riparian plant communities affords a wide variety of niches for animal species that live in riparian areas on both a short-term and long-term basis. Riparian habitat types along the Ohio mainstem overlap considerably and include wetlands, bottomland hardwood forests, riparian edge/shoreline areas, embayments, and islands.

Prior to impoundment, the Ohio River was a relatively shallow river with numerous islands, gravel bars, channel wetlands (riverine emergent and riverine aquatic bed), and adjacent overflow sloughs surrounded by bottomland hardwood forests. Impoundment of the river for navigation interests created primarily deepwater habitat along the main channel corridor (average depth in channel 20-30 feet), with many islands, shallow bars and channel wetlands consequently disappearing. Most of the remaining shallow water and wetlands in the floodplain occur in embayments – the tributary mouths inundated by backwaters from the impounded Ohio River (USFWS 2000a). Later in this chapter, Table 9 summarizes riparian habitat types in the Ohio Islands National Wildlife Refuge from the Montgomery to Meldahl pools.

6.7.7 Wetlands

Wetlands formed by rivers are of several types, including oxbow marshes, floodplain bottomlands, and backwater lakes. An oxbow pond is formed when a meandering river changes course and leaves a portion of its channel isolated except during floods. In time, this pond fills in and becomes an oxbow marsh.

Backwater (bottomland) lakes form when soil and sand settle out of river currents and form long islands in the river. If such an island becomes high enough to completely separate the side channel from the main river, a bottomland lake is formed. In addition, human activities create as well as destroy wetlands. Impoundments, excavations, and the construction of dikes produce some wetlands.

Emergent wetlands are dominated by erect, rooted, herbaceous hydrophytic vegetation (e.g.,, sedges, grasses, and numerous species of forbs). Vegetation may remain visible throughout the year or die back in the nongrowing season. Emergent wetlands are classified into two categories: shallow marsh/wet meadow (where standing water or soil saturation is present for brief to moderate periods during the growing season) and deep marsh (where standing water is present, or the soil is saturated, on a semipermanent to permanent basis during the growing season). Examples of wet meadow include sedge meadows dominated by tussock sedge (*Carex stricta*), and wet prairie dominated by cord grass (*Spartina pectinata*). Water depth in marshes ranges from zero (saturated soil) to 6.6 feet (2m). In Midwestern marshes, both floating-leaf plants (e.g., water lily, *Nymphaea tuberosa*) and submerged aquatic plants (e.g., pondweed, *Potamogeton*) are frequently associated with cattails and emergent species. The soils that underlie marshes are sometimes mineral, but are often covered by muck (organic sediment).

Marshes are highly productive habitats in which hundreds of species of birds, insects, and other wildlife spend most of their lives. Two factors account for the high productivity of marshes. One is the ability of marsh plants to capture large amounts of energy from the sun and transform and store much of it as chemical energy in the form of plant tissue. The other is the efficient recycling of nutrients already produced.

Forested wetlands are dominated by woody vegetation. They are differentiated into swamps or bottomland forest based on the duration of the presence of water. Swamps are forested areas in which the woody vegetation is 20 feet (6m) or more in height and water is present on a permanent or semipermanent basis; the woody vegetation is adapted to prolonged exposure to standing water. Forested swamps, once common in the southern Midwest, are often dominated by bald cypress and water tupelo. The soil in forested swamps may be either organic or mineral, but usually has a topmost organic layer underlain with mineral soil. Shrub swamps are similar to forested swamps except that less of the vegetation is in the form of trees. Typical plants include willows, buttonbush, swamp rose, and a few species of dogwood growing in mostly mineral soils.

6.7.8 Bottomland Hardwood Forests

In contrast to swamps, bottomland hardwood forests are temporarily or seasonally flooded areas that usually occur along streams and rivers, usually in mineral soils. They represent the natural climax community of the Ohio River floodplain. Industrial, residential, and agricultural development, draining, and construction of dams and navigation pools have eliminated much of this habitat type. In fact, between 1800 and 1970, approximately 1,235,000 acres (65%) of the Ohio mainstem's forested floodplain habitat was lost or converted to other uses (ORBC 1978). Prior to development, a typical floodplain habitat was a matrix of bottomland forest interspersed with upland habitat components as well as other wetland types, including sloughs and oxbows. The remaining riparian area is often less than a few hundred feet wide (USFWS 2000a).

High quality bottomland hardwood forests typically have four plant layers consisting of:

1) an overstory of dominant trees, including sycamore, silver maple, eastern cottonwood, pin oak, and hickories

2) a lower canopy of smaller trees including hackberry, black locust, green ash, box elder, and black walnut
3) shrubs, including spice bush, dogwoods, poison ivy, and Virginia creeper and
4) herbaceous plants.

Density and diversity of the herbaceous ground cover varies with levels of light penetration.

Bottomland forests overlap broadly with wetlands. In most cases, historical wetland complexes along the Ohio River existed within a matrix of bottomland forest. Some bottomland forests on alluvial soils are relatively well drained, and forest on floodplain terraces may be flooded only irregularly. The interspersion of aquatic habitat types makes all types of bottomland hardwood forests especially valuable for wildlife (USFWS 2001).

Diverse floodplain forests provide good habitat for fur-bearing species such as beaver and cavity nesting species such as raccoon, fox squirrel, wood duck, pileated woodpecker, and warblers. The canopy structure and insect life also support many migratory songbirds and many species of bats (discussed in more detail later in this chapter). Mature trees provide habitat for fish-eating birds such as osprey, herons, and bald eagle, while the understory provides habitat for white-footed mice, white-tailed deer, wood thrush, Carolina wren, and other species. Significant wildlife use of bottomland forest habitats and wetlands include the Indiana bat (federally endangered), bald eagle (federally threatened), copperbelly water snake (federally threatened in the northern part of its range), several state-endangered species, furbearers, waterfowl, colonial wading birds, neotropical migrant songbirds, and a variety of reptiles and amphibians. Federal species of concern are discussed in further detail later in this chapter.

Recent studies in the Upper Mississippi River system, which appear applicable to the Ohio River System, underscore that bottomland forest dynamics are more complex than meets the eye. While existing riverine forests may appear natural and pristine, some important processes that determine forest growth and survival have been altered compared to pre-settlement conditions. Changes in the natural flood pulses and rising water tables have shifted forest composition from a diversity of tree species, including mast trees (important as wildlife food) to a more monotypic forest type dominated by silver maple. Little or no understory or seedling regeneration, crucial for bird and other wildlife diversity, occurs in such altered forest settings (UMRCC 2002). However, invasive exotic species such as honeysuckle, kudzu and garlic mustard may dominate the understory. Knutson and Klaas (1998) emphasize the need to reestablish cottonwood, willow and other understory trees to ensure a continued source of future nest and roost sites. Further, management of snags and downed woody debris and woody shrubs in the understory can provide additional structural features to improve the quality of wildlife habitat (UMRCC 2002).

6.7.9 Riparian Edge/Shoreline Areas

Riparian edge/shoreline areas are physical, chemical, and biological transition zones between terrestrial habitats and open water. Such areas are important for a variety of birds, mammals, amphibians, reptiles, and fishes dependent on this limited habitat type. These organisms also live in adjacent habitats and are discussed elsewhere. Rooted aquatic

plants or macrophytes, however, represent a conspicuous group of organisms primarily found in riparian edge/shoreline areas, as well as in embayments.

Factors controlling the growth of rooted aquatic plants include current speed, water levels, light availability, and nutrient inputs. In general, the number of macrophyte species that occur in running water compared to slower-moving water is limited (Hynes 1970). Shallow water and slower currents promote growth of vascular plants and macrophytic algae in the Ohio River (Thorp 1992). In quieter waters, aquatic vegetation provides food for river wildlife and migratory waterfowl, as well as shelter for aquatic insects and young and spawning fish.

Most information on macrophytes in the Ohio River is within the context of other studies. Pearson and Krumholz (1984) remarked that rooted aquatic vegetation is rare in the Ohio River, but when present, occurs in bands 6-20 ft. wide at depths of 4-6 ft. and 15-50 ft. offshore. Gar, crappie, and catfish are among the fishes that utilize these zones.

A 1975 study of approximately 126 miles of the upper river from Pittsburgh to New Martinsville, WV, (Koryak 1978) found that conspicuous emergent vegetation is not abundant in that reach of the mainstem. Only ten areas of significant emergent plant growth were identified, generally narrow bands parallel to the river and 150 ft. or less in length. The most impressive locations were all on the upstream, back channel sides of islands. Only one species, smartweed (*Polygonum coccineum*), was found growing in dense mats in then newly created Proctor Creek embayment near New Martinsville. Koryak, however, predicted that new embayments created by high-lift dams would eventually support productive, diverse aquatic plant communities and cited a 1975 USFWS inventory of a more stabilized embayment, Indian Short Creek (RM 79) which supported 64 plant species.

Table 6-8 lists the most common emergent and submerged riverine wetland plants reported along the Ohio River by USFWS. Rooted aquatic plants have been observed to be more abundant in the river during warm months of moderate drought when light penetration and photosynthesis increase with water clarity (Morrison, personal communication.).

TABLE 6-8

Common Submerged and Emergent Plants Along the Ohio River and Backwaters (Not including trees and shrubs)

Submerged Plants	
Scientific Name	**Common Name**
Vallisneria americana	eelgrass
Najas minor	eutrophic water-nymph
Najas flexilis	naiad
Myriophyllum heterophyllum	water milfoil
Potamogeton crispus	curly pondweed
Potamogeton diversifolius	variable pondweed
Potamogeton foliosus	leafy pondweed
Elodea nuttalli	waterweed
Ceratophyllum demersum	Coontail

Emergent Plants	
Scientific Name	**Common Name**
Justicia americana	water willow
Saururus cernuus	lizard tail
Sagittaria latifolia	duck potato
Alisma subcordatum	water plantain
Peltandra virginica	arrow arum
Iris pseudacorus	yellow iris
Acorus americanus	sweet flag
Ammania coccinea	scarlet ammania
Bidens spp.	tickseeds/beggar-ticks
Verbena hastata	blue vervain
Verbena urticifolia	white vervain
Sparganium americanum	American bur reed
Cyperus spp.	sedges
Carex spp.	sedges
Scirpus spp.	bulrushes
Juncus spp.	rushes
Eleocharis spp	spikerushes
Equisetum spp.	horsetails
Leersia spp.	cutgrass and white grass
Ludwigia spp.	primrose willows
Lythrum salicaria	purple loosestrife
Mimulus spp.	monkeyflowers
Polygonum spp.	smartweeds
Typha latifolia	cattail
SOURCE: Patricia Morrison, Ohio River Valley Ecosystem Team Leader, Ohio River Islands National Wildlife Refuge, Parkersburg, WV, e-mail communication, July 19, 2002.	

6.7.10 Embayments

Most remaining shallow water and wetland habitats in the Ohio mainstem floodplain occur in the embayments – the tributary mouths inundated by backwaters from the impounded Ohio River (USFWS 2000a). According to USFWS (2000a), major wetland habitat types and dominant plant species (if present) in embayments include:

1) **riverine open water** – deep water, mudflats, and exposed cobble/gravel;

2) **riverine emergent** – water willow, American lotus, lizardtail, bullhead lily, arrowhead, horsetail, arrow arum, yellow iris; typically adjacent to rivers

3) **riverine aquatic bed** – water celery, pondweeds, milfoils, duckweed, *Elodea* sp., coontail, naiads, and similar plants that require surface water for optimal growth and reproduction

4) **palustrine open water** - deep water and mudflats, cut-off from flow

5) **palustrine emergent** – smartweeds, wild millet, cattail, sedges, rushes, sweet flag, bulrushes, wild rye, rice, cutgrass, false nettle, spike rushes, swamp milkweed, sensitive fern, swamp rose mallow, burreed, marsh purslane, monkeyflowers, vervains, spotted and pale touch-me-nots, boneset, cardinal flower, beggar-ticks, loosestrife, seedbox, bedstraw, bugleweed, water horehound, tickseed sunflowers,

black elderberry, St. Johnswort, moneywort, ditch stonecrop, primrose willow, and dodder

6) **palustrine scrub/shrub** – black willow, brookside alder, buttonbush, dogwoods, false indigo, sandbar willow, and swamp rose

7) **palustrine forested** – black willow, eastern cottonwood, sycamore, slippery elm, silver maple, American elm, river birch, green ash, pin oak, and hackberry

In summer, during the height of the growing season, the diversity of the wetland plants and habitat types in Ohio River embayments provide excellent food and cover for migratory and resident wildlife. The shallow water habitats are important feeding areas for wading birds such as great blue herons, great egrets, and black-crowned night herons, which nest in heronries nearby and feed in the embayments while raising their young. After fledging, juvenile herons concentrate in the embayments as well. Wood ducks, mallards, and Canada geese nest and raise their broods in embayments and along the mainland wetlands in summer.

Young-of-year fishes find shelter in the riverine aquatic bed and emergent wetlands. Consequently, embayments are important nursery areas for Ohio River fishes, particularly species in the sunfish family. Embayments also support an abundance of amphibians and reptiles and at least 19 mussel species.

Typically lower water levels in the embayments during fall exposes mudflats and invertebrates as well as aquatic plants that are attractive as food for migrating shorebirds, wading birds, and waterfowl. Native wildlife food plants such as smartweeds, bulrushes, wild rye, and millet begin to die back and become available to migratory birds and other wildlife. Soft mast-producing trees and shrubs dominate in the embayments (elderberry, cherry, spicebush, hackberry, grape, and dogwoods), providing abundant food for migratory landbirds en route to their southern destinations.

During winter, the emergent wetland vegetation in the embayments lies down and dies back, but submerged aquatic vegetation and rootstocks remain as important food for wintering waterfowl and muskrats. While high water and swift currents are common on the main river in winter, the embayments provide quiet resting places off the main river for fish and wildlife.

The most comprehensive assessment of embayments and wetlands along the Ohio River has occurred in the Ohio River Islands National Wildlife Refuge's planning area, which encompasses approximately 400 Ohio River miles from the Montgomery to Meldahl pools. **Table 6-9** quantifies the habitat types within more than 5,400 acres of relatively undisturbed embayments and mainland wetlands within the refuge planning areas which are affected by Ohio River backwaters and have some significance for wildlife. The USFWS plans to include some of these priority habitats in the Ohio River Islands refuge. Riverine open water represents 35.7 percent of embayment habitat while immature and mature bottomland hardwood forests together comprise 29.2 percent of the total. Agricultural lands rank fourth (8.9 percent of the total). Of the channel wetland types typical of the natural river, only riverine aquatic bed is listed and it comprises less than 1

percent of the total habitat. Riverine emergent habitat, once typical of the natural river, is not sufficiently present to be listed.

TABLE 6-9
Priority Wetland and Embayment Habitats along the Ohio River

Habitat Type	Total Acreage	% of Total
Palustrine forested	372.5	6.9
Palustrine emergent	365.3	6.7
Palustrine scrub/shrub	136.9	2.5
Palustrine open water	136.4	2.5
Riverine open water	1,931.9	35.7
Riverine unconsolidated shorelines	107.4	2.0
Riverine aquatic bed	22.6	0.4
Mature bottomland hardwood	496.4	9.2
Immature bottomland hardwood	1,038.8	20.0
Late oldfield	210.3	3.9
Early oldfield	54.7	1.0
Agricultural land	480.4	8.9
TOTALS (<100 percent due to rounding)	**5,418.9**	**99.7***

SOURCE: USFWS. 2000a. Draft Comprehensive Conservation Plan and Environmental Assessment - Ohio River Islands National Wildlife Refuge, Appendix E.

6.7.11 Islands

With two exceptions, the islands of the Ohio River were formed by accretion of flood deposits over mostly gravel and sandbars to the height of the floodplain. The two exceptions are Eureka and Letart Islands, whose bases are composed of bedrock (USFWS 2000a). The extensive bars where islands formed are generally located along reaches where the banks of the river eroded back and the river broadened. Most of the sediment transport and deposition associated with island formation occurred toward the end of the most recent history of glaciation. Additional information on the fluvial and geomorphologic processes at work in the formation of islands is presented in the next section of this chapter.

Because there is no longer any glacial transport of the sand, gravel, cobble, and boulders which formed the islands of the Ohio River, and because of the current navigation system and the system of flood control reservoirs in the drainage basin, it is not likely that any significant future island creation will naturally occur. For the same reasons, there will be no significant natural maintenance of existing river islands. They are then irreplaceable.

Islands are most abundant along the upper and lower reaches of the Ohio River and were once more numerous than they are today. USACE aerial photographs of the Ohio River indicate a clustering pattern of distribution with islands more abundant along the upper 200 and lower 281 miles of the river than along the 500 mile-long reach between RM 200 and 700. Notably, there is only one island in the reach between RM 400 and 500 (Pearson and Krumholz 1984). Along the upper 437 miles of the river, which encompass the Ohio River Islands National Wildlife Refuge (ORINWR), there were 61 islands in the early 1900s. With the advent of industrialization, improvements for navigation, and commercial aggregate dredging, 21 of these islands were lost and apparently one (Lesage

Island) was created. Natural forces modified at least four islands: Grape and Bat Islands were "fused" through sedimentation. A palustrine wetland complex now exists within the area between these two islands. Goose Island, formerly located between RM 230 and 231, disappeared through sedimentation and a shift in the flow direction of Mill Creek. Upper Brothers Island (or French Island) at RM 157.6 may have experienced the same fate. A change in flow patterns associated with Interstate 79 bridge pier construction in the early 1970s very quickly scoured away an island at RM 9 in the back channel of Neville Island (Michael Koryak, Personal communication).

Of the 40 existing islands between Pittsburgh, PA (RM 0) and Meldahl, Ohio (RM 437), five have been heavily urbanized and/or industrialized (i.e., Brunot, Davis, Neville, Wheeling, and Browns). Boggs Island has been extensively disturbed in recent years.

Recently, the ORINWR office completed a comprehensive assessment of the number and acreages of islands lost from the Ohio River since 1900. Of 124 islands present according to 1911-1914 navigation charts, 31 islands have disappeared, including 20 from the upper river. While some islands in the lower river have increased in size since 1900, the overall acreage gain of 1,094.8 is far outweighed by the 12,001.3 acres lost. The ORINWR analysis indicates an overall loss of 43.1 percent of historic island acreage, due primarily to pool raises, construction of high-lift dams on islands, and dredging (USFWS, undated). **Table 6-10** shows the island-by-island changes occurring since the early 1900s. Islands shown in italics no longer exist.

TABLE 6-10
Ohio River Island Gains and Losses since Early 1900s

Island*	Presence	Present Acreage	Historic Acreage	River Mile	Book Mile	Loss (acres)	Gain (acres)
Brunot Island	Y	157.2	187.2	1.6	1.8	30.0	
Davis Island	Y	57.8	34.3	4.6	4.6		23.5
Neville Island	Y	1136.1	1089.5	4.9	4.9		46.6
Deadman's Island	N		12.9		13.2	12.9	
Crow Island	N		137.9		20	137.9	
Hog Island	N		105.1		20	105.1	
Montgomery Island	N		31.4		31.4	31.4	
Phillis Island	Y	25.0	118.3	35.1	34.6	93.3	
Georgetown Island	Y	9.0	104.2	37.6	37.3	95.2	
Line Island	N		76.5		40.5	76.5	
Babbs Island	Y	38.0	104.3	41.8	41.5	66.3	
Bakers Island	N		67		48.9	67.0	
Cluster Islands	Y (1OF2)	13.0	163.6	51.8	51	150.6	
Black Island	N		126.5		53.5	126.5	
Browns Island	Y	374.2	356.7	60.9	60.5		17.5
Upper Griffen Island	Y	5.0	36.7	62.9	63.1	29.7	
Lower Griffen Island	Y	2.0	above value includes	63.5	63.1		

Island*	Presence	Present Acreage	Historic Acreage	River Mile	Book Mile	Loss (acres)	Gain (acres)
			both islands				
Mingo Island	N		162.6		70.5	162.6	
Pike Island	N		67.6		83.2	67.6	
Lower Sister Island *Upper Sister Island*	Y N	10.0	142.1 above value includes both islands	85.3 85.8	84.2	131.9	
Wheeling Island	Y	389.0	483.5	89.4	89	94.5	
Boggs Island	Y	16.0	71.5	93.2	92.7	55.5	
Captina Island	Y	17.0	78.4	108.1	107.3	61.4	
Fish Creek Island	Y	60.0	134.7		112.3	74.7	
Clines Island	N		64	113.1	115.2	64.0	
Paden Island	Y	90.0	127.7	131.8	132	37.7	
Williamson	Y	133.0	208	133.9	133.4	75.0	
Witten Towhead	Y	7.0	48.8	135.5	135.4	41.8	
Crab Island	Y	2.0	7.8	138.1	138	5.8	
Wells Island	Y	48.0	124.4	138.8	138.3	76.4	
Mill Creek Island	Y	23.0	77.8	141.3	140.8	54.8	
Grandview Island	Y	8.0	93.7	142.6	142.2	85.7	
Grape (Bat) Island	Y	38.0	114.5	151.5	151.2	76.5	
Middle Island	Y	240.0	325.8	152.8	152.6	85.8	
Upper Brothers (French)	N		60	157.6	157.6	60.0	
Broadback (Middle Brother)	Y	40.0	122.2	158.4	158	82.2	
Eureka (Lower Brothers)	Y	17.0	70.2	159.7	159.1	53.2	
Willow Island	N		63.1		161.3	63.1	
Buckley, Marietta, Kerr Island	Y	160.0	235.7	168.8	169	75.7	
Muskingum Island	Y	105.0	260.3	175.2	173.8	155.3	
Vienna, Halfway, or James	Y	30.0	94.1	178.0	177.5	64.1	
Neal Island	Y	110.0	233.6	181.1	180.3	123.6	
Blennerhassett Island	Y	500.0	730.6	185.9	185.7	230.6	
Newberry Island	Y	2.0	64	194.7	193.5	62.0	
Mustapha	Y	24.0	126.8	196.6	195.7	102.8	

Island*	Presence	Present Acreage	Historic Acreage	River Mile	Book Mile	Loss (acres)	Gain (acres)
Island							
Belleville Island	N		91.5		202.7	91.5	
Buffington Island	Y	156.0	247.9	216.4	215.8	91.9	
Oldtown Towhead Island	N		95	226.0	225.7	95.0	
Goose Island	N		155	230.0	228.8	155.0	
Letart Island (2)	Y (1 of 2)	29.0	175.2	234.9		146.2	
Eight Mile Island	Y	16.0	122.6	257.7	256.5	106.6	
Six Mile Island	N		77.1		259	77.1	
Gallipolis Island	Y	5.0	75.5	268.5	267.7	70.5	
Raccoon Island	N		73.3		274	73.3	
Lesage Island	Y	25.0		289.0			25.0
Brush Creek Island	Y	18.0	171.6	387.8	385.9	153.6	
Manchester Island No. 1	Y	24.0	52.2	395.1	393.5	28.2	
Manchester Island No. 2	Y	110.0	288.1	395.2	395	178.1	
Laughery Island	Y	28.8	160	501.8	499.2	131.2	
Big Bone Island	N		130.2		514.3	130.2	
Vevay Island	N		99.6		533	99.6	
Eighteen Mile Island	Y	131.5	197	581.5	578.8	65.5	
Twelve Mile Island	Y	142.8	212.9	592.0	589.3	70.1	
Six Mile Island	Y	77.7	113.8	597.2	594.3	36.1	
Towhead/Willow Island Towhead	Y	0.0	44.6	601.8		44.6	
Shippingport Island		224.9		604.6			224.9
Rock Island (at Falls)	N		8.4			8.4	
Goose Islands (at Falls)	Y	96.3	15.4				80.9
Corn Island (at Falls)	N		3.4		604.4	3.4	
Sand Island	Y	55.0	150.9	606.7		95.9	
Upper Blue River Island	Y	12.5	146.2	660.8	657.2	133.7	
Blue River Island	Y	2.5	160.1	662.5	658.7	157.6	
Flint Island	Y	109.0	135	688.6	685.2	26.0	
Rock Island	N		2.6		715.5	2.6	
Corn Island	N		493.9	733.4	729.1	493.9	

Island*	Presence	Present Acreage	Historic Acreage	River Mile	Book Mile	Loss (acres)	Gain (acres)
Anderson Island	Y	25.0	86.8	735.0	731	61.8	
Beeler Island (Little Yellow Bank)	N		99	752.0		99.0	
Yellow Bank Island	Y	142.8	376.7	753.8	747.5	233.9	
Little Hurricane Island	Y	258.0	787	760.4	756.1	529.0	
French Island No. 1+ Ellis Island	Y	165.0	395	765.4	760	230.0	
French Island No. 2	Y	268.0	563.5	766.0	761	295.5	
Scuffletown Island	Y	47.0		775.8			47.0
Three Mile Island	Y	119.0	202.6	779.0	773.8	83.6	
Dutch Island	Y	26.3		796.8			26.3
Henderson Island	Y	203.0	361.7	805.4	800.3	158.7	
Deadmans Island	Y	103.9	344	807.4	807.7	240.1	
Carpenter Creek Island	Y	7.5		814.6			7.5
Diamond Island	Y	1372.9	1727	818.0	811.5	354.1	
Emerald Island	Y	18.7		818.0			18.7
Diamond Island Towhead	N		122.5		821.5	122.5	
Mt. Vernon Towhead	Y	71.4	366.4	827.6	826.2	295.0	
Slim Island	Y	553.7	991	832.3	828	437.3	
Towhead Island	Y	46.0	68.9	832.5	825	22.9	
Slim Island Towhead	Y	25.0	129.3	836.6	836	104.3	
Wabash Island	Y	1742.0	2022	846.5	838.7	280.0	
Wabash Island Towhead	Y	18.7		851.0			18.7
Belle Island	N		272		845.9	272.0	
Raleigh Bar Island	Y	18.8		853.5			18.8
Lower Shawneetown Bar Island	Y	79.0		857.4			79.0
Cincinnati Island	Y	99.0		860.0			99.0
Cincinnati Island Towhead	N		69.6		862	69.6	
Saline/Cywell Island	Y	5.0	474.8	866.0	856	469.8	
Sturgeon	Y	65.0	474.6	870.0	869.7	409.6	

Island*	Presence	Present Acreage	Historic Acreage	River Mile	Book Mile	Loss (acres)	Gain (acres)
Island/Battery Rocks TH							
Cave In Rock Island	Y	179.0	242.1	878.8	870	63.1	
Walkers-McKinley Island	Y	165.0	129.5	882.9			35.5
Hurricane (Plew) Island	Y	1081.0	1128.7	885.1	876	47.7	
Hurricane Island Towhead	Y	7.0		885.1			7.0
Irish Jimmie's Island	Y	3.8		894.2			3.8
Rondeau Island	Y	278.0	418.9	899.9	890.4	140.9	
Pryor Island	Y	202.0	296.7	904.7	894	94.7	
Sisters Islands	Y	206.3	428.7	906.6	897.8	222.4	
Stewarts Island	Y	467.0	323.4	913.0	902		143.6
Deen Towhead	Y	8.7	15.2	916.0	915.9	6.5	
Cumberland Island	Y	338.0	491.1	920.0	909	153.1	
Cumberland Towhead Island	Y	68.9	136.6	922.0	922	67.7	
Cuba Towhead	Y	37.5		932.5			37.5
Owens Island	Y	258.0	343.6	932.8	922.3	85.6	
Paducah Towhead	N		120.4		935.2	120.4	
Ivy Island	Y	2.3		949.6			2.3
Mound City Bar Island	Y	107.0		970.6			107.0
Cache Island	Y	274.0	249.3	971.0			24.7
Mound City Towhead Island	Y	70.1	188.1	972.0	971.9	118.0	
Total	Y= 93 N=31	14384.6	25291.3			12001.3	1094.8

* Islands listed in *italics* no longer exist.
Source: USFWS. (undated). Incremental analysis of islands and other habitats completed by the Ohio River Island National Wildlife Refuge office.

The importance of islands in the Ohio River ecosystem can hardly be overstated, nor can their apparent vulnerability. The island habitats contain natural assemblages of plants and animals that are endemic to the ecosystem. Except at islands directly downstream from locks and dams, the head of an island generally resembles a natural riffle/run habitat, which was a major habitat of the Ohio River prior to impoundment. The distribution of bottomland and riparian habitats and deep and shallow water aquatic habitats make islands extremely beneficial to fish and other wildlife. A great diversity of species (waterfowl, shore birds, wading birds, neotropical migratory land birds, furbearers, fish, and benthic

organisms, including freshwater mussels) find these areas invaluable for resting, feeding, nesting, spawning, and other life functions. The deep and shallow water habitats associated with the islands are major fish and mussel production areas of the Ohio River. A total of 193 bird species (76 of which breed there), 42 mollusk species, at least 15 species of reptiles and amphibians, 101 species of fish, 25 mammals, and 500 species of plants have been identified so far within the Ohio River Islands National Wildlife Refuge (USFWS 2000a). Though less well documented, wildlife also is abundant in two island preserves protected by Kentucky: 1) the 81-acre Six Mile Island State Nature Preserve at RM 598 near Louisville and 2) the 1,375-acre Ohio River Islands Wildlife Management Area, which includes Rondeau, Pryor, Twin Sisters and Stewart islands between RM 901 and RM 914, in the river reach bordering Livingston County, KY, and Pope County, IL.

The shallow waters of the river provide quality habitat for freshwater mussels, including at least two federally endangered species, the pink mucket and fanshell, discussed in more detail in Chapter 5, Mussels. Bald eagles, peregrine falcons, and Indiana bats also use the refuge habitats. In addition, many species of plants and animals considered endangered, rare, or of special interest in Pennsylvania, Ohio, West Virginia, and Kentucky occur within the refuge.

6.7.12 Fluvial and Geomorphologic Processes Relevant to Island Resources

Islands are formed by geologic processes that have become better understood in recent decades. Using flume experimentation and extensive field observations, Leopold et al (1964) examined fluvial processes which can contribute to the creation, maintenance, or degradation of river bars and islands. The shape of the cross-section of a river channel at any location is a function of: 1) historic and contemporary flow regimes, 2) the quantity and character of the sediment in movement through the section, and 3) the character or composition of the materials in the bed and banks of the channel. The last will usually include vegetation. Flow exerts a shear stress upon the bed and banks. An adjusted or stable form that a channel can assume is one where shear stress is balanced by the resisting stress of the bed or bank at each point. As was discussed in the previous section, with only two exceptions, the 124 historic islands of the Ohio River are depositional features formed by fluvial processes. While much of the sediment transport and deposition which formed these islands occurred towards the end of the most recent period of glaciation, these processes still continue and are relevant to the topic of island protection and management.

Stream channel reaches divided by islands and bars are referred to as braided. Braided or anatomizing channels are typically but not always associated with riffles and friable bank materials, and offer greater resistance to flow than otherwise comparable straight channels. In the formation of braided channel river islands, the growth surfaceward of a central bar tends to concentrate flow in the flanking channels, which then scour their beds or erode their banks. As the cross-section is enlarged, the water surface is lowered, and the bar emerges as an island. In a natural stream the emergent bar may be stabilized by vegetation, which prevents the island from being easily eroded and, in addition, tends to trap fine material during high flow periods. Thus the gravel base tends to become veneered with silt. Flume experiments and field observations of bars and islands in the channels of braided streams indicate that they tend to build by addition at the downstream end and also on some parts of the lateral boundaries, but not on the upstream tip.

If a reach of river possessing a single channel is compared with an otherwise similar reach where the channel is divided by a bar or island, the braided portion will have a steeper slope. The ratio of slope of divided to undivided channels was found to range from 1.4 to 2.3 in field situations and 1.3 to 1.9 in flumes. The sum of the widths of the individual branches is also greater than the width of the undivided channel, the ratio varying from 1.6 to 2.0 in field examples and 1.05 to 1.70 in flume experiments. Steeper slopes contribute to sediment transport and to bank erosion and are often associated with coarse heterogeneous materials. All of these are conditions that contribute to braiding.

Conversely, equilibrium disruption can contribute to the erosion of braided channel bars and islands. If the banks are unerodible and the channel width confined, the capacity of the reach for the transport of sediment would be increased, reducing the likelihood of deposition. In addition, any bars or islands which formed would be attacked as flow increased, since bank erosion could not take place. Thus, for the bars or islands to become stable and divert the flow, the banks must be sufficiently erodible so that they, rather than the incipient bar or island, give way as the flow is diverted around the depositional structure. Sediment transport and a low threshold of bank erosion provide the essential conditions of braiding. Rapidly fluctuating changes in stage contribute to the instability of the transport regime and to the erosion of the banks; hence, they also provide a contributory but not essential element of the braiding environment. Heterogeneity of the bed material in the same way creates irregularities in the movement of sediment and thus also may contribute to braiding.

Braiding then represents a response or adjustment among the controlling variables, which may provide an equilibrium condition over a period of time. Braiding can be considered to represent a particular combination of variables in a continuum of river shapes and patterns. Once established, the braided pattern may be maintained with only slow modification, and the braided river reach may be as close to equilibrium as are meanders or other patterns.

Among the primary lessons applicable to the Ohio River island loss problem that can be derived from this cursory review of basic fluviology is that the islands themselves are not the basic habitat or management unit, rather the focus is the dynamic equilibrium of the larger braided channel reaches of the river. Activities such as bank stabilization or encroachment along a channel braid would be expected to create resistance and direct the attack of erosive forces elsewhere, such as at unprotected islands and bars. Similarly, moderation of stage fluctuations and scouring flood flows or sediment starvation are forces that over time would be expected to degrade island habitat. It is a serious dilemma that these activities are universally considered to be desirable “improvements” to the river, but that their long-term cumulative impacts are not conducive to maintenance of highly valued island habitat.

Fluvial processes must be carefully considered in future efforts to protect and restore Ohio River island habitat. Among the restoration opportunities available might be excavation and restoration of the filled backchannels of Crab Island at RM138.1 and French (or Upper Brothers Island) at RM157.6. Dredge spoils might be creatively disposed of at towheads where deposition is already occurring and it appears that conditions for island creation are highly favorable. Tributary depositional bars might be managed to create shoal and island habitat. Rather than or in addition to using riprap as

shoreline protection at the heads of islands, the larger issue of braided channel unit equilibrium might be considered, and islands might be protected by means of cross-sectional enlargement.

6.7.13 Upland and Unique Habitats

Historically, the Ohio River floodplain was primarily forested habitat, with scattered prairies, canebrakes, and wetlands in the floodplains of the main river and its tributaries. Scattered remnant unique habitats such as dry forest glades, post oak flatwoods, and clay barrens may still be found. Bluffs bordering some areas of the Ohio River shoreline provide habitat for a number of species of concern. Most of this area has been settled, cleared, drained, farmed, and developed, resulting in the outright loss of habitat, and fragmentation of that which remains. Significant wildlife use of upland forests in the study area includes the endangered Indiana bat and gray bat, raptors (including nesting bald eagles) and neotropical migrant songbirds, as described in the following section.

Upland habitats along the Ohio River's 981-mile expanse are varied topographically, geologically, and climatically, as reflected by the diverse flora and fauna of the river's riparian areas. For much of its course, the Ohio mainstem flows through eastern temperate forests, but as the river reaches its confluence with the Mississippi River, it flows through forests more typical of southeastern humid regions that include bald cypress and tupelo trees.

Included among the unique upland geological features visible from the Ohio River mainstem are:

- Split Rock – a large glacial conglomerate deposited during the Illinoian glaciation at present day RM 500 in Boone County, Kentucky, and
- Cave-in-Rock – a 55 ft.-wide limestone cave, now the centerpiece of Cave-in-Rock State Park at RM 881 in Hardin County, Illinois.

6.7.14 Wildlife of Ohio River Riparian Areas

As previously emphasized, the varied riparian habitats along the Ohio River support a diverse assemblage of wildlife. Birds are an especially important component of wildlife along the river and are conspicuous by their numbers, visibility, and overall species diversity. Riparian areas' diversity in plant species and variations in vertical and horizontal structure provide an array of niches for birds. Riparian areas along the Ohio River mainstem afford important habitat for breeding birds, stopover habitat for migratory birds, and wintering habitat for birds that live in North America year-round. The Ohio River corridor is poised on the boundary between the Atlantic and Pacific Flyways, and is a major migration route for birds. On the Ohio River Islands refuge, the principal species of management concern include migratory birds and endangered species.

Over 25 species of waterfowl (ducks, geese, swans, and mergansers) utilize the Ohio River corridor. The majority of these species are migratory, using riparian habitats as feeding and nesting areas. Annual floods create areas attractive to migratory waterfowl. Bottomland hardwoods produce mast (fruits and nuts), used extensively as a food source by mallards, black ducks, and wood ducks when the bottoms are flooded. More open

sloughs produce emergent vegetation used by widgeon, gadwall, blue-winged and green-winged teal, and ring-necked ducks. These wetlands also offer abundant invertebrates, an important source of protein for migrating ducks. Because the lower Ohio River is included in the Mississippi flyway, it is an important migratory route with significant wintering populations of ducks. It also is part of the wintering area for the Mississippi Valley population of the Canada goose (USFWS 2000a).

Numerous shorebirds (e.g., lesser and greater yellowlegs, spotted sandpipers, semipalmated plovers, ruddy turnstone, common snipe, American woodcock, solitary sandpiper, least sandpiper, semipalmated sandpiper and killdeer) utilize the Ohio River corridor during spring and fall migration. Important areas include mudflats and emergent wetlands. The USFWS (2000) notes that before the Ohio River was extensively altered, its floodplains and tributaries provided numerous sandbars, mudflats, and oxbows that were ideal habitat for shorebirds.

According to the Shorebird Conservation Plan for the Upper Mississippi Valley/Great Lakes Region, the Central Hardwoods Bird Conservation Region, which includes the lower Ohio River, is used by 20 shorebird species. Most are long-distance migrants that require suitable wetlands where they can replenish their fat reserves. Such staging areas must have shallow water (< 8 in. deep), and/or mudflats with sparse vegetation (<25% cover), undisturbed resting areas and abundant invertebrate food resources (http://www.manomet.org/USSCP/files.htm). Wetland conditions and use by shorebirds in inland regions are directly influenced by precipitation patterns. Consequently, the dynamics of climatic cycles and changing availability of habitat cause shorebirds migrating through the Ohio River basin to be scattered over larger areas in small numbers at numerous sites, compared to large concentrations at few major sites, as is common along the Atlantic and Pacific coasts (Skagen and Knopf 1993, Skagen et al. 1999, as cited by USFWS 2000a).

The great blue heron and green-backed herons are the most commonly observed wading birds along the Ohio River. Both species feed and roost in shallow water zones, fringe wetlands, and interior wetlands along the river and islands. Wading birds also include the interior least tern, listed as federally endangered due to low numbers and loss and degradation of nesting islands. Nesting habitat loss along many interior river systems within the population's range has occurred primarily from various channelization and irrigation projects and from construction of reservoirs and pools. The Corps, USFWS and state resource agencies currently are working together to use dredged materials to create least tern nesting habitat in Ohio River waters in Illinois. Information on the interior least tern and other federally listed species is included in **Table 6-11** at the end of this section.

The bald eagle is another federally listed species occurring in the Ohio River corridor, although in 1995 it was downlisted from an endangered to a threatened species. The USFWS (2000) indicates bald eagles are more abundant along the Ohio River in winter than at other times of the year, as they shift south from frozen lakes and rivers in the north.

Neotropical migratory landbirds (including warblers, thrushes, vireos, cuckoos, flycatchers, and tanagers) spend winters in Central or South America, but migrate to breeding grounds in the Ohio River Valley and to points north. The USFWS lists more

than 30 neotropical migrants that occur in the Ohio River watershed as species of concern. Stresses on these species include fragmentation and loss of habitat on both their wintering grounds and their spring and summer ranges (USFWS 2000a). Further information on the status and conservation of land birds along the Ohio mainstem is included in the Partners in Flight Bird Conservation Plans prepared for the Ohio Hills and Interior Low Plateaus at www.partnersinflight.org. Of 20 species of concern identified by the West Virginia Partners in Flight team, 15 species are known to nest on the Ohio River Islands National Wildlife Refuge.

More than 25 mammal species occur along the Ohio River mainstem, including furbearers such as mink, beaver, and muskrat. These species are noticeably more abundant along back channels and wetland habitats of embayments than along the main channel/navigation sides of islands (USFWS 2000a). Somewhat less conspicuous are the endangered Indiana bat and gray bat that roost along the river during summer.

Although not as conspicuous as birds or mammals, most amphibians and many reptiles are intimately associated with riparian areas and their waterbodies. Many species of amphibians and reptiles are found in Ohio River riparian zones, although most have not been well studied. However, the 15 species of reptiles and amphibians documented as of 2000 for the Ohio River Islands National Wildlife Refuge (USFWS 2000a) might be considered to be representative of the typical herpetofauna common to the Ohio River riparian zone.

The wetland habitats on and around the islands and within the embayments and mainland wetlands provide suitable habitat for and have been observed to support American toad, Fowlers toad, green frog, bullfrog, gray tree frog complex, northern spring peeper, pickerel frog, and northern leopard frog. Four species of turtles have been recorded on the refuge so far: the terrestrial eastern box turtle, and the more aquatic snapping, midland painted, and eastern spiny softshell turtles. Snakes in general are not abundant on the islands, primarily because of the tendency of the islands to flood regularly. Snakes, which might den or overwinter on the islands, would probably not survive a winter flood event. However, the occasional garter snake or black rat snake is observed on the refuge, northern water snakes swim to and from the islands. No salamander information is available.

The only Federally endangered, threatened, proposed, or candidate species of reptile or amphibian listed in the USFWS's Ohio River Valley Ecosystem Team website for counties contiguous with the Ohio River mainstem is the copperbelly water snake (*Nerodia erythrogaster neglecta*), found in several counties in Southern Illinois. In Indiana and Ohio the copperbelly water snake is threatened in the northern part of its range, but is not listed in these states in the southern part of its range near the Ohio River. However, Conservation Agreements have been signed between USFWS and the Illinois, Indiana, and Kentucky Departments of Natural Resources, other state agencies, and a number of coal companies as a means of protecting and enhancing habitat for the copperbelly in the southern portion of its range.

Amphibians and reptiles as a group are in decline. A species of concern in this group in the Ohio River is the eastern hellbender (*Cryptobranchus alleganiensis*). Lang (1968) reported that *Cryptobranchus* bones have been excavated in quantities from Indian

middens along the Ohio River, and that the hellbender was once abundant in the river and was extensively utilized as a food resource by Woodland tribes. McCoy (1982) reports that the hellbender has been extirpated from the Upper Ohio River by past acid mine drainage and industrial pollution. Similarly, the midland smooth softshell turtle (*Trionyx muticus muticus*) has apparently been extirpated from the northeastern portion of its range in major rivers of the Upper Ohio River drainage basin. McCoy states that no records of the midland smooth softshell in Pennsylvania exist after 1901 and that the character of the large rivers of the Upper Ohio drainage basin has been so altered by pollution that *T. muticus* may have been extirpated from these streams. The only well documented and relatively recent record for this turtle in West Virginia was from Mason County in 1968 (Green and Pauly, 1987).

TABLE 6-11
Reptiles, Birds and Mammals of Concern along Ohio River Mainstem

Common Name (Scientific Name)	Federal Status	Range/Habitat along Ohio River	Reasons for Concern
Reptiles			
Copperbelly water snake (*Nerodia erythrogaster neglecta*)	T (in N part of range, but not on Ohio mainstem)	Southern Indiana, southern Illinois and western Kentucky	1) Drainage and filling of lowland swamps and clearing of adjacent upland woods where they forage and hibernate. 2) Collection because of rarity, size, color and value in pet trade. 3) Predation when migration routes are interrupted by cleared areas. 4) Road kills and other human-induced mortality.
Birds			
Least tern, interior population (*Sterna antillarum*)	E	Breeds in isolated areas along Ohio River and other large inland rivers late April-August. Probably winters in coastal areas of Central and South America.	1) Loss of nesting sites on sandbars near rivers and along shorelines resulting from dams, reservoirs and other changes to river systems. 2) Nest disturbance during recreational activities, causing terns to abandon nests.
Bald eagle *(Haliaeetus leucocephalus)*	T	Range includes entire Ohio River mainstem. Generally more common during winter months. Builds huge nests in tops of trees near rivers, lake and marshes.	Upgraded from endangered to threatened status after more than three decades of conservation efforts. Continuing concerns include: 1) Hunting for feathers and talons. 2) Electrocution on power poles. 3) Poisoning from lead shot.

Common Name (Scientific Name)	Federal Status	Range/Habitat along Ohio River	Reasons for Concern
Peregrine falcon (*Falco peregrinus*)	Removed from Federal T/E list in 1999.	Migrates through Ohio River Valley in fall and spring.	Killing and illegal possession are among remaining concerns. In 1999, the USFWS began a 13-year monitoring program to obtain data that reflect the status of at least two generations of peregrines. If the species is not maintaining its recovered status, it could be re-listed.
Mammals			
Gray bat *(Myotis grisensens*)	E	Occupies limestone karst areas of Kentucky, southern Indiana and southern Illinois. During winter, gray bats hibernate in deep, vertical caves, but in summer, they roost in caves scattered along rivers.	1) Human disturbance of hibernation caves. 2) Cave commercialization and gates on caves that prevent access or alter habitat conditions 3) Habitat loss by flooding of caves.
Indiana bat *(Myotis sodalis)*	E	Found over most of eastern half of U.S. with large populations hibernating in caves in IN, IL, KY, OH and WV. In summer, they usually roost under loose tree bark (e.g., shagbark hickory).	1) Human disturbance of hibernation caves. 2) Cave commercialization and gates on caves that prevent access or alter habitat conditions 3) Loss and fragmentation of forest habitat. 4) Pesticides that contaminate bat food supply (insects), water and feeding areas.
SOURCES: USFWS endangered species website (http://midwest.fws.gov/endangered) and Ohio River Valley Ecosystem Team website (http://orve.fws.gov/endspec.html).			

Healthy, functional riparian areas also support an abundance and diversity of fish. Over 100 fish species have been recorded in the ORINWR (USFWS 2000a). Studies cited in NRC (2002) note that floodplains, side channels, and alcoves serve as low-velocity refuges during winter and during floods and provide access to abundant food resources for fish communities during flooding.

6.7.15 Invasive Exotic Plants

A summary of current RFR baseline conditions would be incomplete without discussing invasive exotic plant species, which have become an extremely serious problem along the Ohio River floodplain. In fact, the USFWS considers invasive exotic plants second only to direct habitat losses as a threat to native species (USFWS 2000a, and Morrison, personal communication). Along the RM 0 to 437 river reach considered within the scope of the Ohio River Islands National Wildlife Refuge's management strategy, one of the greatest obstacles to efforts to restore and protect wildlife habitat is invasion by non-native plants such as Japanese knotweed, mile-a-minute, and multiflora rose. The riparian corridor along this reach of the Ohio River includes a diverse assemblage of about 500

species of plants. Of these, 39 species are considered rare, 100 species are considered exotic, and 35 species are problematic invasive exotic species.

Executive Order 13112 **(Table 6-2)** defines an invasive species as a species that is: 1) non-native or alien to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health. **Table 6-12** lists the ten invasive plant species believed to constitute the most serious problems and threats in the Ohio River Valley ecosystem. Of these, Japanese knotweed is overwhelmingly considered the most serious invasive plant species (USFWS 2000a and Morrison, personal communication).

Japanese knotweed (*Polygonum cuspidatum*) is an herbaceous plant introduced from Japan in the late 19th century, which has since become invasive, especially in riparian zones. According to studies cited in Kalisz and Dunn (2002), outside its native range, Japanese knotweed is male-infertile and propagates through long lateral rhizomes. Therefore, flood scour and human movement of soil easily disperse the plant. Once stands of Japanese knotweed become established, herbaceous plant species fail to survive under its dense canopy, and recruitment of woody species is impaired.

In a survey of navigation pools in the vicinity of Pittsburgh, PA, Kalisz and Dunn (2002) found Japanese knotweed comprised 11.5% of the abundance of all woody species and was more abundant than over 90% of the native species. They found it in areas in which it had not occurred only two years prior, confirming the species' ability to spread rapidly. The abundance of Japanese knotweed along the rivers surveyed, led the investigators to conclude that it is overtaking native riparian plant species in the region. Kalisz and Dunn also noticed a positive correlation between the abundance of introduced plant species and human disturbance of the riverbanks. Finally, they noted a high level of public recognition and concern about problems related to invasive exotic riparian plants, expressed at River Dialogue public forums held near Pittsburgh in 2001 and 2002.

TABLE 6-12
The Ten Most Problematic Invasive Exotic Plant Species Along the Ohio River (RM 0 to RM 437)

Common Name	**Scientific Name**
Tree of heaven	*Ailanthus altissima*
Garlic mustard	*Alliaria petiolata*
Japanese hop	*Humubus japonicus*
Japanese honeysuckle	*Lonicera japonica*
Tatarian honeysuckle	*Lonicera tatarica*
Japanese knotweed	*Polygonum cuspidatum*
Mile-a-minute	*Polygonum perfoliatum*
Giant knotweed	*Polygonum sachalinense*
Kudzu	*Pueraria montana var. lobata*
Multiflora rose	*Rosa multiflora*
Source: Morrison, Personal communication 2003.	

Purple loosestrife (*Lythrum salicaria*), an exotic species of serious concern in the northeastern U.S., is not included in the top ten list. Its distribution along the Ohio River mainstem is patchy, as favorable habitat is limited to narrow bands along mud flats (Morrison, personal communication).

6.8 INTERACTIONS WITH OTHER VECS

The following statement on the multiple functions of riparian areas succinctly connects RFR with several other VECs, including water quality, land use, threatened and endangered species, and recreation:

> Riparian areas provide essential life functions such as maintaining stream flows, cycling nutrients, filtering chemicals and other pollutants, trapping and redistributing sediments, absorbing and detaining floodwaters, maintaining fish and wildlife habitats, and supporting the food web for a wide range of biota. The future success of at least five national policy objectives -- protection of water quality, protection of wetlands, protection of threatened and endangered species, reduction of flood damage, and beneficial management of federal public lands -- depend on the restoration of riparian areas (NRC 2002):

As discussed in previous sections of this chapter, past development patterns have determined the present day configuration of riparian resources along the Ohio River. The interrelationship between riparian areas and human activity on the Ohio River is underscored by the fact that existing and potential future quality of the RFR is largely dependent upon management of the lock and dam navigation infrastructure, as well as upon on-the-ground decisions of how riparian resources will be used or protected. The extent, variety, and complexity of RFR along the Ohio River are significantly influenced by the amount of flow variability associated with the maintenance of pool elevations. Historically, flow control has focused on maintaining a minimum pool depth or minimizing flood peaks. In the future, the possibility of mimicking natural flow variations could be introduced so as to affect desired riparian habitat outcomes.

The potential value of flow variability to riparian habitats is recognized by the USFWS. Although the Ohio River Islands NWR has no direct control of water levels in the river, the USFWS advocates the resource benefits to be gained by water level management that mimics natural hydrological cycles. Where feasible, USFWS will manage water levels on Ohio River Island Refuge wetlands to mimic natural fluctuations and promote aquatic and wetland vegetation.

The future of riparian areas also is related to the management and potential development of privately owned land and to the demographics that, in turn, drive development. River transportation and traffic, which similarly are driven by demographics and market demands, also influence riparian areas in many ways, as indicated by the issues from project scoping **(see Table 6-1)**.

Water quality improvements have led to increases in boating and contact recreation. These recreation activities, however, cause potential bank erosion and other adverse effects on RFR, including development of marinas and other related businesses. On the other

hand, better water quality has improved riparian area aesthetics with regard to appearance and odor and has renewed interest in the Ohio River as a community asset. This renewed interest appears to be increasing the demand for more parks, bike trails and other green spaces along the river. Sustainable management of such lands to maintain or restore more diverse wildlife habitat could result in more functional riparian areas along the mainstem.

6.9 RELEVANT ACTIONS AFFECTING RIPARIAN/FLOODPLAIN RESOURCES

RFFAs were evaluated by members of the IWG, utilizing the RFFA Matrix for RFR (see Chapter 2 discussion of RFFA matrices). The Riparian RFFA Team formed subcommittees to address each of the five subVECs associated with the Riparian VEC: 1) terrestrial habitats, 2) wetlands, 3) riparian threatened and endangered species, 4) islands, and 5) the combined topic of floodplain hydrology, soils, and geology. SubVEC matrices were combined and evaluated, resulting in the identification of 15 RFFAs with potentially high importance (composite importance score $\geq$ 20) and 20 RFFAs with medium importance (composite importance score $\geq$ 15 - 19). These RFFAs are presented in **Table 6-13**.

The table also indicates the principal riparian function or functions affected positively or negatively by the proposed action, according to the following key:

H/S = affects hydrology and sediment dynamics
B/N = affects biogeochemistry and nutrient cycling
Ha = affects habitats and food web maintenance

The following discussion focuses on RFFAs ranked high and medium in the combined Riparian RFFA matrix. RFFAs are grouped according to their influence on riparian functions. It is important to bear in mind, however, that most actions have multiple interrelated effects on riparian functions. In fact, 22 RFFAs in **Table 6-13** are shown as affecting all the above mentioned riparian functions.

6.9.1 Actions Influencing Hydrology and Sediment Dynamics

A wide array of actions in and along the Ohio River influence riparian hydrology and sediment dynamics. Such actions are undertaken by the USACE, navigation industry, mining industry, and other river users.

Land-based activities that involve soil compaction, excavation, mining of mineral resources, or curtailment of periodic flows of water affect RFR by altering or eliminating water storage capacities, severing hydrological linkages, changing flow directions, velocities, variability, and sediment dynamics. Included in these activities are:

- lock extensions/replacements
- dam replacements/rehabilitation
- levees
- dry dams and other flood reduction projects off the mainstem
- channel modifications
- pool maintenance
- power generating facilities

- instream and floodplain sand and gravel mining, and limestone aggregate mining
- all types of floodplain development

All types of land development reduce the extent and functioning of riparian areas through land-use conversion and creation of hydrologic conditions that reduce aquatic habitat quality and lessen effectiveness of remaining riparian areas for water quality protection and other functions. Lock extensions or replacements and dam replacements or rehabilitation typically involve clearing of riparian areas during construction activities with impacts to local hydrology and habitat. Such impacts may be considered temporary; however, even with timely revegetation of a disturbed site, decades may elapse before riparian areas return to pre-disturbed conditions. Further, alterations in lock and dams can cause temporary or long-term alterations in river flow that may lead to erosion of riverbanks and nearby islands.

The impacts of residential, commercial, and industrial development on RFR are profound because of their long-term nature, the accompanying increase in imperviousness, and the development of related infrastructures that sever hydrological connections, permanently change soils, and fragment or eliminate habitat. The compaction of soils and replacement of vegetation by impervious rooftops, parking lots, and roads decreases infiltration, groundwater recharge, and groundwater contributions to streams, while increasing overland flow volumes and peak runoff rates which, in turn, contribute to erosion and nonpoint source pollution. Highway network and rail lines that support urban development, commerce, and large facilities such as power generating plants and other industrial sites further impact riparian areas by: 1) altering local topography, 2) changing infiltration and rerouting surface and groundwater, and 3) removing riparian vegetation.

One activity often stimulates another activity, compounding negative impacts. Floodplain development, for example, can create a demand for flood damage reduction structures such as levees and floodwalls that, subsequently, cause floodplain loss and severing of hydrologic connections. Levees alter connections between a channel and its RFR by changing the frequency, magnitude, and duration of overbank flows.

Ongoing maintenance of present pool elevation, superficially considered a rather passive activity, contributes to the loss of flow variability, which adversely affects riparian habitats, islands, soils, and floodplain hydrology. Similarly off-mainstem flood control dams and reservoirs dampen the magnitude of flood events. Natural flooding, in contrast, tends to rework channel sediments such that riparian areas continually gain and lose substrates, which contribute to their nature and productivity (NRC 2002).

Instream sand and gravel mining and channel maintenance dredging (ranked low in **Table 6-13**) also change sediment transport in the river channel, can eliminate or damage aquatic habitat, and may lead to island erosion and bank undercutting and failure, which, in turn, alters hydrology and compromises habitat and nutrient cycling. With instream sand and gravel mining, removal of large amounts of materials may induce channel down-cutting, which influences local groundwater patterns, frequency of overflows, bank stability, and the character of riparian vegetation (Collins and Dunne 1989; Kondolf 1995, as cited in NRC 2002).

To the rather limited extent that such activities may occur along the length of the mainstem, wetlands mitigation, ER projects, nonstructural flood damage reduction measures, and implementation of ES practices (rated high) can restore some floodplain hydrology functionality. Over time, storm water regulations also may contribute to restoration of functionality. Environmental awareness education, also rated high, could incrementally contribute to future protection or recovery of RFR.

Emergency streambank stabilization measures (ranked low) potentially prevent soil loss and sediment deposition, but may reduce hydraulic roughness along channel margins, thereby increasing flow velocities along banks during high flows, and often precluding survival of many riparian plant species (NRC 2002).

6.9.2 Actions Influencing Biogeochemistry and Nutrient Cycling

Actions in this category alter soil morphology and the ability of RFR to filter pollutants and trap sediments. Major transformations and transport processes associated with RFR include infiltration, deposition, filtration, adsorption, degradation, and assimilation. The importance of these mechanisms in controlling water quality depends on the extent and quality of RFR, as well as on local topography - all of which influence water retention time from upland areas. Included in actions influencing biogeochemistry and nutrient cycling are:

- agriculture
- silviculture
- public and private land acquisition and management, especially for heavy recreational use
- natural climatic events, especially floods, and
- the TMDL program (not listed in **Table 6-13**)

Nationwide and along the Ohio River mainstem, traditional agriculture is probably the largest contributor to the decline of riparian resources for several reasons:

1) Conversion of undeveloped land to agriculture has the potential to decrease infiltration and increase overland flow volumes and peak runoff rates.
2) Land conversion, consequently, may lead to high erosion rates that inundate RFR with sediment and limit their filtering functions.
3) Tile drainage of agricultural lands circumvents many biological processes that typically occur in riparian areas.
4) Transport of agricultural chemicals from uplands can negatively impact riparian fauna and flora, as well as downstream receiving waters.
5) Finally, livestock grazing results in loss of vegetation, compaction of underlying soils and dispersal of exotic plant species and pathogens, which have long-term CE on soil structures and the composition and productivity of plant and animal communities (NRC 2002).

In natural settings, RFR protect the soil surface. Further, the flora and fauna are constantly creating macropores, which help maintain high infiltration and percolation rates. Typical agricultural conversion to rowcrops and pasture exposes soil to raindrop impact and surface sealing, which decrease infiltration. Although agricultural tillage helps

maintain soil porosity, it does not achieve the porosity characteristic of undisturbed RFR. The 2002 Farm Bill includes cost share incentives and educational outreach efforts that promote the benefits of healthy riparian areas to agricultural activities, but traditional farm practices do not tend to change quickly.

The practice of silviculture likewise results in substantial structural and composition changes to RFR, especially when large tracts of standing timber are harvested or when the period between harvest operations is short (NRC 2002). In general, the impacts of forestry are most severe when forests are clear-cut or harvested right up to the streambank.

As with agriculture and silviculture, the development and use of public recreational facilities and private campgrounds and seasonal trailer parks can profoundly affect RFR and all their functions. A unique characteristic of riparian recreation areas is the concentration of human activities in often narrow strips of land and the potential for these activities to simultaneously affect both terrestrial and aquatic ecosystems. Heavy foot, animal, and vehicular traffic in riparian recreation areas cause soil compaction, destruction of soil biota, and increased erosion. Damage to riparian habitats can be incidental, as by overuse, or deliberate, as by replacement with impervious surfaces. Collectively, these actions also affect water quality by introducing sediments, bacteria, petrochemicals, pesticides, and refuse to adjacent water bodies. In some cases, the riparian aesthetics that made a site attractive for recreational use initially may be so severely compromised that neither the RFR nor recreation use itself can be sustained.

Because of their ability to move and modify soils and land forms, floods also affect riparian biogeochemistry and nutrient cycling. Floods tend to rework channel sediments causing riparian areas to gain and lose substrates in ways that define riparian composition and productivity. As with agriculture, floods affect all riparian functions. Floods, for example, influence habitat by helping to control the germination, establishment and long-term survival of seedlings. In the natural order, riparian vegetation in turn provides the ecological services of frictional resistance to flowing water and runoff during floods, creation of soil macropores through growth and decay, and streambank stabilization by roots.

The last action in this section, the TMDL program, was not ranked high or medium in **Table 6-13**. According to the NRC (2002), this program may eventually have a significant beneficial effect on RFR, because many TMDL implementation plans that have been developed require restoration of riparian areas as a measure to achieve needed reductions in nonpoint source pollution, thus returning to the major transformation and transport processes provided by RTR.

6.9.3 Actions Influencing Habitats and Food Web Maintenance

Almost all actions listed in **Table 6-13** affect riparian habitat function and food web maintenance. Animal life in riparian areas can be affected by direct disturbance, modification or destruction of habitat, pollution, exploitation (e.g., hunting and fishing), or introduction of pathogens. Impaired riparian habitats are also linked to degraded aquatic habitats as shading benefits and inputs of woody materials and nutrients to the aquatic ecosystem diminish. The structural diversity of native riparian plant communities creates a wide variety of feeding niches for both herbivores and carnivores. Many species utilize

RFR for movement, either as part of their home ranges or for short-term movements. In fact, short-term movements of small mammals and birds within riparian areas have been shown to aid in the cycling of nutrients between the aquatic environment and adjacent uplands (NRC 2002). RFR also provide food resources for animals throughout the food web. To illustrate the intricacy of such connections, a study cited in NRC (2002) indicated riparian vegetation not only is a primary food source for invertebrates but also serves as landing substrate for adult insects (e.g., stoneflies and mayflies) emerging from waterbodies. The insects in turn become food for migratory and resident birds in the floodplain.

As mentioned previously, all types of floodplain development, including ports, navigation structures, power plants, residences, industries, businesses, and recreation facilities negatively affect RFR directly by fragmentation, degradation, or complete elimination of habitat. Repercussions of these developments compound the effects on riparian habitat. For example, a study cited in NRC (2002) found that highways developed to serve floodplain facilities have ecological effects that extend as far as 600 m on each side of the road. New roads also become conduits for the dispersal of exotic plant species that alter native plant communities in riparian areas.

Among the RFFAs affecting habitat that have not been discussed in the two preceding sections are:

- nonstructural flood control measures
- pool maintenance
- barge queuing
- increased and dispersed barge traffic
- modification of Corps project for environmental improvement (as authorized by Section 1135 of WRDA 1986)
- ER projects
- floodplain sand and gravel mining and limestone aggregates mining
- environmental regulations and initiatives.

Nonstructural flood control measures include flood damage reduction practices that do not rely on dams or built structures. Examples include installation of riparian buffer strips along waterways and relocation of housing out of a floodplain. Both actions are potentially beneficial to RFR, as additional native habitat may be actively restored or allowed to return.

Table 6-13 rates pool maintenance as having the maximum impact on all components of RFR. The most apparent effect of pool maintenance is the loss of riparian structure and function due to inundation. A further deleterious effect on RFR relates to changes in river flows that alter flow seasonality, sediment dynamics, and moisture availability. Some riparian plants require drawdown periods for seed germination and seedling establishment. Cottonwood, a common component of riparian forests, is an example of a species that requires high flows that precede seed release and flow recession that permits seedling establishment at appropriate streambank elevations. As discussed previously, river regulation with pool maintenance has created embayments at the mouths of flooded tributaries along the Ohio mainstem. Embayments represent additional habitat that is static and differs from previously more abundant riverine habitat.

Although ranked low, barge queuing can adversely affect riparian habitat, including wetlands, if barges in queues are tied to trees or anchors and "deadmen" are placed. These concerns are heightened if queuing occurs along islands, where loss of trees can accelerate erosion and the consequent loss of limited island habitat. Likewise, increased and dispersed barge traffic, both ranked medium, are of concern because of wave-induced erosion and possible damage to riparian vegetation. Because vegetation of islands below the Newburgh and John T. Myers L/D have been affected by barge traffic, the dams will continue to be modified to allow for navigation over fixed weirs during flood events.

Modification of Corps projects for environmental improvements and ER projects are considered of high benefit to RFR. Of five broad habitat types considered, four are included in RFR – bottomland hardwood forests, islands, shorelines, and wetlands. The fifth habitat type, aquatic habitat, is linked to RFR and could benefit from riparian restoration efforts.

Floodplain sand and gravel mining and limestone aggregate mining directly fragment habitat and reduce riparian vegetation. Additional impacts of mining result from soil excavation and alteration of groundwater flows. Floodplain hydrology is further altered when mining operations end and excavated pits become flood storage areas.

Floodplain development, including marinas and small navigation projects that require Corps permits, if allowed, also negatively affect riparian habitat. Restrictions imposed on permits and evaluation of CE when permits are considered can help lessen such affects. GIS and other recent assessment tools used by the Corps also can increase accuracy and geographic comprehensiveness in projecting impacts to riparian areas.

Lastly, environmental awareness education and environmental sustainability practices offer positive benefits for RFR, but are voluntary actions that will require wider interest, acceptance, and practice before environmental benefits will be realized. Wetland mitigation banking and the Endangered Species Act also offer positive RFR benefits that are somewhat better defined and more site-specific.

TABLE 6-13
Combined RFFA for Riparian VEC

RFFA[1]	Time Period[2]	Probability[3]	Location[4]	Terrestrial habitat	Islands	Wetlands	Soils/Geol.	Floodplain hydrology	Importance[5]	Functions Influenced[6]
Navigation Investment Actions										
Lock Extensions/New Locks/Replacement or Rehabilitation	A	H	E	5	3	5	3	3	19	All
Dam replacement and/or rehabilitation[6]	A	H	E	5	5	5	5	5	25	All
Other Corps Actions										
Flood Damage Reduction Projects										

RFFA[1]	Time Period[2]	Probability[3]	Location[4]	Terrestrial habitat	Islands	Wetlands	Soils/Geol.	Floodplain hydrology	Importance[5]	Functions Influenced[6]
levees/floodwalls	A	M	E	5	3	5	3	5	21	
dry dams, other projects off mainstem	A	M	E	5	0	3	3	5	16	H/S, Ha
channel modifications				5	0	5	0	5	15	H/S, Ha
nonstructural measures (e.g., relocation)				5	3	5	0	5	18	Ha
Modification of Corps structures for environmental improvements (Sec. 1135)	A	L	E	5	5	5	3	1	19	Ha
Environmental restoration of aquatic ecosystems (Sec. 206)	A	L	E	5	5	5	3	3	21	Ha
ERP Projects - 5 categories	A	M	E	5	5	5	3	3	21	All
Port development (Sec. 107) and maintenance dredging	A	M	E	5	1	3	3	3	15	All
Pool maintenance[6]	A	H	E	5	5	5	5	5	25	H/S, Ha
"But for" Actions										
Commercial Navigation										
terminals	A	M	E	5	1	5	3	1	15	All
multi-modal sites	A	M	E	5	1	5	3	1	15	All
increased traffic				5	5	5	0	0	15	Ha
dispersed barge traffic				5	5	5	0	0	15	Ha
Instream sand and gravel mining	A	H	E	5	5	3	5	0	18	H/S, Ha
Floodplain sand and gravel mining	A	H	E	5	0	5	5	5	20	H/S, Ha
Limestone aggregates mining	A	H	E	5	0	3	5	5	18	H/S, Ha
Coal utilities	A	H	E	5	3	3	5	5	21	All
Other coal industries	A	H	E	5	0	3	5	5	18	All
Hydropower on dams	A	M	E	5	3	3	3	3	17	All
Recreation facilities - Construction and O&M				5	3	5	3	0	16	All
Actions by Others										
Public lands acquisition and management	A	H	U	5	5	5	5	0	20	B/N, Ha
Floodplain development										
residential	A	H	E	5	0	5	5	5	20	All
commercial	A	H	E	5	0	5	5	5	20	All
industrial	A	H	E	5	0	5	5	5	20	All
Private recreational - camps, docks, seasonal trailer parks[6]	A	H	E	5	5	3	5	1	19	B/N, Ha
Crossings - bridges	A	H	E	3	5	5	3	3	19	All
Silviculture	A	H	E	5	3	3	5	0	16	Ha
Agriculture	A	H	M,L	5	3	5	5	5	23	B/N, Ha
Natural Climatic Events										
floods	A	L	E	3	5	5	3	1	17	All

RFFA[1]	Time Period[2]	Probability[3]	Location[4]	Terrestrial habitat	Islands	Wetlands	Soils/Geol.	Floodplain hydrology	Importance[5]	Functions Influenced[6]
Regulatory Environment										
COE permitting programs	A	H	E	5	5	5	3	5	23	All
Small navigation projects	A	M	E	3	3	5	3	5	19	All
Environmental Awareness Education	A	H	E	5	5	5	5	5	25	All
Environmental sustainability practices	A	M	E	5	5	5	5	5	25	All
Lower Scored RFFAs										
Channel dredging/dredged material disposal				3	5	5	0	0	13	H/S, Ha
Emergency streambank stabilization (Sec. 14)	A	H	E	5	0	5	3	1	14	H/S, Ha
Fleeting areas/barge storage	A	M	E	5	3	5	1	0	14	H/S
Industrial users, excluding coal-related	A	H	E	5	0	3	5	0	13	All
Marina development & operation	A	H	E	3	3	3	3	0	12	B/N, Ha
Site remediation	A	L	E	3	1	5	3	1	13	All
Wetland Mitigation Banking	A	L	E	0	0	5	3	5	13	All
ESA (Endangered Species Act)	A	H	E	5	3	5	0	0	13	All

[1] Reasonably Foreseeable Future Actions

[2] Time period in which the RFFA may occur: 1 = within 10 years, 2 =10 - 25 years, 3 = 25 – 60 years, A = applicable all time periods

[3] Occurrence probability or likelihood RFFA will happen: H = high, M = medium, L = low

[4] Location or setting on river where RFFA is expected to occur: U = upper (Pittsburgh - Huntington), M = middle (below Huntington – Louisville), L = lower ((below Louisville - mouth), E = along entire length of river, SL = specific location, e.g., locks and dams, U = urban setting, R = rural setting

[5] Importance of RFFA = sum of subVECs. For individual Sub VEC: High = 5 points, Medium = 3 points, Low = 1 points, None = 0 points

6 Functions influenced: H/S = hydrology and sediment dynamics, B/N = biogeochemistry and nutrient cycling, Ha = habitat and food web maintenance

6.10 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve environmental sustainability (ES). ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of CE can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An analysis of environmental sustainability (AES) has been and is being used in several other

programmatic studies of the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps: (1) delineation of "common effects" on eight indicators of ES from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix; (2) selection of three service areas provided by RFR, and their grouping, as appropriate; and (3) consideration of the "connections" among the common effects, the indicators, and the service area groups. The relationship among the three service areas (functional groups) and the eight indicators are summarized as follows:

- Hydrology and Sediment Dynamics

  -- adequacy of hydrologic connections between riparian areas and adjacent water bodies and uplands -- these connections are necessary for maintaining appropriate water flows and riparian storage of surface water and sediment

  -- capacity for water storage in the floodplain -- adequate capacity is needed in order to reduce downstream flood damages; such capacity can also facilitate the cycling and removal of undesirable chemical constituents prior to their movement to nearby streams and rivers

  -- water table and groundwater recharge -- shallow groundwater systems play a vital role in the subsurface flow of water to and from nearby streams and rivers, and local wetlands; this resource is also basic to groundwater usage and to the subsurface attenuation or movement of chemical contaminants

  -- sustainability of sediment dynamics -- natural movement of sediment from riparian areas to streams and rivers, and the continuing transport downstream; provides nutrients and bottom habitat materials for the aquatic ecosystem

- Biogeochemistry and Nutrient Cycling

  -- quality of soil structures -- adequate soil structures can aid in reducing erosion and providing a diverse floral setting for associated fauna

  -- capacity of riparian areas to intercept pollution -- attenuation of pollutant movement to nearby streams and rivers is beneficial to the aquatic ecosystem; such attenuation is a function of chemical and microbiological characteristics of the pollutants, soil structure and chemistry, and local hydrodynamic conditions

- Habitat and Food Web Maintenance

  -- integrity of riparian habitats -- integrity relates to the resiliency of habitats relative to hydrodynamic, climatic, biotic, and abiotic stresses; such integrity is a function of the type, size, and quality of the habitat, as well as the contiguous nature of the habitat

-- measures of biodiversity -- greater diversity is typically associated with more stable and properly functioning riparian ecosystems

The output of the AES consists of a qualitative (descriptive) discussion of the "connections", with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions -- what is the current ES for RFR, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable -- the composite conditions for the 8 indicators and the selected 3 service areas (functional categories) provided by RFR do not reflect conditions that would facilitate a healthy, diverse, and robust riparian zone along the majority of the Ohio River mainstem; further, there are no organized institutional controls and management measures for sustaining riparian areas.

- Marginally sustainable -- the composite conditions for the 8 indicators and the selected 3 service areas are problematic at several locations along the Ohio River; these problematic conditions are somewhat tenuous both in location and likelihood of occurrences, and there are uncertainties regarding specific quantitative measures of the indicators; therefore, the conditions are "borderline" regarding a healthy, diverse, and robust riparian zone along the majority of the Ohio River mainstem; further, while some institutional programs for riparian area management may be in place, they do not encompass all RFR.

- Sustainable -- the composite conditions for the 8 indicators and the 3 service areas reflect conditions that would facilitate a healthy, diverse, and robust riparian zone along the majority of the Ohio River mainstem; further, comprehensive institutional controls and management measures are in place to sustain RFR.

As noted in **Table 6-13**, the 35 RFFAs ranked as high (H) or medium (M) can be grouped into actions having effects on the three functional categories. These three groups of actions, along with the eight environmental indicators, and three functional categories, are displayed in **Tables 6-14 through 6-16**. **Table 6-14** includes 26 RFFAs that are anticipated to cause effects on the Hydrology and Sediment Dynamics functional group (service area). The connections between the 26 RFFAs and the four indicators for the group are summarized in terms of common anticipated effects. Finally, the right-most column summarizes the composite resulting effects on all three functional groups. In addition, pertinent conclusions are drawn relative to the ES of RFR. In general, the CE of the majority of the listed actions in **Table 6-13** would move the RFR away from a sustainable condition.

Table 6-15 relates to 23 RFFAs that are anticipated to affect the Biogeochemical and Nutrient Cycling functional group. The structure of **Table 6-15** is similar to that for **Table 6-14**. The information in **Table 6-15** also indicates that the CE of the majority of the RFFAs would move the RFR away from a sustainable condition.

Finally, **Table 6-16** highlights the CE of all 35 high and medium importance RFFAs relative to their affects on the Habitat and Food Web Maintenance functional group.

Again, the structure of **Table 6-16** is similar to that for **Tables 6-14 and 6-15**. Also, the CE on this functional group would move the RFR away from sustainability.

To summarize, **Tables 6-14 through 6-16** indicate that the high and medium importance RFFAs will have the following CE on the three functional groups:

- Regarding the Hydrology and Sediment Dynamics functional group, the RFFAs are expected to cause: (1) further disruptions and decreases in natural hydrologic connections; (2) changes in upstream to downstream flow patterns; (3) lowering (decrease) of the water storage capacity of the floodplain; (4) undesirable declines in the water table and recharge rates; (5) changes in flow patterns between aquifers and the river; (6) perturbations in the environmental movement of sediment; and (7) reductions in the inputs of nutrients and bottom habitat materials moving to the river.

- Regarding the Biogeochemical and Nutrient Cycling functional group, the RFFAs are expected to cause: (1) undesirable soil compaction; (2) reductions in the diversity of floral settings; and (3) reductions in the interception capacity of the riparian areas due to soil compaction and decreases in areas with diverse floral coverings.

- Regarding the Habitat and Food Web Maintenance functional group, the RFFAs are expected to cause: (1) reductions in the resiliency, size, quality, and contiguous nature of many existing riparian habitats and (2) decreases in the biodiversity and food web maintenance associated with numerous habitat areas.

TABLE 6-14
AES Tiers for Actions that Affect the Hydrology and Sediment Dynamics Functional Group

RFFAs that Affect Hydrology and Sediment Dynamics	Indicators for Hydrology and Sediment Dynamics	Composite Considerations for ES for Riparian/Floodplain Resources
(1) Lock extensions, new locks, replacement or rehabilitation (M) (see Note 1) (2) Dam replacement and/or rehabilitation (M)(see Note 1) (3) Levees/floodwalls (H) (see Note 1) (4) Reservoirs and other projects off mainstem (M) (see Note2) (5) Channel modifications (M) (see Note 2) (6) ERP projects (H) (see Note 1) (7) Port development and maintenance dredging (M) (see Note 1) (8) Pool maintenance (H) (see Note 2) (9) Commercial navigation -- terminals (M) (see Note 1) (10) Commercial navigation -- multi-modal sites (M) (see Note 1) (11) Instream sand and gravel mining (M) (see Note 2) (12) Floodplain sand and gravel mining (H) (see Note 2) (13) Limestone aggregates mining (M) (see Note 2) (14) Coal utilities (H) (see Note 1) (15) Other coal industries (M) (see note 1) (16) Hydropower on dams (M) (see note 1) (17) Recreation facilities (by others) -- construction and O&M (M) (see Note 1) (18) Floodplain development -- residential (H) (see Note 1) (19) Floodplain development	• Adequacy of hydrologic connections --. Hydrologic connections are disrupted and decreased in local riparian areas by RFFA numbers 1, 2, 3, 7, 9, 10, 17, 18, 19, 20, 21, and 23; such disruptions or decreases will occur in larger riparian areas as a result of RFFA numbers 12, 13, 14, and 15. Movement of water from upstream to downstream locations will be altered by RFFA numbers 4, 5, 7, 8, 11, 16, 21, 22, 23, and 24. Likely increases in hydrologic connections would occur from RFFA numbers 6, 25, and 26. Therefore, in summary, the cumulative effects of the listed RFFAs would be expected to be manifested as further disruptions and decreases in riparian area hydrologic connections to the Ohio River mainstem, and in changes in the upstream to downstream flow patterns of the Ohio River. • Capacity for water storage in the floodplain -- Small and local decreases in the water storage capacity of the floodplain would occur from RFFA numbers 1 and 17. Larger local decreases in the storage capacity would be expected from RFFA numbers 7, 9, 10, 13, 14, 15, 18, 19, 20, and 23. Imposed mitigation measures on 18, 19, and 23 could reduce the local decreases in storage capacity; further, increases could be achieved via the design features of retention basins and the use of Best Management Practices (BMPs). Local increases in floodplain water storage capacity would be expected to result from RFFA	• Maintenance of sufficient hydrology and sediment dynamics -- The RFFAs are expected to cause: (1) further disruptions and decreases in natural hydrologic connections, (2) changes in upstream to downstream flow patterns, (3) lowering (decrease) of the water storage capacity of the floodplain; (4) undesirable declines in the water table and recharge rates; (5) changes in flow patterns between aquifers and the River; (6) perturbations in the environmental movement of sediment; and (7) reductions in the inputs of nutrients and bottom habitat materials moving to the River. As a result, this functional group will move further away from contributing to sustainable conditions for the riparian/floodplain resources. • Facilitation of biogeochemical processes and nutrient cycling -- Because of the reduced maintenance of the functions of the hydrology and sediment dynamics component of ES, the facilitation of biogeochemical processes and nutrient cycling as a component of ES will decline. • Provision of diverse habitat and maintenance of related food webs -- Because of the

RFFAs that Affect Hydrology and Sediment Dynamics	Indicators for Hydrology and Sediment Dynamics	Composite Considerations for ES for Riparian/Floodplain Resources
-- commercial (H) (see Note 1) (20) Floodplain development -- industrial (H) (see Note 1) (21) Crossings -- bridges (M) (see Note 1) (22) Floods (M) (see Note 1) (23) COE permitting programs (H) (see Note 1) (24) Small navigation projects (M) (see Note 1) (25) Environmental Awareness Education (H) (see Note 1) (26) Environmental sustainability practices (H) (see Note 1)	numbers 3, 6, 12, 22, 25, and 26; with RFFA number 8 having the potential to increase or decrease the capacity. No effects on water storage capacity would be expected from RFFA numbers 2, 4, 5, 11, 16, and 24. Therefore, in summary, the cumulative effects of the listed RFFAs would be expected to lower (decrease) the water storage capacity of the floodplain of the Ohio River mainstem. • Water table and groundwater recharge -- Groundwater recharge will be decreased in local alluvial aquifers as a result of RFFA numbers 1, 17, and 21; such decreases are expected in larger areas from RFFA numbers 7, 9, 10, 14, 15, 18, 19, 20, and 23 (lesser decreases could occur with implementation of designed retention basins and BMPs for 18, 19, and 20). Increased recharge in larger areas would be expected from RFFA numbers 3, 6, 12, 25, and 26. Local physical alterations to water tables could occur from RFFA numbers 2, 13, and 24. Increases in groundwater usage and consequent lowering of the water table could occur in local areas via usage of the resource by RFFA numbers 7, 9, 10, 14, and 15. Declines in groundwater usage would be expected from numbers 25 and 26. Finally, changes in natural temporal patterns and quantities of groundwater inflow to the Ohio River, along with patterns of river flow moving into alluvial aquifers would result from RFFA numbers 4, 5, 8, 11, 16, and 22. Therefore, in summary, the cumulative effects of the listed RFFAs would be expected to cause undesirable declines in the water table and recharge rates, and also cause changes in the natural patterns	reduced maintenance of the functions of the hydrology and sediment dynamics component of ES, the provision of conditions for diverse habitats and maintenance of related food webs will decrease. • Conclusion relative to ES of riparian/floodplain resources -- The composite effects summarized herein are such that the riparian/floodplain resources would move away from a more sustainable condition. This situation creates an immediate need for planning and implementing an institutional program for riparian area management for the Ohio River mainstem.

RFFAs that Affect Hydrology and Sediment Dynamics	Indicators for Hydrology and Sediment Dynamics	Composite Considerations for ES for Riparian/Floodplain Resources
Notes: (1) this RFFA also affects the Bio-geochemistry and Nutrient Cycling functional group, and the Habitats and Food Web Maintenance functional group (2) this RFFA also affects the Habitats and Food Web Maintenance functional group	of flows between the aquifers and the Ohio River. • Sustainability of sediment dynamics -- Disruptions of sediment movement from riparian/floodplain areas into the Ohio River would be expected from RFFA numbers 3, 7, 9, 10, 12, 13, 14, 15, 17, 18, 19, 20, and 23. Further, decreases in nutrient input and bottom habitat materials for aquatic ecosystems are anticipated from RFFA numbers 3, 18, 19, 20, and 23. Disruptions in downstream sediment movement would occur from RFFA numbers 1, 2, 4, 5, 7, 8, 11, 16, 21, 22, and 24. RFFA numbers 25 and 26 would be expected to promote natural sediment movement from the riparian/floodplain areas. Finally, the influence of RFFA number 6 would be dependent on the location, type, and extent of the ecological restoration program; the effects could be beneficial or detrimental, or they could be so small as to be classified as no effect. Therefore, to summarize, the cumulative effects of the listed RFFAs would be expected to cause disruptions in the environmental movement of sediments, and to cause reductions in nutrient inputs and bottom habitat materials moving to the Ohio River.	

TABLE 6-15
AES Tiers for Actions that Affect the Biogeochemistry and Nutrient Cycling Functional Group

RFFAs that Affect Biogeochemistry and Nutrient Cycling	Indicators for Biogeochemistry and Nutrient Cycling	Composite Considerations for ES for Riparian/Floodplain Resources
(1) Lock extensions, new locks, replacement or rehabilitation (M) (see Note 1) (2) Dam replacement and/or rehabilitation (H) (see Note 1) (3) Levees/floodwalls (H) (see Note 1) (4) ERP projects (H) (see Note 1) (5) Port development and maintenance dredging (M) (see Note 1) (6) Commercial navigation -- terminals (M) (see Note 1) (7) Commercial navigation -- multi-modal sites (M) (see Note 1) (8) Coal utilities (H) (see Note 1) (9) Other coal industries (M) (see Note 1) (10) Hydropower on dams (M) (see Note 1) (11) Recreation facilities (by others) -- construction and O & M (M) (see Note 1) (12) Public lands acquisition and management (H) (see Note 2) (13) Floodplain development -- residential (H) (see Note 1) (14) Floodplain development -- commercial (H) (see Note 1) (15) Floodplain development -- industrial (H) (see Note 1) (16) Private recreational -- camps, docks, seasonal trailer parks (M) (see Note 2) (17) Crossings -- bridges (M) (see Note 1) (18) Agriculture (H) (see Note 2) (19) Floods (M) (see Note 1)	• Quality of soil structures -- Compaction of local soils would take place due to RFFA numbers 1, 2, 11, 16, 17, 20, and 21; compaction over larger areas would occur due to numbers 3, 5, 6, 7, 8, 9, 13, 14 and 15. In general, soil compaction is undesirable relative to riparian areas. Reductions in the diversity of floral settings, and their related faunal species, would be expected from RFFAs 3, 5, 6, 7, 8, 9, 13, 14,15and 18. Several RFFAs would be expected to enhance soil quality and promote diverse habitats; the RFFA numbers include 4, 12, 19, 22, and 23. Hydropower on dams (number 10) would not be expected to cause effects. Therefore, in summary, the majority of the cumulative effects would be associated with undesirable soil compaction ad reductions in the diversity of floral settings. • Capacity of riparian areas to intercept pollution -- Decreases in the interception capacity would be expected for local areas subjected to RFFA numbers 1, 2, 11, 16, and 17; similar decreases over larger areas would be expected for numbers 3, 5, 6, 7, 8, 9, 13, 14, 15, and 20. Potential increases in pollution interception capacity would be expected from RFFA numbers 4, 12, 18, 19, 22, and 23. Hydropower on dams (number 10) and small navigation projects (number 21) are not anticipated to alter interception capacity. In summary, the	• Facilitation of biogeochemical processes and nutrient cycling -- The RFFAs are expected to cause: (1) undesirable soil compaction; (2) reductions in the diversity of floral settings; and (3) reductions in the interception capacity of the riparian areas due to soil compaction and decreases in areas with diverse floral coverings. As a result, this functional group will move further away from contributing to sustainable conditions for the riparian/floodplain resources. • Maintenance of sufficient hydrology and sediment dynamics -- Because of greater soil compaction and losses of floral diversity, overland runoff will be increased, and greater soil erosion is likely. Accordingly, the hydrology and sediment dynamics functional group as a component of ES will decline. • Provision of diverse habitat and maintenance of related food webs -- Because of the reduced facilitation of the functions of the biogeochemistry and nutrient cycling component of ES, the provision of conditions for diverse habitats and maintenance of related food webs will decrease. • Conclusion relative to ES of riparian/floodplain resources -- The composite effects summarized herein are such that the riparian/floodplain resources would move away from a more sustainable

RFFAs that Affect Biogeochemistry and Nutrient Cycling	Indicators for Biogeochemistry and Nutrient Cycling	Composite Considerations for ES for Riparian/Floodplain Resources
(20) COE permitting programs (H) (see Note 1) (21) Small navigation projects (M) (see Note 1) (22) Environmental Awareness Education (H) (see Note 1) (23) Environmental sustainability practices (H) (see Note 1) <u>Notes:</u> (1) this RFFA also affects the Hydrology and Sediment Dynamics functional group, and the Habitats and Food Web Maintenance functional group (2) this RFFA also affects the Habitats and Food Web Maintenance functional group	majority of the 23 listed RFFAs would be expected to cause reductions in the interception capacity; the primary mechanisms would probably be associated with soil compaction and reductions in floral coverings.	condition. This situation creates an immediate need for planning and implementing an institutional program for riparian area management for the Ohio River mainstem.

TABLE 6-16
AES Tiers for Actions that Affect the Habitat and Food Web Maintenance Functional Group

RFFAs that Affect Habitat and Food Web Maintenance	Indicators for Habitat and Food Web Maintenance	Composite Considerations for ES for Riparian Floodplain Resources
(1) Lock extensions, new locks, replacement or rehabilitation (M) (see Note 1) (2) Dam replacement and/or rehabilitation (H) (see Note 1) (3) Levees/floodwalls (H) (see Note 1) (4) Reservoirs and other projects off mainstem (M) (see Note 2) (5) Channel modifications (M) (see Note 2) (6) Nonstructural measures (M) (7) Modification of Corps structures for environmental improvements (Sec.1135) (M)	• Integrity of riparian habitats -- The resiliency, size, quality, and contiguous nature of local riparian habitats will be reduced by RFFA numbers 1, 2, 14 (islands), 22, 27, and 28; such reductions in larger riparian habitat areas will occur as a result of numbers 3, 10, 12, 13, 17, 18, 19, 20, 24, 25, 26, 29, 30, and 32. Increases in habitat fragmentation would be expected from RFFA	• Provision of diverse habitat and maintenance of related food webs -- The RFFAs are expected to cause: (1) reductions in the resiliency, size, quality, and contiguous nature of many existing riparian habitats; and (2) decreases in the biodiversity and food web maintenance associated with numerous habitat areas. Accordingly, this

RFFAs that Affect Habitat and Food Web Maintenance	Indicators for Habitat and Food Web Maintenance	Composite Considerations for ES for Riparian Floodplain Resources
(8) Environmental restoration of aquatic ecosystems (Sec.206) (H) (9) ERP projects (H) (see Note 1) (10) Port development and maintenance dredging (M) (see Note 1) (11) Pool maintenance (H) (see Note 2) (12) Commercial navigation -- terminals (M) (see Note 1) (13) Commercial navigation -- multi-modal sites (M) (see Note 1) (14) Commercial navigation -- increased traffic (M) (15) Commercial navigation -- dispersed barge traffic (M) (16) Instream sand and gravel mining (M) (see Note 2) (17) Floodplain sand and gravel mining (H) (see Note 2) (18) Limestone aggregates mining (M) (see Note 2) (19) Coal utilities (H) (see Note 1) (20) Other coal industries (M) (see Note 1) (21) Hydropower on dams (M) (see Note 1) (22) Recreation facilities (by others) -- construction and O & M (M) (see Note 1) (23) Public lands acquisition and management (H) (see Note 3) (24) Floodplain development -- residential (H) (see Note 1) (25) Floodplain development -- commercial (H) (see Note 1) (26) Floodplain development -- industrial (H) (see Note 1) (27) Private recreational -- camps, docks, seasonal trailer parks (M) (see Note 3) (28) Crossings -- bridges (M) (see Note 1) (29) Silviculture (M) (30) Agriculture (H) (see Note 3) (31) Floods (M) (see Note 1) (32) COE permitting programs (H) (see Note 1) (33) Small navigation projects (M) (see Note 1) (34) Environmental Awareness Education (H) (see Note 1) (35) Environmental sustainability	numbers 24, 25, and 26 (all three involve floodplain developments). Enhancement of the resiliency, size, quality, and contiguous nature of riparian habitats is anticipated from RFFA numbers 4, 7, 8, 9, 23, 31, 34, and 35. Finally, no effects are anticipated for aquatic environment actions involving numbers 5, 6, 11, 15, 16, 21, and 33. In summary, the majority of the cumulative effects would be associated with declines in the resiliency, size, quality and contiguous nature of existing riparian habitats. • Measures of biodiversity -- The biodiversity of local riparian habitats will be reduced by RFFA numbers 1, 2, 14 (islands), 22, 27, and 28; such biodiversity declines in larger habitat areas will occur as a result of numbers 3, 10, 12, 13, 17, 18, 19, 20, 24, 25, 26, 29, 30, and 32. Enhancement of the biodiversity of larger habitats is anticipated from RFFA numbers 4, 7, 8, 9, 23, 31, 34, and 35. No effects are anticipated for aquatic environment actions involving numbers 5, 6, 15, 16, 21, and 33. Pool maintenance (number 11) could cause beneficial or adverse effects, depending upon location and specific water level fluctuations. To summarize, the majority of the cumulative effects are associated with reductions in the biodiversity, and associated food web maintenance, of riparian habitat areas.	functional group will be reduced in its ability to positively contribute to sustainable conditions for riparian/floodplain resources. • Maintenance of sufficient hydrology and sediment dynamics -- Because of declines in both the integrity and biodiversity of habitats, and the maintenance of food web relationships, the more natural conditions for hydrology and sediment dynamics will be reduced. Accordingly, this functional group will be reduced in its contribution to sustainable riparian/floodplain resources. • Facilitation of biogeochemical processes and nutrient cycling -- Because of the declines in the habitat and food web maintenance functional group, reductions will also occur in biogeochemical processes and nutrient cycling. • Conclusion relative to ES of riparian/floodplain resources -- The composite effects summarized herein are such that the riparian/floodplain resources would move away from a more sustainable condition. This situation creates an immediate need for planning and implementing an institutional program for riparian area management for the Ohio River mainstem.

RFFAs that Affect Habitat and Food Web Maintenance	Indicators for Habitat and Food Web Maintenance	Composite Considerations for ES for Riparian Floodplain Resources
practices (H) (see Note 1) Notes: (1) this RFFA also affects the Hydrology and Sediment Dynamics functional group and the Biogeochemistry and Nutrient Cycling functional group (2) this RFFA also affects the Hydrology and Sediment Dynamics functional group (3) this RFFA also affects the Biogeochemistry and Nutrient Cycling functional group		

6.11 CONCLUSIONS

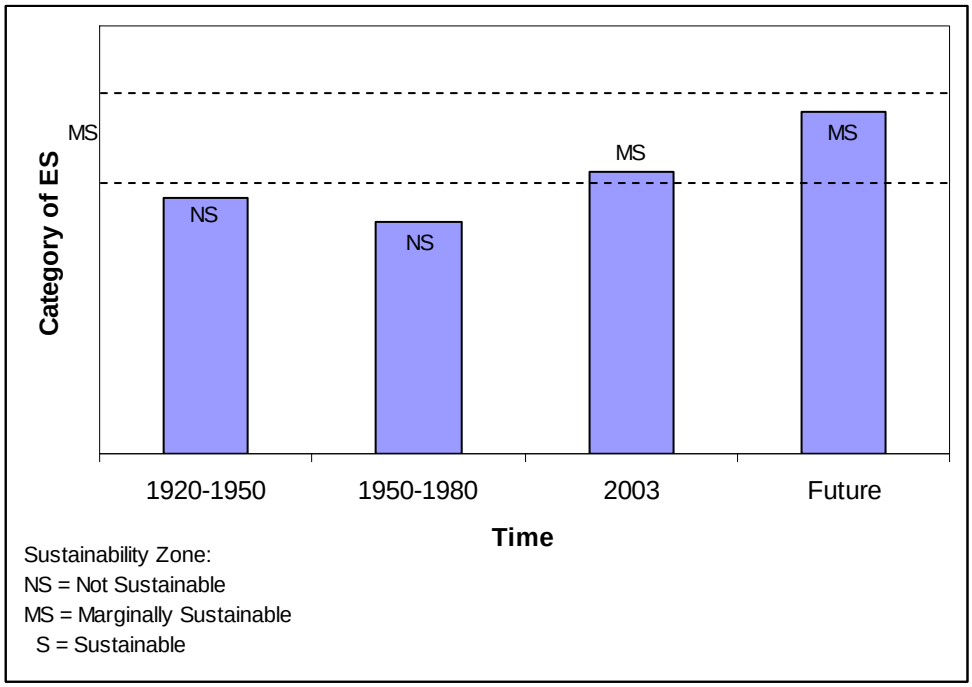
Based upon the above-described historical information, the actions and effects, the changes in the eight indicators for the effects, and the three functional groups related to the ES of RFR, the sustainability can be characterized and depicted in **Figure 6-1** as follows:

- In the time period prior to 1920, and continuing up to about 1950, the RFR can be classified as "not sustainable" due to relatively rapid losses of riparian habitats and their functions, the lack of knowledge of the importance of these resources to both terrestrial and aquatic ecosystems, and to the essential absence of any institutional programs to manage or control riparian areas. Further, the lack of awareness of environmental services performed by RFR coupled with ongoing floodplain development, especially in the upper and middle river, led to the loss and fragmentation of valuable RFR along the Ohio mainstem before such resources could be well-documented.

- In the time period from 1950 to 2000, worsened "not sustainable" conditions occurred in the first several decades as a result of still more disruptions and losses of riparian areas. However, recent decades have included an increasing awareness of riparian services, including regulation of wetlands, a highly productive riparian component. The establishment of the Ohio River Islands National Wildlife Refuge has slowed the disappearance of another riparian habitat type, islands, and also has brought greater visibility to riparian resources of the Ohio mainstem embayments. These initiatives suggest the current status of RFR may be moving toward "marginally sustainable". Accompanying these initiatives is an increasing recognition that institutional programs must be established to protect RFR.

- Regarding the future, the growing awareness of environmental services performed by RFR, as well as increasing demand for river corridor enhancement and protection for passive recreation may help move RFR toward a more sustainable future. However, it is less certain if environmental regulations and institutional programs will be in place to support RFR sustainability and stem fragmentation and loss of RFR from development along the Ohio River mainstem. Pending the establishment of such protective measures, RFR can be expected to remain within the range of "marginally sustainable."

FIGURE 6-1
ES of Riparian Resources



- An important issue is the need for institutional programs for riparian area management. While it is beyond the scope of this chapter to completely explore the types of programs and considerations related to their implementation, examples of program features include, but are not limited to (NRC 2000):

  (1) requiring impact identification and mitigation via the NEPA process,

  (2) designation of special management areas on public lands,

  (3) regulation of activities on privately-owned riparian areas,

  (4) utilization of incentives such as cost-sharing, low-cost loans, or tax reductions to encourage the use of BMPs on riparian areas, and

  (5) the purchase of privately owned riparian lands, either in fee or by easement, for public management.

The above examples are only illustrative. Further, they are not mutually exclusive; they can be used in combination.

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Chapter 7

AIR QUALITY

7.1 CONTENTS

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References

Supplement – Future Impacts of Air Quality Regulatory Programs

7.2 DEFINITION OF AIR QUALITY

This chapter considers how Cumulative Effects (CE) of human use of the Ohio River have influenced air quality and what air quality impacts may be anticipated in the foreseeable future. In the Ohio River Mainstem Systems Study (ORMSS), air quality refers to ambient or outdoor air that is safe to breathe by all members of the general population, including young children, elderly citizens and other ”at risk” individuals such as asthmatics. Air quality standards are used to assess the levels at which a particular area is being protected; specific air quality parameters evaluated in the ORMSS are discussed in the section titled Indicators of Air Quality. The effects of air quality on other Valued Evironmental Components (VECs) are integrated in the section titled Interactions with Other VECs.

7.3 OBJECTIVES AND SCOPE OF THE AIR QUALITY STUDY

7.3.1 Introduction

This chapter assesses the system-wide cumulative air quality impacts of all likely major navigation improvements along the mainstem of the Ohio River during the period from 2000 - 2070. Air quality impacts that are directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFAs) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFA. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, actions by non-governmental entities, and predictions of general economic expansion and development.

The results of the Cumulative Effects Assessment (CEA) are intended to contribute to two levels of subsequent public debate; whether the impacts of the RFFAs constitute acceptable outcomes for the affected resources, and the manner in which the proposed navigation improvements contribute to those outcomes.

7.3.2 Geographic Scope

For the Air Quality section of the CEA, the geographic area of focus for air pollutant sources includes the region directly served by Ohio River barge transport, e.g., counties adjacent to the main stem of the Ohio River. The contribution of these sources to both local and regional air quality concerns is discussed in this chapter.

7.3.3 Time Frame

The established time frame for this CEA project is 1920 to 2070. The earlier date approximates the initiation of Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the ORMSS.

7.4 INPUT FROM PUBLIC SCOPING MEETINGS

A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state or local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. A more detailed discussion of the scoping meetings is presented in Section 2 (Methodology) of this report.

185 people attended the meetings and over 200 vocal comments were recorded from the question and answer sessions. These comments accounted for the large majority of

input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Only one comment directly addressed air quality, noting the "importance of continued air quality improvements as a high priority."

7.5 INDICATORS OF SUSTAINABILITY

National air quality standards are established by the USEPA under authority of the Clean Air Act (CAA). CE are explicitly recognized in the establishment of air quality standards. In addition to tracking compliance with the standards, the CAA requires that USEPA continually evaluate the effectiveness of the standards in protecting human health and other resources. New standards, as well as revisions of existing standards, are developed and implemented to maintain these protections.

7.6 LAWS, REGULATIONS, ORDINANCES, AND PROGRAMS

7.6.1 Impacts of Air Pollution

Air pollutants that are currently contributing to significant air quality issues in the Ohio Valley region include; ground level ozone (O_3), particulate matter ($PM_{2.5}$, PM_{10}), oxides of nitrogen (NOx), sulfur dioxide (SO_2), and volatile organic compounds (VOCs).

NOx combines with VOC to produce ground level O_3, which is a threat to human health in a growing number of Ohio River communities. Primary sources of NOx include motor vehicles, power plants, and other industrial combustion sources. VOCs are produced from motor vehicles, chemical plants, refineries, factories, and some consumer or commercial products. Short-term (1-3 hours) and prolonged (6-8 hours) exposures to O_3 are associated with increased hospital admissions and emergency room visits for respiratory distress, especially among active children and adults with a pre-existing susceptibility such as asthma. Exposures to O_3 contribute to respiratory infections, lung inflammation, decreased lung function, chest pains, and cough. Ozone also impacts agriculture, commercial forestry, and urban parks; causing increased susceptibility to disease, pests, and other stresses.

SO_2 and NOx are the primary causes of acid rain, which impacts people and ecosystems throughout the midwest and northeast, and in southeastern Canada. Coal-fired power plants are the primary source of SO_2. Other sources include metal smelting, other industrial processes, and combustion of sulfur containing fuels such as diesel. Acidification of soils, lakes, and streams has caused the destruction of commercial and recreational fisheries, degraded agricultural and forest production, and accelerated corrosion of buildings and monuments (USEPA, August 2000, 2001a, b).

NOx, VOC, and SO_2 are also major precursors to fine particulate matter ($PM_{2.5}$). These gases interact with other compounds in the air to form fine particles. $PM_{2.5}$ also consists of dry particles emitted directly from sources such as fuel combustion by motor vehicles, power plants, and industrial facilities. Fine particles are associated with deep penetration into the lungs, contributing to increased hospital and emergency room visits, increased respiratory symptoms and disease, decreased lung function, and even premature death. By comparison, course particles (PM_{10}) are emitted by vehicle travel on unpaved roads, materials handling, crushing and grinding operations, and windblown dust.

Exposure to coarse particles is primarily associated with the aggravation of respiratory conditions, such as asthma.

Carbon Monoxide (CO) is a potentially poisonous by-product of motor vehicle exhaust, and high concentrations typically occur in areas with heavy traffic congestion. Peak CO concentrations typically occur in winter when CO emissions are greatest and nighttime inversion conditions concentrate the pollutants. Motor vehicle engine design standards and "winter blend" reformulated gasoline for problem areas have combined to reduce average CO ambient concentrations by 57% in the past 20 years, with an estimated 93% reduction in the number of exceedances of the standard.

7.6.2 Air Quality Standards and Regulations

National Ambient Air Quality Standards (NAAQS) have been established by USEPA for the seven categories of air pollutants presented in **Table 7-1** (USEPA, June 2004). New standards for ground level ozone and fine particulate matter are included in this table.

In 1997, USEPA revised the NAAQS for ozone by setting a new 8-hour 0.08 ppm standard. Legal challenges held up implementation of the new standard until the U.S. Supreme Court affirmed USEPA on Feb. 27, 2001. USEPA reviewed the results of the litigation and conferred with states and other interested parties to determine the approach and schedule for implementing the ozone standard. The new standard, including the identification of areas designated "attainment" or "nonattainment," was formally implemented in April, 2004.

In 1997, USEPA added new $PM_{2.5}$ standards to the existing particulate standards. These new standards were upheld in the Feb. 27, 2001 Supreme Court ruling. USEPA cannot start implementing the 1997 fine particle standards until three years of data have been collected to determine which areas are not attaining the standards. The fine particle monitoring network was completed in 2000. Designations of attainment and nonattainment areas under this new standard went into effect on April 5, 2005. An ambient monitoring and analysis program for $PM_{2.5}$ that was conducted from 1987 through 2001 found the highest concentrations of $PM_{2.5}$ to be occurring in the east. The primary source of these particles was sulfates from utility and industrial boilers throughout the region. Some of the highest concentrations were measured in KY, TN, WV, and VA.

Air quality is monitored primarily by the states, but with substantial assistance of larger monitoring networks supported by USEPA and others. States are additionally responsible for establishing and maintaining emission inventories that quantify the location, concentration, and net emissions from major, minor, and mobile sources statewide. The combination of monitoring and inventory management is the primary basis for tracking air quality trends and the progress of emission control efforts.

Areas failing to meet one or more NAAQS are identified as nonattainment. Nonattainment areas may be individual communities or multi-county regions, depending on the type and extent of the pollution problem. Nonattainment areas typically cross state lines wherever population centers are located near such borders.

TABLE 7-1
National Ambient Air Quality Standards

Pollutant	Primary Standards.	Averaging Times	Secondary Standards.
Carbon Monoxide	9 ppm (10 mg/m^3)	8-hour[1]	None
	35 ppm (40 mg/m^3)	1-hour[1]	None
Lead	1.5 µg/m^3	Quarterly Average	Same as Primary
Nitrogen Dioxide	0.053 ppm (100 µg/m^3)	Annual (Arithmetic Mean)	Same as Primary
Particulate Matter (PM_{10})	50 µg/m^3	Annual[2] (Arith. Mean)	Same as Primary
	150 ug/m^3	24-hour[1]	
Particulate Matter ($PM_{2.5}$)	15 µg/m^3	Annual[3] (Arith. Mean)	Same as Primary
	65 ug/m^3	24-hour[4]	
Ozone	0.08 ppm	8-hour[5]	Same as Primary
	0.12 ppm	1-hour[6]	Same as Primary
Sulfur Oxides	0.03 ppm	Annual (Arith. Mean)	-------
	0.14 ppm	24-hour[1]	-------
	-------	3-hour[1]	0.5 ppm (1300 ug/m^3)

[1] Not to be exceeded more than once per year.

[2] To attain this standard, the expected annual arithmetic mean PM10 concentration at each monitor within an area must not exceed 50 ug/m^3.

[3] To attain this standard, the 3-year average of the annual arithmetic mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed 15 ug/m^3.

[4] To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 65 ug/m^3.

[5] To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm.

[6] (a) The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is <= 1, as determined by appendix H. (b) The 1-hour standard is applicable to all areas notwithstanding the promulgation of 8-hour ozone standards under Sec. 50.10. On June 2, 2003, (68 FR 32802) EPA proposed several options for when the 1-hour standard would no longer apply to an area.

Source: U. S. Environmental Protection Agency, June, 2004, http://www.epa.gov/air/criteria.html

States have primary responsibility for establishing management goals and implementing programs to achieve the standards. States manage nonattainment programs in their portion of multi-state areas. State programs are formally documented as State Implementation Plans (SIPs) which are subsequently approved by USEPA. Additionally, air quality programs in some areas have been delegated by the states to local authorities. In the Ohio River Valley ORV these include the Department of Environmental Services in Cincinnati, OH; the Allegheny County Health Department in Pittsburgh, PA; and the Louisville Metro Air Pollution Control District.

In actual practice, programs to reduce air pollution include a complex mixture of national, state, local, and multi-jurisdictional initiatives. Basic emission standards for automobiles and gasoline are national programs as are forthcoming regulations addressing diesel engines and fuels. Inspection programs to insure vehicles are properly maintained to minimize emissions are administered by the states and implemented at the local level. More recently, a variety of market oriented initiatives such as emission caps for a specific group of sources and trading of emission allotments have been implemented. These are intended to allow the group of sources to utilize more cost-effective strategies to reduce net emissions from the group. The acid rain program addresses SO_2 and NOx emissions from coal-fired electric utilities nationwide. Three additional programs address NOx from utilities and other industrial sources throughout the midwest and northeast.

7.7 PAST TO CURRENT BASELINE CONDITIONS

7.7.1 Historic Air Quality Conditions

Information about air quality impacts during the earlier decades of the study period is primarily anecdotal. Comprehensive monitoring of emissions and research addressing the relationships between human health and air pollution dates from the early 1970's, corresponding to the first generation of national air quality laws and regulations (e.g., CAA of 1970) and establishment of USEPA and state level air agencies. The year 1980 serves as a convenient benchmark of the point at which many regulations began to take effect and air emission quantities began to level off or decline. It is frequently the earliest date from which reliable trend data is reported by USEPA.

The extensive and diverse industrial development in the Ohio River Valley (ORV) continued up to about 1970 without regulation of air emissions. Extensive highway development from 1945 through 1970 contributed to the growing popularity of the automobile for personal transportation as well as development of an extensive commercial trucking industry. Leaded gasoline and diesel fuel from these mobile sources added concentrations of lead, VOC, CO, NOx, PM and other pollutants to the air. While detailed local or regional estimates are difficult to establish, USEPA estimates that national emissions of NOx increased 690% between 1900 and 1970. During the same period, VOC emissions increased 260% and SO_2 increased by 210% (USEPA, Aug. 2000). Air quality trends in the ORV probably approximate these national trends with the exception of SO_2, which was very heavily concentrated in the ORV. Localized impacts of smog, PM, and lead attracted the most attention during the two decades of debate that preceded finalization of national air quality regulation in the early 1970's. Long-range transport and atmospheric chemical interactions that contributed to acid rain, O_3, and other impacts were less obvious, but the earliest legislation established the monitoring and research programs that led to better understanding of these processes.

One of the earliest programs to improve air quality focused on the automobile. Beginning in the mid-70's, all new vehicles sold in the U.S. were required to have catalytic converters, which reduced emissions and required the vehicles to operate on unleaded gasoline. Additional engine design and performance standards also contributed to reduced emissions of VOC and CO. Subsequent fuel efficiency standards reduced emissions by increasing the number of miles traveled per gallon of fuel consumed. Significant progress

towards improved air quality was gradually achieved over about 15 years as the previous generation of leaded vehicles was gradually retired.

Many local air pollution problems are the result of concentrated populations and local weather patterns that concentrate pollutants over a period of several days. This is especially true of O_3 nonattainment areas in the ORV. Transportation management is one of the primary strategies at the local level for nonattainment communities, as well as for communities trying to maintain their attainment status. Vehicle inspection programs are a fundamental means of assuring that owners perform routine maintenance to keep their vehicle emissions in compliance. Communities can also require the use of reformulated fuels that burn more efficiently and emit fewer pollutants. Support of mass transit programs is motivated, in part, to reduce vehicle emissions.

Local program efforts are supplanted with emergency procedure approaches when local air quality threatens to exceed compliance thresholds. Local authorities may encourage or require reduced activities by public agencies, local industries, area sources, and individuals until air quality improves.

In general, regional conditions in the ORV reflect the national pattern for overall improvement in air quality. **Table 7-2** illustrates the progress of 42 areas in the ORV designated nonattainment since 1992. A total of 31 out of the 42 areas have achieved attainment redesignation. Between 1970 and 1999, emissions of the six NAAQS pollutants had decreased by 31 percent nationwide. These advances were achieved in concert with significant economic and population growth. During the same time period, U.S. Gross Domestic Product increased 147%, vehicle miles traveled increased 140%, and the U.S. population increased by 33%. Since 1970, national emissions from all of the NAAQS pollutants have decreased, with the exception of NOx. Between 1970 and 1999, emissions of NOx increased 17%. The majority of this increase can be attributed to heavy-duty diesel vehicles and coal-fired power plants (USEPA, Aug. 2000).

TABLE 7-2
Attainment History in the Ohio River Valley

State County	Pollutant	Area Name	Nonattainment in Year	Redesignation to Attainment
Indiana Floyd Co	1-Hr Ozone	Louisville, KY-IN	92 93 94 95 96 97 98 99 00 01	11/23/2001
Vanderburgh Co	1-Hr Ozone	Evansville, IN	92 93 94 95 96 97	12/9/1997
Kentucky Boone Co	1-Hr Ozone	Cincinnati-Hamilton, OH-KY (KY Portion)	92 93 94 95 96 97 98 99 00 01 02	8/30/2002
Boyd Co	1-Hr Ozone	Huntington-Ashland, WV-KY	92 93 94	6/29/1995
Boyd Co	SO2	Boyd County (part), KY	92 93 94 95 96 97 98 99 00 01 02 03	/ /
Bullitt Co	1-Hr Ozone	Louisville, KY-IN	92 93 94 95 96 97 98 99 00 01	11/23/2001
Campbell Co	1-Hr Ozone	Cincinnati-Hamilton, OH-KY (KY Portion)	92 93 94 95 96 97 98 99 00 01 02	8/30/2002
Daviess Co	1-Hr Ozone	Owensboro, KY	92 93 94	1/3/1995

State County	Pollutant	Area Name	Nonattainment in Year	Redesignation to Attainment
Greenup Co	1-Hr Ozone	Huntington-Ashland, WV-KY	92 93 94	6/29/1995
Hancock Co	1-Hr Ozone	Owensboro, KY	92 93 94	1/3/1995
Jefferson Co	1-Hr Ozone	Louisville, KY-IN	92 93 94 95 96 97 98 99 00 01	11/23/2001
Kenton Co	1-Hr Ozone	Cincinnati-Hamilton, OH-KY (KY Portion)	92 93 94 95 96 97 98 99 00 01 02	8/30/2002
Livingston Co	1-Hr Ozone	Paducah, KY	92 93 94	4/10/1995
Oldham Co	1-Hr Ozone	Louisville, KY-IN	92 93 94 95 96 97 98 99 00 01	11/23/2001
Ohio				
Butler Co	1-Hr Ozone	Cincinnati-Hamilton, OH-KY (OH Portion)	92 93 94 95 96 97 98 99 00 01 02 03	/ /
Clermont Co	1-Hr Ozone	Cincinnati-Hamilton, OH-KY (OH Portion)	92 93 94 95 96 97 98 99 00 01 02 03	/ /
Columbiana Co	1-Hr Ozone	Columbiana Co, OH	92 93 94	3/10/1995
Gallia Co	SO2	Addison Township (Gallia County), OH	92 93 94 95 96 97 98 99 00	7/5/2000
Hamilton Co	1-Hr Ozone	Cincinnati-Hamilton, OH-KY (OH Portion)	92 93 94 95 96 97 98 99 00 01 02 03	/ /
Jefferson Co	1-Hr Ozone	Steubenville, OH	92 93 94	3/10/1995
Jefferson Co	PM-10	Jefferson Co, OH	92 93 94 95 96 97 98 99 00	1/10/2001
Jefferson Co	SO2	Steubenville & Mingo Junction, OH	92 93 94 95 96 97 98 99	9/29/1999
Warren Co	1-Hr Ozone	Cincinnati-Hamilton, OH-KY (OH Portion)	92 93 94 95 96 97 98 99 00 01 02 03	/ /
Washington Co	SO2	Waterford Township, OH	92 93 94	10/21/1994
Pennsylvania	CO	Pittsburgh, PA	92 93 94 95 96 97 98 99 00 01 02	1/13/2003
Allegheny Co				
Allegheny Co	1-Hr Ozone	Pittsburgh-Beaver Valley, PA	92 93 94 95 96 97 98 99 00 01	11/19/2001
Allegheny Co	PM-10	Clairton & 4 Boroughs, PA	92 93 94 95 96 97 98 99 00 01 02 03	10/14/2003
Allegheny Co	SO2	Hazelwood, PA	92 93 94 95 96 97 98 99 00 01 02 03	/ /
Beaver Co	1-Hr Ozone	Pittsburgh-Beaver Valley, PA	92 93 94 95 96 97 98 99 00 01	11/19/2001
Butler Co	1-Hr Ozone	Pittsburgh-Beaver Valley, PA	92 93 94 95 96 97 98 99 00 01	11/19/2001
Fayette Co	1-Hr Ozone	Pittsburgh-Beaver Valley, PA	92 93 94 95 96 97 98 99 00 01	11/19/2001
Washington Co	1-Hr Ozone	Pittsburgh-Beaver Valley, PA	92 93 94 95 96 97 98 99 00 01	11/19/2001
Westmoreland Co	1-Hr Ozone	Pittsburgh-Beaver Valley, PA	92 93 94 95 96 97 98 99 00 01	11/19/2001

State County	Pollutant	Area Name	Nonattainment in Year	Redesignation to Attainment
West Virginia	PM-10	Follansbee, WV	92 93 94 95 96 97 98 99 00 01 02 03	10/27/2003
Brooke Co				
Brooke Co	PM-10	Weirton, WV	92 93 94 95 96 97 98 99 00 01 02 03	/ /
Cabell Co	1-Hr Ozone	Huntington-Ashland, WV-KY	92 93 94	12/21/1994
Hancock Co	PM-10	Weirton, WV	92 93 94 95 96 97 98 99 00 01 02 03	/ /
Hancock Co	SO2	New Manchester-Grant Mag. Dis (Hancock), WV	92 93 94 95 96 97 98 99 00 01 02 03	/ /
Hancock Co	SO2	Weirton, WV	92 93 94 95 96 97 98 99 00 01 02 03	/ /
Wayne Co	1-Hr Ozone	Huntington-Ashland, WV-KY	92 93 94	12/21/1994
Wood Co	1-Hr Ozone	Parkersburg, WV	92 93 94	9/6/1994

Source: U. S. Environmental Protection Agency, June, 2004

7.7.2 Current Air Quality in the ORV

The current status of air quality in the ORV as of June, 2004 is summarized in **Table 7-3** and **Figures 7-1 and 7-2**. As indicated in **Table 7-3**, 10 counties or subareas in 4 states continue to be designated as non-attainment for ozone (based on the 1-hour standard), PM_{10}, or SO_2. The new 8-hour standard for ozone has resulted in designation of 37 counties in 5 states. All of the nonattainment counties are within or adjacent to standard metropolitan statistical areas for major cities within the Ohio River corridor.

In addition to the 8-hour ozone standard, the new standard for $PM_{2.5}$ placed several localities in the ORV into nonattainment status. Formal designation of nonattainment counties for $PM_{2.5}$ occurred in April, 2005, however some of these will be eligible for delisting after submittal and USEPA review of 2002-2004 monitoring data.

These new standards will require some localities to continue or reinstate air quality regulatory programs from earlier periods when they were in noncompliance status (e.g., Pittsburgh and Northern Kentucky) while others will be required to implement regulatory programs for the first time. As summarized above, programs for 8-hour O_3 and $PM_{2.5}$ would primarily focus on transportation management, vehicle inspections, public education, and emergency procedures. In some cases, nonattainment localities may acquire the authority to impose stricter emission limits for NOx, SO_2, VOC, and $PM_{2.5}$ from stationary sources such as printers, distilleries, dry cleaners, industrial boilers, and related sources.

Emission standards or emission reduction programs at the national or multi-state regional level will play a critical role in helping all local programs achieve their air quality objectives. While most of these programs are currently in some stage of implementation, other program elements and impacts will be realized in the near to long-term future. These initiatives are discussed below in the Future Air Quality Section.

FIGURE 7-1
Ohio River Counties Designated Nonattainment for 8-Hour Ozone Standard

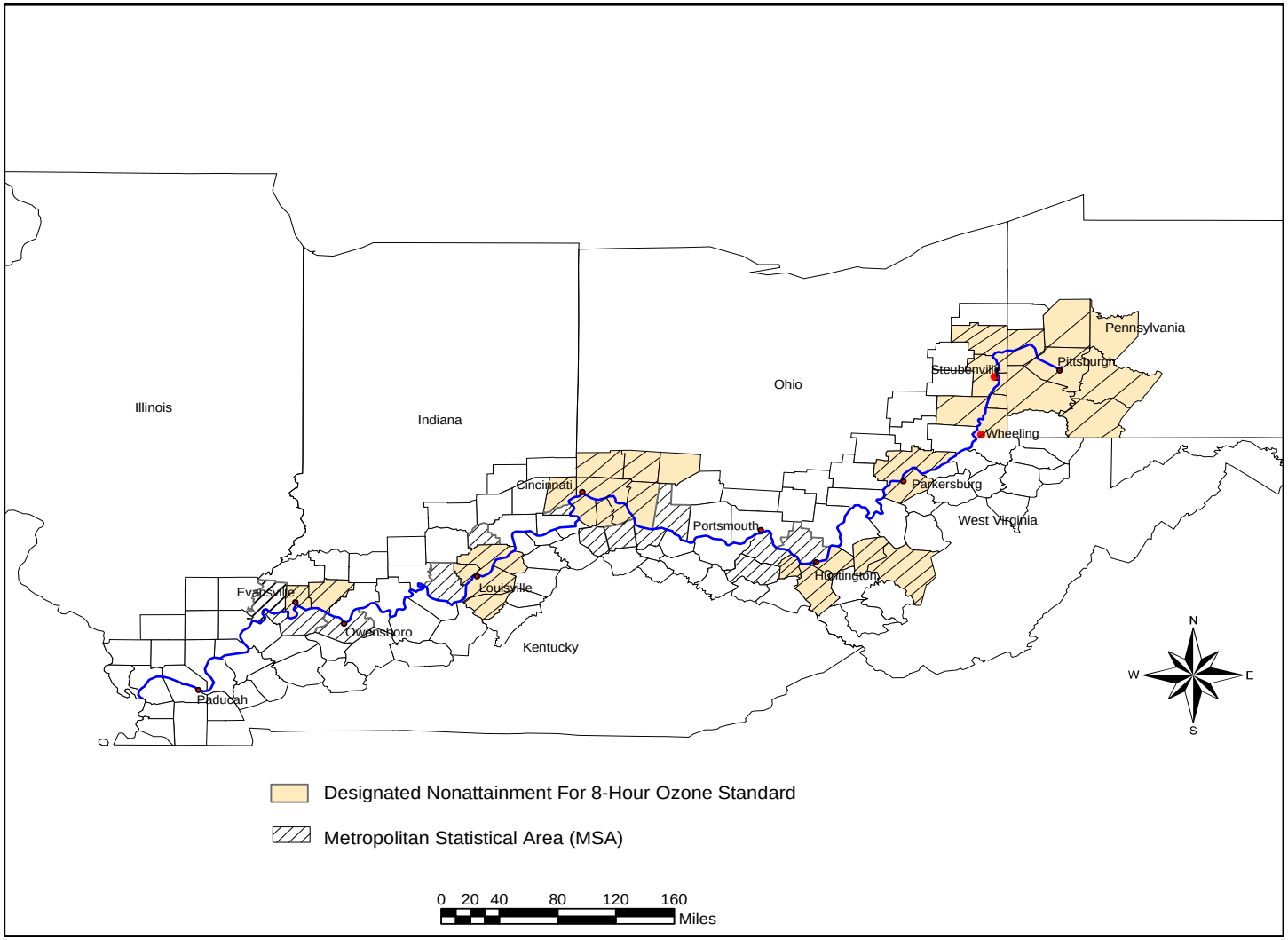


FIGURE 7-2
Ohio River Counties Designated for Other Nonattainment Criteria

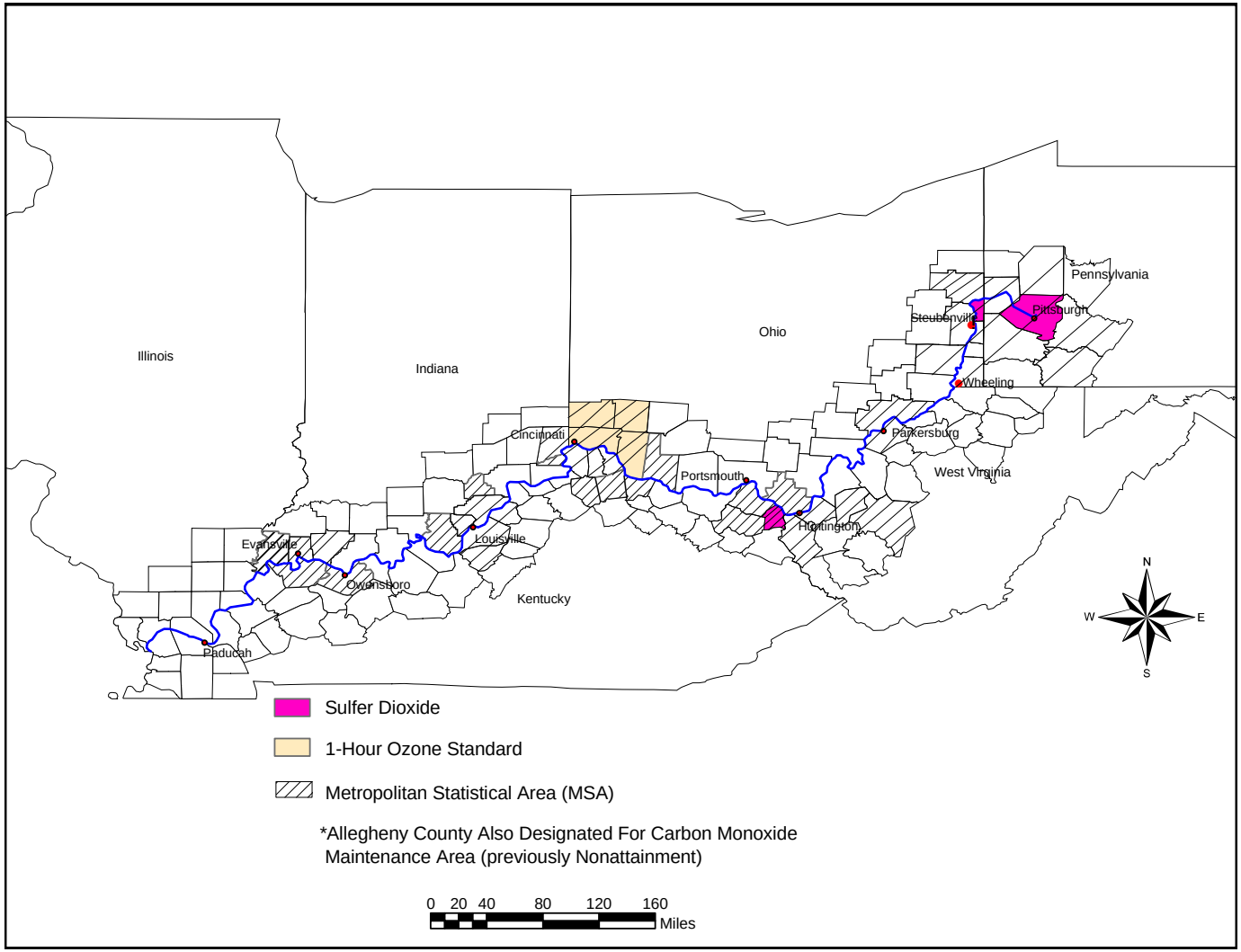


TABLE 7-3
Summary of ORV Nonattainment Counties

State	Nonattainment Area Name	Counties	Classification	Maximum Attainment Date (8-hour Ozone, from June 15, 2004)
Boundary Designations for 8-hour Ozone Standard				
Pennsylvania	Pittsburgh-Beaver Valley, PA	Allegheny Armstrong Beaver Butler Fayette Washington Westmoreland	Basic	June 2009
West Virginia	Charleston, WV	Kanawha Putnam	Basic	June 2009
	Huntington-Ashland- KY-WV	Cabell Wayne	Basic	June 2009
	Parkersburg-Marietta, OH-WV	Wood	Basic	June 2009
	Steubenville-Weirton, OH-WV	Brooke Hancock	Basic	June 2009
	Wheeling, OH-WV	Marshall Ohio	Basic	June 2009
Kentucky	Cincinnati-Hamilton, OH-KY-IN	Boone Campbell Kenton	Basic	June 2009
	Huntington-Ashland, KY-WV	Boyd	Basic	June 2009
	Louisville, KY-IN	Bullitt Jefferson Oldham	Basic	June 2009
Ohio	Cincinnati-Hamilton, OH-KY-IN	Butler Clermont Hamilton Warren Clinton	Basic	June 2009
	Steubenville-Weirton, OH-WV	Jefferson	Basic	June 2009
	Youngstown-Warren-Sharon, PA-OH	Columbiana	Basic	June 2009
	Wheeling, WV-OH	Belmont	Basic	June 2009
	Parkersburg-Marietta, WV-OH	Washington	Basic	June 2009
Indiana	Louisville, KY-IN	Clark Floyd	Basic	June 2009
	Evansville IN-KY	Vanderburgh Warrick	Basic	June 2009
	Cincinnati-Hamilton OH-KY-IN	Dearborn (P)	Basic	June 2009
Boundary Designations for 1-hour Ozone Standard				
Ohio	Cincinnati-Hamilton OH-KY-IN	Butler Clermont Hamilton Warren	Moderate	

State	Nonattainment Area Name	Counties	Classification	Maximum Attainment Date (8-hour Ozone, from June 15, 2004)
Boundary Designations for Carbon Monoxide Maintenance Areas (Previously Nonattainment)[1]				
Pennsylvania	Pittsburgh, PA	Allegheny		
Boundary Designations for Sulfur Dioxide				
Pennsylvania	Hazelwood, PA	Allegheny	Primary	
West Virginia	Weirton, WV	Hancock	Primary, Secondary	
	New Manchester-Grant Mag. Dis	Hancock	Primary	
Kentucky	Boyd County (Part), KY	Boyd	Primary	
Boundary Designations for PM_{10}				
West Virginia	Weirton, WV	Brooke Hancock	Moderate	
[1]No ORV counties or sub areas are designated nonattainment for CO, NO_2, or Lead.				
Source: U. S. Environmental Protection Agency, June, 2004				

7.7.3 Current Air Emissions in the ORV

Recent emission inventories (USEPA, 1999) for every county adjacent to the Ohio River were aggregated to produce an emission inventory for the ORV (**Table 7-4)**. The category 'marine vessels' includes all watercraft activities on the Ohio River and tributaries within the adjacent counties. In addition to all aspects of barge traffic (tows underway, port, and fleeting operations), this category includes dredging operations, recreational boating activity, and commercial excursion boating.

TABLE 7-4
Emission Inventory for Ohio River Corridor (1999)

EMISSIONS	CO	NO_X	SO_2	PM_{10}
Marine vessel emissions (tons) from counties adjacent to the Ohio River	6,246	59,430	25,081	3,216
Total emissions (tons) from counties adjacent to the Ohio River	2,557,184	1,253,044	2,182,054	336,708
% Of emissions originating from marine vessels in counties adjacent to the Ohio River	0.24	4.74	1.15	0.96

Source: U. S. Environmental Protection Agency, 1999

The most significant emissions associated with marine vessels are NOx, as would be expected from a source group dominated by diesel engines. The emission rates reported here for the ORV are consistent with other estimations of marine diesel contributions to emission inventories in port and waterway areas (USEPA, 1999a, b). For the ORV inventories of total emissions, the most significant contributions of NOx come from coal-fired utilities and highway transportation.

A study published by USEPA (Sept. 1999b) calculated emission factors from diesel engines for commercial marine emissions on inland waterways. The emission factors are expressed as emissions per ton-mile of barge freight and incorporate an adjustment for the percentage of barges returning empty. This makes it possible to calculate emissions for tows underway on any reach of the Ohio River where the total tonnage of barge freight has been recorded. Emissions from tows underway were calculated for each L&D on the Ohio River and are presented in **Table 7-5**.

The emission totals from **Table 7-4** for NOx, PM, and CO can be compared to the marine vessel emission totals from **Table 7-5**. For NOx, the 'tons underway' calculation represents 45 per cent of total emissions from marine vessels. The remaining 55 per cent includes tug emissions from fleeting operations and port activities, dredging, recreational boating activity, and commercial excursion boating. Regarding the percent of the total emissions shown in Table 6, NO_x from "tows underway" comprise 2.1% of the annual NO_x inventory, while PM is 0.38% and CO is 0.12% of their respective inventories.

TABLE 7-5
Emission Inventory for Tows Underway

L&D Project	Length (miles)	1998 tonnage (000's)	NOx E/yr (tons)	PM E/yr (tons)	CO E/yr (tons)	VOC E/yr (tons)
L&D 53	23.7	97,695	1388	66	165	33
L&D 52	20.4	97,695	995	47	118	24
Smithland	72.5	84,606	1823	87	217	43
Myers	69.9	74,151	2439	116	290	58
Newburgh	55.4	64,131	1856	88	221	44
Cannelton	113.9	54,386	2127	101	253	51
McAlpine	75.3	52,867	2311	110	275	55
Markland	95.3	56,119	2212	105	263	53
Meldahl	95.2	63,739	2805	134	334	67
Greenup	61.8	70,636	2562	122	305	61
Byrd	41.7	57,855	1383	66	165	33
Racine	33.6	40,517	705	34	84	17
Bellville	42.2	48,688	853	41	101	20
Willow Is.	35.3	44,766	801	38	95	19
Hannibal	42.2	47,627	853	41	102	20
Pike Is.	29.8	43,027	716	34	85	17
New Cumberland	22.7	35,425	430	20	51	10
Montgomery	18.4	26,866	255	12	30	6
Dashields	7.1	24,563	122	6	15	3
Emsworth	6.2	23,153	104	5	12	2
Ohio River Total	962.6		26,739	1,273	3183	637
% of Total Emissions Shown in Table 7-4			2.1	0.38	0.12	

Notes
Emission factors: NOx = 0.00042 kg/ton-mile; PM = 0.00002 kg/ton-mile; CO = 0.00005 kg/ton-mile; HC = 0.00001 kg/ton-mile
Source: U. S. Army Corps of Engineers (3), April 2000 and U. S. Environmental Protection Agency, Sept. 1999b.

7.8 INTERACTIONS WITH OTHER VALUED ENVIRONMENTAL COMPONENTS

The public health impacts of degraded air quality constitute the most significant interaction of air quality with other VECs. The importance of this interaction is reflected in the extent to which air quality regulations focus on improved health standards.

Air quality also interacts significantly with recreational and cultural resource values. Visibility impairment can detract from the enjoyment of urban or rural parks, river viewscapes, and cultural features. Corrosion from acid rain results in permanent damage to cultural features and reduces the quality of recreational experiences associated with impacted cultural features.

Corrosion from acid rain also impacts transportation structures such as bridges and overpasses and generally affects broader socioeconomic values through impacts to building facades, agriculture, forest, and aquatic resources. Air pollution impacts to natural systems within the ORV are generally attenuated by the buffering capacity of the region's deep soils and forest cover. Downwind areas such as the Adirondack Mountains Region of New York have less buffering capacity and are more susceptible to forest and aquatic resource impacts. Interactions between air quality and other VECs are summarized in **Table 7-6**.

TABLE 7-6
Interactions of Air Quality Factors with Other VECs

VEC	Factors & Impacts	Past/Present Trends	Future Trends	Comments
Recreation	Particulate emissions and ozone formation can impair visibility.	Viewscapes, recreational quality have benefited from improved air quality.	Appears likely present air quality will be maintained or improved.	Haze from coal burning, other sources persists throughout Ohio River corridor.
Cultural Resources	Corrosive impacts of acid rain.	Loss or degradation of grave markers, building facades, historic artifacts.	Improved air quality should reduce rate of degradation.	Continuing impact of damaged resources (no recovery).
Health & Safety	Respiratory infections, lung inflammation, decreased lung function, asthma	Improved air quality contributes to improved public health	Shift of focus to air quality in buildings (mold, air conditioning impacts).	Ozone monitoring and alerts to minimize health impacts of short term air quality degradation episodes.
Transport-ation	Role of transportation as major source. Corrosive impacts of acid rain.	Modification of cars, trucks, and vehicle fuels (gasoline).	Modification of diesel fuels, vehicles and equipment.	Minimal application to date of travel restrictions, regulation of transportation infrastructure.
Aquatic and Riparian Resources	Degradation impacts of acid rain.	Loss of fisheries, forest diversity, soil productivity.	Resource recovery in response to reduced deposition rates.	Impacts most prominent to downwind resources (PA, NY, New England).

VEC	Factors & Impacts	Past/Present Trends	Future Trends	Comments
Socio-economic Resources	Development restrictions in non-attainment areas, regional health care costs.	Emission controls, industrial process modifications, new source performance standards.	Impacts, restrictions minimized in response to improved air quality.	Air quality regulations can also spur improved production efficiencies, modernization of equipment.

7.9 RELEVANT ACTIONS AFFECTING AIR QUALITY

RFFAs were evaluated for air quality issues utilizing the RFFA Matrix (see Exhibit B, Procedure and Methods, for discussion of RFFA matrix). The matrix evaluation process resulted in identification of five RFFAs with high importance for air quality issues and an additional 15 that were rated as having medium importance. Results of the RFFA evaluation are summarized in **Table 7-7** and discussed in further detail in text following the table.

TABLE 7-7
RFFA Cumulative Effects Matrix for Air Quality VEC

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Impact	Impor-tance[5]
Navigation Investment Actions					
Lock Extensions/New Locks/Replacement or Rehabilitation	A	H	SL	-	M
L&D operation and maintenance	A	H	SL	-	L
Non-structural navigation improvements	A	H	SL	+	M
Dam replacement and rehabilitation	A	H	SL	-	L
Other Corps Actions					
Port development (Sec. 107) and maintenance dredging	A	H	SL	-	M
"But for" Actions					
Commercial Navigation					
barge queuing	A	H	SL	-	H
fleeting areas/barge storage	A	H	SL	-	M
terminals	A	H	SL	-	M
multi-modal sites	A	H	SL	-	M
increased traffic	A	H	E	-	M
Instream sand and gravel mining	A	H	SL	-	M
Floodplain sand and gravel mining	A	H	SL	-	M
Limestone aggregates mining	A	H	SL	-	M
Coal utilities	A	H	SL	-	H
Other coal industries	A	M/L	SL	-	M
Industrial users, excluding coal-related	A	H	SL	-	H
Actions by Others					
Floodplain development					
Residential	A	H	SL	-	M
Commercial	A	H	SL	-	M
Industrial	A	H	SL	-	M

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Impact	Impor-tance[5]
Regulatory Environment					
More stringent quality standards for environmental media	A	H	E	+	H
Pollutant source control	A	H	E	+	H
Emissions trading	A	H	SL	+	M
[1] Reasonably Foreseeable Future Actions					
[2] Time period in which the RFFA may occur: 1 = within 10 years, 2 = in 10 - 25 years, 3 = in 25 - 60 years, A = applicable for all time periods					
[3] Occurrence probability or likelihood RFFA will happen: H = high, M = medium, L = low					
[4]Location or setting on river where RFFA is expected to occur: E = along entire length of river, SL = specific location, e.g., locks and dams					

7.9.1 Direct Action Sources of Air Pollution

This section discusses air emissions that may occur as a direct result of project actions. These direct actions include lock construction and maintenance, navigation system operation and maintenance, other direct actions by the Corps, and direct actions by others. Potential emissions from each class of activities are summarized. In addition, the potential relationship between direct emissions and the With Project or Without Project alternative is assessed.

7.9.1.1 Construction of Lock Chamber Extensions.

Two primary classes of air emissions may be expected to occur as a result of the lock chamber projects described in **Table 7-7**. Particulate (PM) and combustion emissions from the construction site are discussed here. Emissions from commercial tow traffic delayed by site construction activities are discussed in the "Direct Action by Others" section.

Construction of the lock chambers requires establishment of parking and maintenance areas for equipment, burning of cleared vegetation, a lay-down yard for materials, disposal areas for excess soil and rock, and some earthwork where portions of the new lock chamber connect with the riverbank. Potential dust problems are controlled through a variety of standardized Best Management Practices (BMPs) such as seeding, periodic wetting of bare surfaces, or wind screens. These practices are routinely employed as needed to minimize nuisance dusts and PM emissions at Corps construction sites. Other potential sources of air pollution from construction include dust from concrete removal (sawing or blasting) and from concrete batch plants (if needed onsite). Concrete batch plants normally require a state air emissions permit.

The diesel engines that power bulldozers, crawler tractors, cranes, generators, and other equipment are the primary source of combustion air emissions at most construction sites, while gasoline powered equipment accounts for the remainder. Emissions from these sources include NOx, VOC, CO, sulfur oxides (SOx), and PM. This has traditionally been an unregulated class of combustion equipment, and large projects that require substantial equipment operations can produce locally significant quantities of air pollutants.

Air emissions from a construction site are subject to state and local air quality regulations (including rights of inspection and enforcement), and contractors may be

required to obtain an air emissions permit in some cases. Except for unusual cases, such permit conditions are fairly straightforward, requiring use of BMPs appropriate to the scale of operations, maintenance of equipment in good working order to minimize unnecessary emissions, and prohibition of open burning of construction wastes. In certain situations (e.g., a large project in a heavily populated area) there may be provisions for additional control or restriction of construction activities during ozone seasons when pollution is a problem or during ozone alert conditions.

7.9.1.2 Lock Maintenance, Repair, and Rehabilitation

The ongoing commercial use of the lock and dam facilities will require periodic upkeep and maintenance. This will include major and minor repairs of both primary locks and auxiliary locks. As existing locks age, the need for such repairs becomes more frequent. The frequency of repairs also increases in proportion to ongoing increases in the amount of commercial traffic (and resultant use of the lock chambers) on the Ohio River.

Each lock repair event will produce the same types of air quality impacts as was described above for lock construction projects. Construction site and equipment emissions will be smaller, in proportion to the reduced scale of the repair activity. If the repairs require lock closures, emissions attributable to delayed barge traffic will be proportional to the period of time that the locks are closed.

Maintenance and repair events would also continue to be required following completion of lock extension projects. However, completion of lock extensions can reduce repair activities and associated air quality impacts in several ways. First, it may be feasible to schedule some lock extensions so as to eliminate an auxiliary chamber repair event. Second, each extension creates a lock in new condition, allowing for a longer time interval between the auxiliary chamber repair events. The original full-sized lock will be required to do less work, since the total number of cycles can now be shared equally between the two full sized locks, allowing for a longer time between the main chamber repair events (U. S. Army Corps of Engineers (1), April, 2000). Finally, increased capacity would allow improved lockage efficiency during future repairs, thus minimizing barge queuing impacts associated with such repairs.

7.9.1.3 Operations

Locks and dams (L&D) on the Ohio River are operated by electrical power and produce no direct air emissions. Lights, loudspeakers, and instrumentation are also generally operated by electric power and also produce no direct air emissions. L&D facilities may have back up power facilities such as diesel powered generators on site. This type of equipment may require a state-issued basic or “source registration” permit which allows for periodic testing, emergency operation, and listing in local emission inventories. Additional air emissions result from L&D employees driving their vehicles to the site and maintenance operations such as lawn mowing. This amount of air emissions attributable to operations is constant for all levels of lock activity.

Dredging to maintain the nine-foot navigation channel in the Ohio River is a significant component of L&D operations. Diesel emissions from dredging operations emit the same types of pollutants (NOx, VOC, and PM) as do engines on linehaul and

harbor towboats. However, these emissions account for only a small proportion of total towboat emissions. Additionally, navigation channel dredging occurs at locations remote from L&Ds and would not be expected to change with lock improvements.

7.9.1.4 Other Direct Actions by U.S. Army Corps of Engineers

The Corps conducts other actions with potential air quality impacts. These include the full spectrum of maintenance and repair of all components of the navigation system infrastructure other than the locks. These ongoing activities (and their attendant air quality impacts) will occur independently of the lock maintenance or extension activities addressed by this study and are not expected to cause significant delays of towboat traffic.

The largest of these activities involves major rehabilitation of the dams (as opposed to rehabilitation of lock chambers). While the timing of rehabilitation projects is subject to numerous variables, this activity primarily corresponds to the useful life cycle of the dam. Of the 20 dams currently on the river, 6 have been rehabilitated in the past two decades, at an average age of 60 years following their initial construction. With a life cycle of 60 years, all of the dams currently on the Ohio River may require major rehabilitation during the 60-year cycle of the study period.

Air emissions from dam rehabilitation projects will be similar to construction site and construction equipment emissions described previously for lock extension projects. The activities will be subject to the same state and local permit requirements. Air emission quantities from these projects would likely be comparable to rehabilitation or new construction of interstate interchanges, office buildings, or other major projects occurring over a several month period.

7.9.2 Direct Actions by Others

7.9.2.1 Commercial Navigation

Commercial towboats operating on the Ohio River can be classified into two general categories; large towboats that move the fleets of barges up and down the river (linehaul) and smaller harbor tows operating in the ports and major fleeting areas. Linehaul towboats are typically powered by marine diesel engines of 1,500 hp to 8,000 hp and maneuver tows of up to 15 barges up and down the river. Harbor towboats assemble and disassemble the barge tows within the fleeting areas, assembling individual tows according to their delivery destination. Some barge tows may be assembled and delivered to a single destination, but many contain a mix of commodities with various assembly and delivery points. The harbor towboats add or remove individual barges to these mixed tows while the linehaul towboats maintain control of the primary tow (USEPA, Sept. 1999a).

The marine diesel engines that power these towboats emit NOx, PM, SO_2 and VOC. This has until recently been an unregulated source, but regulations applicable to new and remanufactured engines took effect in 2004 (USEPA, Nov. 1999b). These emissions are treated in this study as a direct consequence of both the existing navigation system and proposed project actions because it is the existence and maintenance of the lock and dam system that makes commercial barge traffic possible on the Ohio River.

One of the reasons that emissions from marine diesel engines have not previously been regulated is that they were considered a relatively minor source when compared to other mobile source classifications. However, as progress has occurred in the control of emissions from other sources, the relative contribution from marine diesel engines has increased. While a very busy river port such as St Louis, Cincinnati, or Pittsburgh may exhibit the highest concentrations of river towboat activity, the linear nature of river transportation means that some degree of activity will be maintained throughout the river corridor area. Additional concentrations of river towboats occur when towboats are forced to queue up due to lock construction, repairs, or general traffic congestion. Finally, several smaller population centers including Evansville, IN and Parkersburg WV (see Table 3), are now classified as nonattainment areas under the revised ozone (O_3-8hr) standards (USEPA, June 2004). While barge tug emissions may be insignificant in a large population center such as St Louis, a similar level of emissions would have a relatively larger effect in the smaller population centers.

7.9.2.2 Towboat Traffic at Locks

Linehaul towboat emissions need to be examined in the context of general commercial traffic levels and in the specific instance of queuing delays associated with lock construction, repairs, and congestion. The relationship between queuing delays, current levels of commercial traffic on the Ohio River, and projected growth of commercial traffic are discussed in greater detail in Section 8 of the SIP Main Report and in the Economics Appendix to the SIP. These studies generally conclude that projections for long term growth of commercial towboat traffic will occur independently of lock and dam navigation improvements on the Ohio River: the existing transportation system has excess capacity, allowing traffic to grow in response to economic demand for barge deliverable commodities.

Queuing delays occur as a result of general traffic congestion and/or due to lock closures for repair or extension. Construction of lock extensions on the lower river dams will require long term closure of the 600’ auxiliary locks and periodic, shorter duration closures of the 1200’ primary locks. Replacement of the 360’ locks with larger locks at the three upper river sites would result in a similar degree of curtailment of lockage services. Since the existing 600’ main chamber is the landward lock at these upper river sites, they would remain in service during construction of new locks riverward of the auxiliary chambers. Linehaul towboats that are delayed by such closures will emit excess pollutants in proportion to the delay times. These excess emissions may be concentrated in specific locales due to queuing in close proximity to the closed locks.

For the Myers lock extension project, 3 separate closures of the 1200’ main chamber are predicted over the 30-month course of project construction. These closures total 11 days, or an annual average of 4.4 days, which is comparable to the average annual closure of 3.1 days/year over the 29 years that the Myers lock has been in operation (U. S. Army Corps of Engineers (1), April, 2000). The Greenup locks are much older and have a history of longer and more frequent closures of the 1200’ main chamber, resulting in an annual average of 23 days of closure. The main chamber of Greenup is projected to be closed 17 days in five different events over the 35 month projected construction period to extend the auxiliary chamber. In addition, the main chamber will close for 12 hours a day for an interval of 39 days.

Linehaul tows that are delayed by construction closures or by repair events emit excess pollutants in proportion to the delay times. Air quality impacts from diesel sources directly attributable to lock extension activities would increase in proportion to delay times created by the construction activity. Following completion of the lock extension, air quality impacts directly attributable to maintenance and repair activities would decrease in proportion to the expected reduction of repair activity. The relationship between these competing air quality impacts is addressed quantitatively in the "Cumulative Effects" section of this chapter. Queuing delays associated with traffic congestion also would significantly decrease following completion of lock extensions since the new chamber capacity would minimize the need for queuing.

7.9.2.3 Barge loading/unloading and other intermodal operations.

These activities include transfer of coal, limestone, sand & gravel, gypsum, grains and other bulk materials. PM emissions are the primary air pollutant from the bulk handling processes (conveyors, open stockpiles, gravel separation, and coal blending) associated with loading and unloading barges. Loading facilities are also typically a minor source of exhaust emissions because the equipment is powered by diesel engines.

Each individual barge loading/unloading facility normally operates under the requirements of a state or local air permit. Permit conditions typically include measures to minimize fugitive dust emissions; for example through the stipulation of equipment maintenance standards, and a variety of BMPs such as wetting stock piles and conveyance points to control dusts. New USEPA regulations address diesel fuel formulations and engine performance standards, and compliance with these regulations will reduce emissions from combustion sources (USEPA, August 1998 and Nov. 2000). Barge loading operations located in nonattainment areas may be subject to closer monitoring or somewhat more stringent standards than would occur at loading sites in attainment areas.

Continued expansion of existing facilities and the establishment of new facilities can be expected to occur in response to general economic/population expansion and subsequent growth in loads carried by barge transport. As mentioned previously, traffic projections indicate that barge traffic growth will occur independently of navigation improvements. Therefore, it can be expected that expansion or addition of barge loading facilities will occur independently of navigation improvements.

7.9.3 Indirect Action Sources of Air Pollution

Indirect actions include activities which derive some benefit from the existence of the improved navigation system. However, these activities would likely have developed in some related form without navigation system improvements and would be expected to persist with or without maintenance or additional improvements to the system.

7.9.3.1 Industrial Development

Many industries in the ORV are to some degree dependent on the existence of an efficient and reliable navigation system. This includes industries that may never have shipped via barge and have no plans for doing so. In fact, some of the most highly dependent industries on waterway transportation do not ship on the rivers, but depend on

the cost-savings that it provides to their suppliers, making them both more competitive. The waterway transportation system allows for lower transportation costs, and, therefore, lower delivered costs of basic raw materials; most importantly coal, stone, ores, and chemicals, to secondary producers of goods such as electricity, coke, specialty chemicals, and construction materials. In turn, these industries generally induce demand for tertiary producers of items like steel coils and slabs, aluminum, and paper products, which are then used in factories that produce final consumer goods such as automobiles, appliances, utensils, packaging, and food products (U. S. Army Corps of Engineers, April, 2000).

Steady growth of waterway traffic on the Ohio River System (ORS) over the past 60 years provides indisputable evidence of basin shipper's dependence on the system. With the exception of export demands for coal and grain, the preponderance of commodities shipped on the waterway are relatively unaffected by changes in waterway transportation costs. Both raw material production facilities and the downstream production facilities they supply represent major capital investments. More importantly for this study, these investments represent a long-term commitment to the waterway, a commitment that is likely not to waiver over 20-30 year time horizons. There are a number of reasons for this. Alternative development sites are extremely limited for quarries, power plants, steel mills, chemical plants, petroleum refineries, and paper mills. In many instances production is geographically limited, as is the case with stone, wood products, and coal.

Consuming plants may also require specifications unique to a particular ORV resource. This is particularly true with respect to the requirements of some utility plants for certain grades of coal for their boilers, chemical properties of limestone for their flue-gas desulfurization units, and adequate supplies of cooling water from the river. Finally, transportation options are often extremely limited. Large machines and fabrications, like electricity generators, often can move no other way than by water, and high volume bulk commodity shipments can be moved in a less disruptive fashion past most major urban concentrations than through them. Limited alternatives for locating new plants, substituting products from other areas, and arranging alternative transportation act to make long run demands for waterway service in the ORV relatively stable (U. S. Army Corps of Engineers (2), April, 2000).

The study area encompasses a broad spectrum of industrial activities. Brief profiles of industries most closely associated with direct utilization of river transportation are presented below.

7.9.3.1.1 Coal Utilities and Related Activities

Abundant coal reserves in states bordering the Ohio River are one of the primary cornerstones of past economic development in the ORV and provide the overwhelming majority of fuel for electric generating capacity in those states today. Coal provided 57% to 98% of total electric generating capacity in 1997 to the six states bordering the study area (U. S. Energy Information Administration, 2001). Development of affordable, reliable coal transport was one of the primary motivations for initial and subsequent development of Ohio River navigation improvements. Coal accounts for over 55% of all commodities shipped on the ORS, and this coal accounts for about 14% of consumption by the electric generating industry nationwide (U. S. Army Corps of Engineers (2), April, 2000).

The concentration of coal-fired power plants in conjunction with the high sulfur content of much of the region's coal results in the number one air pollution source in the region for SO_2, NOx, and PM. Indeed, the sheer quantity of these emissions tends to overshadow the impacts of other sources in the region. Since 1980, the six states bordering the Ohio River have ranked among the top seven or eight nationwide sources of SO_2 from coal-fired utilities. NOx emissions from these sources contribute to local concentrations of O_3; NOx and SO_2 are the key contributors to acid rain impacts throughout the midwest and northeast, and into southeastern Canada SO_2 is a primary contributor to regional haze/visibility and fine particulate impacts (U. S. Environmental Protection Agency, 2001a,b, Nov.,1999b).

7.9.3.1.2 Other Industries Dependent on River Navigation

Regional industries with strong ties to Ohio River navigation can be classified into two broad air quality groups. The first group includes primarily PM sources such as sand and gravel mining, quarrying, and gypsum processing. The second group includes industrial operations that emit a broader spectrum of air pollutants; refineries, chemical plants, steel mills, coke ovens, and related sources. All of these industrial sources are required to obtain air pollution permits and must meet specific emission standards as specified in those permits. Permit requirements are established on the basis of CAA regulations that establish industry standards, control technology feasibility, and the address the sensitivity of impacted areas. Industry standards help to establish regulation of equivalent industrial processes while the control capabilities of available technology help to define what is achievable. Industrial sources located in nonattainment areas, emitting significant quantities of a priority pollutant, or otherwise impacting a sensitive resource may be required to meet more stringent emission control standards. New source performance standards, applicable to new or extensively renovated facilities, require use of the most advanced available controls; helping to integrate reduced air emissions into the process of industrial modernization.

7.9.4 Reasonably Foreseeable Future Actions

7.9.4.1 Future Air Quality in the ORV

USEPA and the states are currently implementing major initiatives to reduce NOx emissions from heavy-duty diesel vehicles, coal-fired power plants, and other industrial sources. The vehicle initiatives will have nationwide impacts through reduction of emissions from highway trucks and buses, diesel locomotives, construction equipment, commercial marine engines, and other classifications of diesel combustion sources. In addition to the acid rain program, which establishes national NOx emission standards, three regional programs are in effect that will further reduce NOx emissions from power plants and other industrial sources in the midwest and northeast. In this region, NOx and VOC are the principal contributors for local ozone problems, NOx and SO_2 are principal contributors for acid rain, and NOx is an additional contributor to the formation of $PM_{2.5}$.

Regulation of utility emissions under national and regional cap and trade allowance programs is reducing present emissions and will impose a ceiling on any future increases. These programs are intended to establish a sustainable balance – enough emissions to allow sustained viability of the coal electric industry, trading of emission allowances to

promote cost effective control of emissions, and enough reductions to allow recovery of impacted populations and resources (USEPA, 2001a, b, and August, 2000).

While emissions from coal-fired utilities can be expected to decline and stabilize during the early years of the study period, the cap and trade regulations may contribute to a number of changes in the transport of coal. For the short term at least, net tonnage of coal transport on the ORS appears to have leveled off. Virtually all expansion of electric utility capacity since 1996 has come from natural gas and no plans for expansion of coal facilities during the next several years have been formally recorded. There is a general expectation that some expansion of coal capacity will eventually occur, however there may be a 10 or 15-year lag relative to coal transport projections previously prepared for ORMSS (U. S. Army Corps of Engineers (3), April, 2000). There is some expert agreement that expansion of coal capacity, when it eventually occurs, will be centered on existing coal-fired plants. These plants already occupy the best sites and would likely face less complicated permitting than would new sites.

Although coal shipments have largely leveled off, distribution patterns have changed and are likely to continue. There has been a significant increase in quantities of low sulfur western coal being shipped up the Ohio River and compensating decreases of higher sulfur coal from mines in the ORV. On a smaller scale, installation of SO_2 scrubber technology is contributing to shipments of limestone to the plants and gypsum (a marketable by-product of desulfurization) from the plants (U. S. Army Corps of Engineers (3), April, 2000). Finally, the long-term relationship between coal consumption and energy production could fluctuate up or down. Western coal tends to have lower energy content, requiring more coal per unit of electricity produced. On the other hand, advances in coal combustion technology could result in a decrease in use of western coal and an increase in use of coal from the ORV over the long term.

As previously noted, VOCs combine with NOx to form O_3. Substantial progress has already been made in the control of VOCs and future gains will be more difficult to achieve. However, new VOC standards are being implemented for recreational boats and other classifications of gasoline combustion engines.

For the Ohio River region, sulfates are the primary precursor to the formation of $PM_{2.5}$, accounting for over 50% of particulate composition at monitoring stations east of the Mississippi River. NOx is an important secondary precursor. The acid rain program, regional NOx programs, and NOx vehicle initiatives are the primary activities that will contribute to reduced $PM_{2.5}$ emissions in the ORV.

National initiatives to control emissions of NOx, VOC, $PM_{2.5}$, and sulfates from SO_2 will reinforce the local and regional programs of the nonattainment areas. Additionally, state and national programs provide a broad spectrum of assistance in the form of training, equipment grant/loans, shared data and information, and approaches to implementing new programs (USEPA, Aug. 2000). More detailed descriptions of these upcoming air pollution control programs are presented in Section 7-13 to this chapter.

In addition to the scheduled programs described in Section 7-13, research and policy analysis continues to address other air quality issues that may be incorporated in future regulatory initiatives. The issue of mercury emissions from coal fired power plants and other sources is prominent in current discussions. USEPA is researching alternative

regulatory approaches and has issued a recommended approach. Eventual implementation of mercury regulations would have potentially significant influences on barge transportation of coal within the ORV. Implications of these potential regulations have been addressed in the Corp's Traffic Demand Forecasts (U. S. Army Corps of Engineers (1), Feb, 2004).

7.9.4.2 Economic and Population Growth

Continued growth of the economy, vehicular travel, and population will erode some of the anticipated future air quality progress. Between 1970 and 1999, the national population grew by about 33%, while total vehicle miles traveled increased by 140%. This dramatic growth of vehicular travel negated much of the progress in controlling pollution from mobile sources. Growth during this 30-year period is attributable to traditional non-drivers becoming full-time drivers and development of the transportation infrastructure that facilitated the suburban commuting lifestyle that is so prevalent today throughout much of the ORV.

During the past 30 years, Gross Domestic Product (GDP) also grew dramatically faster than the population. With unlimited opportunities for continued technological advancements, improved productivity, and growth of trade and service sectors, it is not inconceivable that similarly dramatic growth is possible for the future. However, the growth profile for the future includes a mixture of activities reflecting a shift from a manufacturing economy to a service and information based economy that would produce comparatively less air pollution than associated with past growth. Additionally, the impact of growth in traditionally polluting sectors is mitigated somewhat by the fact that new industrial infrastructure with designed-in pollution control tends to be much cleaner than previous facilities with add-on controls.

Within the states bordering the ORV, it seems likely that coal will continue to be the primary source of electric power generation. The region possesses massive supplies of coal, no alternative power source shows any indication of supplying a significant share of the net load, and the developed infrastructure of mines, coal transport, power plants, and transmission system constitutes one of the most cost efficient power production systems in the nation. The cap and trade system of controlling emissions allows room for significant growth with existing control technology and incentives to achieve additional growth through plant renovation and modernization.

7.9.4.3 Towboat Traffic Projections

The Navigation Data Center based in the Huntington District, monitors waterborne commerce throughout the ORS. The Center collects waterborne commerce and lock performance statistics and performs shipper/consumer surveys. Analysis of this information is used to forecast trends in system traffic demands and to forecast individual lock performance. Results of such analyses are used to determine which facilities are most in need of improvement and to evaluate the feasibility of navigation modernization proposals.

The most recent analyses and forecasts of traffic demand were completed in 2005 for the ORMSS SIP. These analyses addressed five separate scenarios and projected growth rates between 0.50 and 1.03 per cent per year for the Ohio River mainstem. Three

of the scenarios recognized the impacts of potential future air pollution regulations; including the existing program of NAAQS, proposed 'clear skies' amendments to the NAAQS, and 'clear skies' minus proposed new limits for mercury emissions. The forecasts are discussed in greater detail in Chapter 10, Transportation.

7.10 CUMULATIVE EFFECTS: EMISSIONS FROM LOCK AND DAM MAINTENANCE

7.10.1 Emissions from Barge Delays

Emission factors for marine diesel engines are expressed as pollutants emitted per ton of fuel burned (USEPA, September 1999b). Project documentation for construction of lock extensions at Myers and Greenup L&D included estimates of the total quantity of diesel fuel that would be burned as a result of delays during maintenance closures, under the Without Project scenario, over the 60-year span from 2000 to 2070 (U. S. Army Corps of Engineers (1), April, 2000). In these estimates, fuel consumption due to queuing at Greenup was predicted to be more than twice the amount predicted for Myers, due in part to the history of longer and more frequent maintenance closures at Greenup. Using predicted closures at Myers as the case representing a typical lock and dam on the Ohio River, total emissions due to maintenance related queuing were calculated as a function of traffic volume for the entire Ohio River L&D system. These projected emissions are reported in **Table 7-8**.

TABLE 7-8
Total Emissions from Maintenance Delays 2000-2070

L&D Project	1998 Tonnage	Diesel[4] Burned	NOx (tons)	PM (tons)	VOC (tons)	CO (tons)
L&D 53[1]	97,695	-	-	-	-	-
L&D 52[1]	97,695	-	-	-	-	-
Smithland[2]	84,606	-	-	-	-	-
Myers	74,151	7.7	1,892	39.6	79.8	245.4
Newburgh	64,131	6.7	1,637	34.2	69.0	212.4
Cannelton	54,386	5.6	1,388	29.4	58.8	180.0
McAlpine[3]	52,867	-	-	-	-	-
Markland	56,119	5.8	1,432	30.0	60.6	186.0
Meldahl	63,739	6.6	1,627	34.2	69.0	211.2
Greenup	70,638	18.0	4,424	93.0	187.2	574.2
Byrd	57,855	6.0	1,477	31.2	62.4	192.0
Racine	40,517	4.2	1,034	21.6	43.8	134.4
Bellville	48,688	5.1	1,243	26.4	52.8	161.4
Willow Is.	44,766	4.6	1,142	24.0	48.0	148.2
Hannibal	47,627	4.9	1,216	25.8	51.6	157.8
Pike Is.	43,027	4.5	1,098	23.4	46.2	142.8
New Cumberland	35,425	3.7	904	19.2	38.4	117.6
Montgomery	26,866	2.8	686	14.4	28.8	88.8
Dashields	24,563	2.6	627	13.2	26.4	81.6
Emsworth	23,153	2.4	591	12.6	25.2	76.8

L&D Project	1998 Tonnage	Diesel[4] Burned	NOx (tons)	PM (tons)	VOC (tons)	CO (tons)
Ohio River Total		91.2	22,418	472.2	948.0	2,910.6
Notes:						
1 L&D52 & L&D53 to be replaced by Olmsted L&D, with dual 1200' locks. No queuing emissions due to chamber closures.						
2 Smithland has dual 1200' locks. No queuing emissions due to chamber closures.						
3 McAlpine, under construction, will have dual 1200' locks. No queuing emissions due to chamber closures.						
4 Diesel, millions of gallons burned during closure delays over 60-year study period.						
Source: U. S. Army Corps of Engineers (1, 3), April 2000 and U. S. Environmental Protection Agency, September 1999b						

7.10.2 Emissions from Construction Activity

In addition to the queuing emissions described above, air emissions from maintenance and repair construction activities would also occur. For most repairs, construction site and equipment emissions will be smaller, in proportion to the reduced scale of the repair activity compared to those of lock extensions. Major repair events to upgrade or overhaul aging lock systems would be comparable to construction emissions that would occur as a result of a lock extension from 600' to 1200'. Total air emissions attributable to construction activities were calculated for proposed lock improvements at J. T. Myers and Greenup and reported in the Environmental Impact Statement (EIS) for that project (U. S. Army Corps of Engineers(1), April, 2000). Because the two projects are so similar in scope, the estimated air emissions are the same. Estimated construction emissions for one project are presented in **Table 7-9**.

TABLE 7-9
Estimated Air Emissions from Typical 600' to 1200' Lock Extension

Emissions in Tons (numbers rounded)				
600' Lock Extension	**VOC (tons)**	**CO (tons)**	**NOx (tons)**	**PM (tons)**
Year 1	02	12	13	1
Year 2	11	66	74	8
Year 3	01	03	3	<1
Total	**14**	**80**	**91**	**10**
Source: U. S. Army Corps of Engineers (1), April, 2000				

Average annual air emissions attributable to routine and major repair events can be roughly estimated. If major repair events occur about once every ten years, it can be assumed that average annual emissions from construction activity are about 10 per cent of the total estimated for a 600' to 1200' lock extension. This would result in an estimate of 9.1 tons per year of NOx emissions due to construction activities at each lock and dam project on the Ohio River.

7.10.3 Cumulative Emissions from Lock and Dam Maintenance

Air emissions attributable to construction activity and queuing due to lock and dam maintenance activity can be displayed as annual emissions for the entire Ohio River

navigation system and compared to previous estimates for Tows Underway (from **Table 7-5**) and emission inventories for all Marine Emissions and for All Sources (from **Table 7-4**). These comparisons, presented in **Table 7-10**, place air emissions from lock and dam maintenance activity in context with the larger emission categories.

TABLE 7-10
Annual System-Wide Emissions

	NOx (tons/yr)	PM (tons/yr)	HC (tons/yr)	CO (tons/yr)
Maintenance Delays	373.6	7.9	15.8	48.5
Construction Emissions	172.9	19	26.6	152.0
Total Maintenance and Construction	546.5	26.9	42.4	200.5
Total Emissions for Tows Underway	26,739	1,273	637	3,183
Total Marine Vessel Emissions	59,430	3,216		6,246
Emissions from All Sources	1,253,044	336,708		2,557,184

7.11 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve Environmental Sustainability (ES). ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of CEs can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An Analysis of ES (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps:

(1) identification of "common effects" on air quality parameters from the High and Medium importance RFFA as delineated in the pertinent RFFA matrix;
(2) selection of sustainability indicators for air quality, and their grouping, as appropriate; and
(3) consideration of the "connections" between the common effects and the indicator groups.

The output of the AES consists of a qualitative (descriptive) discussion of the "connections", with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for air quality, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – the composite conditions for the selected indicators of ES for air quality do not reflect conditions that would facilitate attainment of acceptable standards or would not maintain existing standards in concert with collective impacts of proposed activities.
- Marginally sustainable – the composite conditions for the selected indicators of ES are such that the attainment of acceptable living conditions and quality of life is accomplished for the majority, but not all, of the potentially affected populations. However, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of air quality for the Ohio River).
- Sustainable – the composite conditions for the selected indicators of ES are such that the attainment of acceptable living conditions and quality of life is accomplished for essentially all of the potentially affected populations in the ORV, and such standards are maintained in concert with foreseeable future activity. Further, the conditions of the indicators exceed regulatory thresholds and various governmental programs are in place to respond to any potential erosion of ambient Air Quality.

Common effects of multiple actions have been previously discussed in the sections entitled "Interactions with Other VECs" and "Relevant Actions Affecting Air Quality".

Indicators or groups of indicators of air quality were identified earlier in the section entitled "Indicators of Sustainability", and relevant information on them have been presented in the section entitled "Past to Current Baseline Conditions". For the purposes of this analysis, the above indicators are grouped into three tiers for the conduction of the AES. The three tiers are as follows:

- first tier – "scientific measures of air quality factors"
  (1) National system for monitoring pollutant releases to the atmosphere, including industry reporting requirements, regulatory inspections and measurement of pollution sources, and state/federal programs to calculate annual emission inventories from all sources.
  (2) National system to monitor ambient air quality.

- second tier – "composite measures of air quality factors"
  (1) Analyses to confirm that pollutant source reductions are contributing to improved ambient air quality.

- third tier – "composite indicators of air quality sustainability"; this includes measures developed from multiple indicators
  (1) Attainment of ambient air quality standards.
  (2) Ongoing health risk assessments to determine whether attainment of existing air quality standards adequately protects human health and other resource values.

7.12 CONCLUSIONS REGARDING CUMULATIVE AIR QUALITY EFFECTS

7.12.1 Mitigation and Monitoring of Cumulative Air Quality Effects

Regarding cumulative air quality effects of the ORMSS, no significant concerns have been identified. This conclusion is based upon a combination of considerations related to: (1) the small contributions of the waterway navigation system to annual emission inventories in the study area and (2) the existence of the CAA and its comprehensive requirements for air pollutant source control measures, pollutant caps, and the attainment of ambient air quality standards. Further, additional reductions in NO_x emissions from marine diesel engines are planned by the USEPA. Accordingly, no unique mitigation requirements are envisioned for the waterway navigation system other than conventional practices used to reduce pollutant emissions during construction. Finally, improvements to the system will reduce barge queuing and associated incremental emissions.

Air quality monitoring is currently conducted in several major cities in the study area. As a result of the lack of significant cumulative air quality concerns and the existing monitoring programs, no additional monitoring related to the waterway navigation system is required.

7.12.2 Summary of Findings

Based upon the analyses included herein, the following findings have been identified:

The spatial boundaries for the study include the corridor along the mainstem of the Ohio River. Regarding emission inventory information, the counties along both sides of the River were included. Finally, long-range transport of air pollutant was considered but not addressed in detail due to the small contributions of the navigation system to the county-based emission inventory.

The temporal boundaries for the study ranged from 1920 to 2070. The future date (2070) was selected based on the Corps' planning horizon for the development of a system-wide investment strategy for the ORMSS. The beginning date (1920) reflects the approximate initiation date for the Corps' modernization program for locks and dams on the Ohio River. However, from a pragmatic standpoint based on the availability of air quality data and the existence of a regulatory program by USEPA, the year 1970 better reflects the utilized historical baseline.

Numerous sources of NO_x, CO, SO_2, PM, and VOC emissions exist within the study area. The sources are associated with direct actions of the Corps (e.g., construction of lock chamber extensions; lock maintenance, repair, and rehabilitation; operation of the system; and dam rehabilitation); direct actions by others (e.g., commercial navigation activities; barge traffic waiting to pass through locks; and barge loading/unloading and other intermodal operations); and indirect actions by others (e.g., industrial plants, coal utilities, urban and rural transportation, and commercial sand and gravel operations).

Air quality management programs were initiated in 1970 with the passage of the CAA. Numerous amendments have occurred since then, thus leading to the current comprehensive program coordinated by USEPA and administered by state agencies in the six states located along the Ohio River mainstem. The current program includes ambient air quality standards, emission standards for stationary sources, emission standards for mobile sources (cars, trucks, etc.), allowance trading for SO_x emissions from power plants, monitoring requirements, and many other features. The current program and the anticipated more stringent requirements in the near-term for related pollutant emission actions in the study area indicate that air quality is subject to numerous controls and regulatory measures focused on reducing undesirable effects on human health.

Using 2004 data, comparisons of current air quality levels with the pertinent ambient air quality standards have revealed that 10 counties in 4 states continue to be designated as non-attainment for either ozone (based on the 1-hour standard), PM_{10}, or SO_2. The counties in Illinois are in compliance with the standards. The new 8-hour standard for O_3 has resulted in designation of 37 counties in 5 states. All of the non-attainment counties are within or adjacent to standard metropolitan statistical areas for major cities within the Ohio River corridor.

The 1999 emission inventories for counties bordering the Ohio River were used to examine the contributions of various pollutant source categories, including direct actions by the Corps and others related to the waterway navigation system. It was found that construction, operation and maintenance, and rehabilitation activities of the Corps contribute considerably less than 1% of the annual emissions inventories for NO_x, CO, and PM. Barge towboats contribute 2.1% of the annual inventory for NO_x, 0.38% for PM and 0.12% for CO. Emissions from towboats in queue at locks, although they are small on a comparative basis to other sources in the study area, can be further reduced:

- Through improvements to auxiliary locks in the system
- Through improved moorage at frequent queuing points in the system.

No significant cumulative air quality effects have been identified. This conclusion is based upon the following considerations: (1) the direct actions associated with the waterway navigation system exhibit only minor contributions to the annual emission inventories; (2) barge towboats contribute 2.1% of the annual NO_x inventory, and new regulations for marine diesel engines should reduce this contribution; and (3) the CAA and the associated ambient air quality standards, source control regulations, and trading programs provide an in-place management structure for both individual and cumulative air quality effects.

Because the cumulative air quality effects are not significant, no special modifications or mitigation measures would be required under either the “With Project scenario” or the “Without Project scenario”. This is based on the valid assumption that environmentally responsible practices would be used to reduce the NO_x, CO, VOC, and PM_{10} emissions during various construction, maintenance, repair, and rehabilitation activities. Further, because an extensive air quality monitoring network already exists in the study area, no special monitoring for cumulative air quality effects will be required.

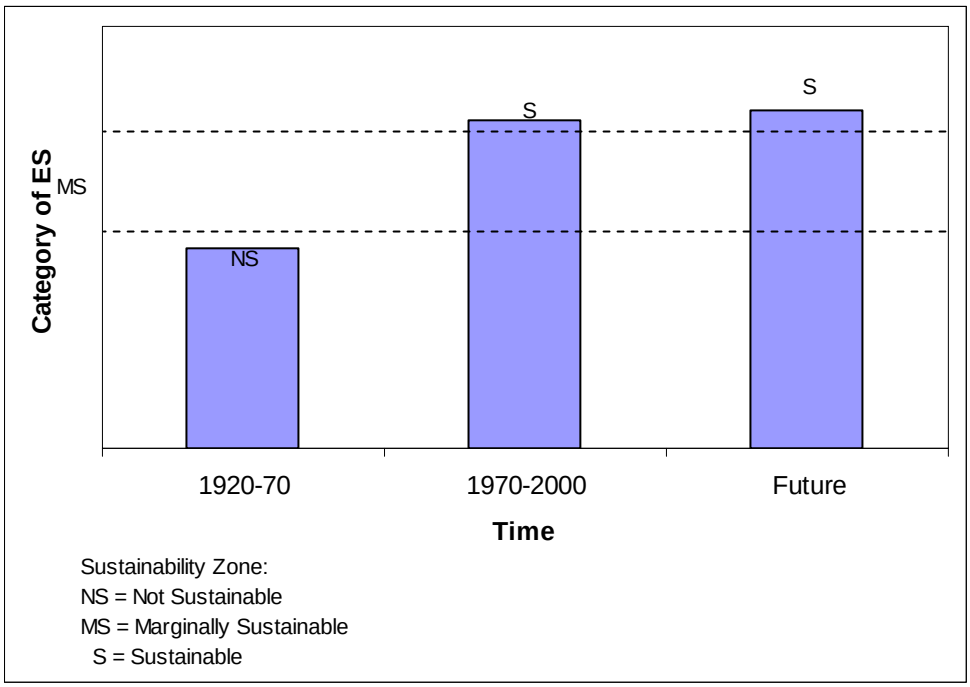
Based upon the above-described actions and effects, the tiers of indicators, and the ES categories, the ES of air quality for the ORV can be characterized and depicted in **Figure 3** as follows:

- In the time period prior to 1920, and continuing up to about 1970, the air quality of the ORV was in a degraded state and thus classified as "not sustainable" due to largely untreated and uncontrolled point and nonpoint pollutant discharges from coal fired power plants, other types of industries, and vehicular sources.

- Due the requirements of the Federal CAA of 1970 and subsequent amendments, the air quality in the region has shown a steady improvement in recent decades; thus it is currently in a "sustainable" category.

- Regarding the future, it is expected that air quality in the ORV will further improve as a result of the continuation of source control and other pollution reduction programs; thus, it will be maintained in a "sustainable" condition. However, this characterization should not bring complacency; rather, vigilant efforts are still needed to continue effective air quality monitoring and management efforts. Such efforts are reflected in the recent implementation of more stringent standards for O_3 and PM, ongoing efforts to establish effective limits for mercury, and to continue analysis of the need to control other types of emissions.

FIGURE 7-3
Environmental Sustainability of Air Quality for the Ohio River Valley



7.13 SUPPLEMENT – FUTURE IMPACTS OF AIR QUALITY REGULATORY PROGRAMS

This section provides information on recent developments and proposed regulatory programs for several categories of air pollutant sources.

7.13.1 NOx Vehicle Initiatives

7.13.1.1 Heavy-Duty Diesel and Gasoline Engines.

After several years of working with fuel refineries and the manufacturers of heavy duty diesel and gasoline engines, USEPA issued final rules in July and December, 2000 that will eventually reduce emissions from these vehicles by over 90%. The first phase takes effect for all diesel engines over 8,500 pounds manufactured in 2004 and for heavy-duty gasoline engines in the 2005 model year. The sulfur content of highway diesel fuel will be reduced by 97% in 2006 and vehicles designed to utilize high-efficiency catalytic exhaust systems will be required beginning in model year 2007. Total phase-in of the program will extend to 2030, when the current heavy-duty vehicle fleet will have been completely replaced by newer, emission compliant vehicles.

Heavy-duty trucks and buses currently account for about one-third of NOx emissions and one-quarter of PM emissions from all mobile sources. NOx emissions will be reduced by 95% from current levels, resulting in net reductions of 2.6 million tons per year (tpy) by 2030. PM emissions will be reduced by 109,000 tpy (a 90% reduction) and VOC by about 115,000 tpy (U. S. Environmental Protection Agency, December 2000a&b).

7.13.1.2 Nonroad Diesel Engines.

This category of emission sources includes construction equipment such as bulldozers, road graders, excavators, and portable generators as well as farm tractors and logging equipment. These sources account for about 10% of total NOx emissions and frequently contribute a larger percentage in communities with air quality problems. Tier I standards for new engines over 50 hp were phased in from 1996-2000 and for engines under 50 hp from 1999-2000. More stringent standards for all engine sizes went in effect from 2001 through 2006 and a third tier of standards will be applied to engines over 50 hp from 2006-2008. By 2010 it is expected that these controls will reduce NOx emissions from this source group by 1 million tpy, with larger reductions in later years as older equipment is replaced with newer, cleaner burning equipment (U. S. Environmental Protection Agency, August 1998 and Nov. 2000).

7.13.1.3 Locomotives.

The final rule for locomotives was issued in December 1997 and began to take effect in 2000. From this point forward, all new and remanufactured locomotives must meet applicable emission standards, which increased in 2002 (Tier I) and again in 2005 (Tier II). Locomotives have an average service life of 40 years or more and are remanufactured every 4 to 8 years. The program is expected to reduce NOx emissions by 267,000 tpy in 2010 and 650,000 tpy in 2040 (a 60% reduction). Prior to these regulations, locomotives accounted for over 10% of NOx emissions from mobile sources, or almost 5% of total nationwide NOx emissions. PM reductions will exceed 12,000 tpy by 2040, a 46% reduction from baseline levels and more than 1% of mobile source emissions (U. S. Environmental Protection Agency, Dec. 1997).

7.13.1.4 Commercial Marine Diesel Engines.

This source group includes engines used for propulsion and auxiliary power on commercial vessels in a variety of marine applications, including tugboats, towboats, and dredgers. A study of air emissions from nonroad engines, conducted by USEPA in 1990, found that commercial marine diesel engines accounted for about 4.4% of total mobile source NOx emissions and about 1% of PM emissions. The study also concluded that NOx and PM emissions from marine engines were likely to be concentrated around commercial ports and heavily populated coasts. In a final rule issued November 1999, emission standards are applicable to new engines manufactured between 2004 and 2007, depending on the size of the engine. When the program is fully phased-in by 2030, these standards are expected to result in a 24% reduction of NOx emissions and a 12% reduction of PM emissions from this source (U. S. Environmental Protection Agency, Nov. 1999b).

7.13.2 VOC Vehicle Initiatives

7.13.2.1 Gasoline Marine Engines.

USEPA issued the gasoline marine final rule in August 1996, applicable to outboard engines and gasoline engines used in personal watercraft and jet boat applications. The new standards did not apply to sterndrive and inboard engines because of the inherently clean technology already utilized by these engines. USEPA's 1990 study of nonroad engines found that recreational marine engines contributed an average of about 3.3% of total VOC emissions, and noted that the percent contribution could be expected to be significantly higher wherever watercraft were concentrated in proximity to population centers. Since VOCs interact with NOx to form ground level O_3, a concentration of both sources in proximity to each other might magnify this effect even more.

Emission reduction goals are to be reached through the phased introduction of new generation engines that offer improved performance and fuel economy and eliminate fuel/oil mixing, in addition to achieving a 75% reduction of VOC emissions. These new generation engines were expected to be available as early as 1997 and are expected to completely replace the existing generation of engines by about 2025 (U. S. Environmental Protection Agency, Aug. 1996).

7.13.3. NOx Power Plant/Industrial Source Programs

7.13.3.1 Acid Rain Program.

Electric utilities generate about 30% of the nationwide total of around 23 million tpy NOx emissions. These emissions have remained relatively stable since the mid-80's. Although cleaner technologies have been introduced in many industrial settings, these reduced emissions have been offset by growth of the electricity generation and vehicle use source categories. Under the national acid rain program, NOx emissions were to be reduced about 400,000 tpy between 1996 and 1999 (Phase I) and by a total of 2 million tpy between 2000 and 2007 (Phase II). These goals are being pursued by designating a NOx emission limit of between 0.40 and 0.86 lbs/mmBtu, depending on the boiler type at the source. Among facilities participating in Phase I of the NOx program, average

emission rates have decreased by 42% since 1996 (U. S. Environmental Protection Agency, Nov. 1999a).

7.13.3.2 Regional NOx Programs.

Within the ORV area, three regional programs to further reduce NOx emissions are being implemented. These include the Ozone Transportation Commission (OTC), the NOx SIP call, and the Federal NOx Budget Trading Program (Sec. 126). All of these programs are intended to reduce ground level ozone and the applicable emission limits that apply to a "summer season" period of compliance. All of the programs apply a cap and trade program internally and some opportunities exist for trading among programs (U. S. Environmental Protection Agency, 2001b).

The OTC applies to a specific group of "other" industrial sources in 12 northeastern states, including Pennsylvania. From a 1990 baseline of 490,000 tpy, these sources are utilizing a cap & trade program that was to reduce emissions to 219,000 tpy by 1999 and to 143,000 tpy by 2003. After 2003, control levels are similar to the Sec. 126 program and trading among programs may become feasible at that time.

The NOx SIP call applies to 22 midwest and northeast states that include all six of the ORV states. The initial compliance year for this program is 2004 and as yet not all states have finalized their lists of participating sources, baseline emissions, and caps. States have an option to participate in the Federal NOx budget trading program, which would allow free trading of emissions credits among participating sources.

The Sec. 126 final action is the result of a settlement of petition to USEPA from four northeastern states seeking to reduce O_3 pollution through reductions in NOx emissions in other states. The program requires 392 facilities in 12 states and the District of Columbia to reduce annual NOx emissions through participation in a cap-and-trade program. All ORV states except Illinois are included in this program, which regulates all large electric utilities and large industrial boilers in the area. Fossil fuel fired boilers or combustion turbines with rated output of greater than 25 MW or maximum rated heat input capacity of greater than 250 mmBtu/hr are included.

The emissions cap established by the Sec. 126 final action picks up where the acid rain program for NOx leaves off. Annual emissions from the 392 facilities will total 510,000 tons less than the year 2007 levels established by the national program. Additionally, all utility and industrial NOx emissions in the region will be capped; new plants will be issued initial NOx "allowances" but will be required to operate within the regional emissions limit. Emission allowances for 2003-2007 were issued in December 1999, with reserve allowances for new sources and incentives for sources that make early reductions in 2001 or 2002.

7.13.3.3 Reduction of SO_2 Emissions

Reduction of SO_2 emissions under the acid rain program is focused on reversing the trend of acidification of lakes, streams, and forests nationwide and associated impacts on visibility, respiratory health, agricultural productivity, and degradation of monuments and buildings. SO_2 is also an important precursor of $PM_{2.5}$, especially in the east, and control of the former will help lessen the human health impacts of the latter. The combustion of

coal for electric power is the principal source of SO_2 emissions; utilities account for about 67% of total annual discharges. The high sulfur content of midwestern coal results in an overwhelming concentration of sources within or adjacent to this region. Since 1980, the six states bordering the Ohio River have ranked among the top seven or eight nationwide sources of SO_2 from coal-fired utilities.

The program to reduce SO_2 emissions began in 1995 with emission reductions from large electric power generators. This group achieved reductions of almost 5 million tpy, or about 30% below allowable emission levels in advance of future limits. Phase II of the program began in 2000, regulating a greater number of smaller plants and requiring further reductions from larger plants. Full compliance by 2010 will result in attainment of the emissions cap of 8.95 million tpy; a reduction of almost one-half from industry wide emissions in 1980 (U. S. Environmental Protection Agency, 2001a and Nov. 1999a).

7.13.4 New standards for O_3 and $PM_{2.5}$

Better understanding of the health impacts of ozone and PM led to the establishment of the new standards. Achieving these health benefits will require greater effort and expense for programs in existing nonattainment areas as well as new programs in areas that were previously designated as attainment. Locally implemented efforts can include requiring the use of cleaner burning gasoline, vehicle inspections, and more stringent enforcement of existing regulatory authority. Some industrial sources may become subject to tighter emission standards in nonattainment areas while area sources such as dry cleaners may benefit from incentive programs to modernize their equipment. Although states retain their individual jurisdictions, it is important to establish communication and program coordination wherever nonattainment areas cross state boundaries, which is likely to apply to virtually all nonattainment areas in the ORV.

There is a direct relationship between weather conditions and the local buildup of O_3. Accumulations of fine particulate are also likely to be dependent on weather conditions. Ambient monitoring resources can be utilized to predict the occurrence of potential exceedances several days in advance. As a result, it is important that nonattainment communities develop and utilize strategies and authorities to restrict pollutant-contributing activities. These can range from asking people not to mow their lawns to requiring a major industrial source to temporarily cease or restrict operations. The ability to constrain emissions for even a day or two can make the difference between passing or failing an air quality standard.

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Chapter 8

HEALTH AND SAFETY

8.1 TABLE OF CONTENTS

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- **Supplement 8-B: Recreational Boating Accident Report Database (BARD)**

8.2 DEFINITION OF RIVER-RELATED HEALTH AND SAFETY IMPACTS

Health and Safety (H&S) considerations are primarily related to human communities rather than resources and ecosystems. However, some H&S measures may impact resources or ecosystems. The H&S Valued Environmental Component (VEC) consists of:

Worker health and safety – this refers to construction workers and workers related to lock and dam (L&D) operation, assemblage/ disassemblage of barges in tow,

operation of tows and helper boats, and barge loading/unloading. Concerns relate to effects on worker H&S from construction accidents (or accidents during maintenance, repair, or rehabilitation of navigation system components), routine system operations, barge accidents, and barge loading/unloading activities.

General population health – this refers to chemical or bacteriological exposures to the human population using the Ohio River as a water supply, or using the river for body contact recreation (swimming and/or water skiing). Exposures can occur from chemical or other spills into the river or its tributaries from industries and barges, from releases of contaminants from industrial or municipal sediments in the river, from releases from nearby hazardous waste sites, and/or from accidents (ruptures) related to pipelines crossing the river. Such exposures can occur from ingestion of river water prior to or following treatment, from ingestion of contaminated fish or aquatic species, and from dermal exposure to the water.

Recreational boater safety – this refers to accidents experienced by those persons engaged in recreational boating on the Ohio River.

Noise refers to the ambient sounds audible in an area or environment, comprised of sounds from varying distances. Both workers and the general population may be subject to noise impacts. Noise impacts may originate from temporary sources (e.g., a construction site) or more permanent activities such as airports and highways.

8.3 OBJECTIVES AND SCOPE OF THE HEALTH AND SAFETY STUDY

8.3.1 Objectives

This chapter assesses the system-wide cumulative health and safety impacts of all likely major navigation improvements along the mainstem of the Ohio River from 2000 - 2070. Health and safety impacts that are directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFAs) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFA. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, actions by non-governmental entities, and predictions of general economic expansion and development.

At the beginning of the study process, noise issues were investigated as a separate VEC from the Health and Safety VEC. Noise and H&S were presented as separate VECs at public scoping meetings and in the analysis of RFFAs. The results of these efforts led to the conclusion that noise issues would be more effectively discussed as a part of the general Health and Safety VEC, rather than as a separate VEC.

The results of the Cumulative Effects Assessment (CEA) are intended to contribute to two topics of subsequent public concern: (1) whether the impacts of the RFFAs constitute acceptable outcomes for the affected resources and (2) how the proposed navigation improvements contribute to those outcomes.

8.3.2 Geographic Scope

The geographic focus for health and safety impacts includes those areas most directly impacted by presence of the navigation system. Other potential health and safety impacts include construction site activities at locks and dams, boating accidents, spills, operational practices associated with commercial navigation, other boating accidents, and impacts from other sources. Potential impacts would mostly occur on the water surface or adjacent banks, but some of the other potential sources of such impacts are located away from the banks such as floodplains. These potential sources include facilities that process, transfer, or store oils and fuels; industrial facilities that use other toxic or hazardous materials; construction sites such as bridges or riverfront developments; contaminated sites that may leach pollutants; other municipal and industrial point sources, and contaminated surface runoff. To account for such sources, the geographic focus for health and safety impacts is defined as the river surface plus the land surface for one mile from either bank. Point and nonpoint sources such as combined sewer system overflows (CSO) or stormwater runoff that do not fit this geographic scope are also recognized.

8.3.3 Time Frame

The established time frame for this project is 1920 to 2070. The earlier date approximates the initiation of modern Corps L&D construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the Ohio River Main Stem System Study (ORMSS).

8.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. More detailed discussions of the scoping meetings are presented in this report in Exhibits A and B.

A total of 185 people attended the meetings and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted.

Public H&S was a significant focus of the meetings. Comments that directly and indirectly addressed H&S are presented in **Table 8-1**. Additionally, questionnaire respondents were asked to assign an importance number to each of the 12 VECs identified in the CEA. Although it is important not to draw too strong a conclusion from only 19 completed questionnaires, it is worth noting that the Health & Safety VEC (including hazardous waste sites and chemical spills) received the highest score of 2.8 out of a possible 3.0. Noise, listed as a separate VEC on this questionnaire, received the lowest ranking among the 12 VECs.

TABLE 8-1
Comments from Public Scoping Meetings

Direct Comments on Health and Safety Issues	Total
Failure of barges to stay in designated shipping lanes	2
Increased spills and accidents potentially affecting aquatic life and impairing water quality	1
Safety concerns related to uneven arrangement of barges on towboats	1
Challenges to water quality presented by CSOs and SSOs	2
High levels of mercury, arsenic, fecal coliform bacteria and agri-chemicals in surface water	1
Importance of continued water quality improvements as a high priority	1
Need to protect public groundwater supplies	1
Impaired water quality and bioaccumulation in fish tissue of harmful substances stirred up by dredging	2
Health and safety concerns related to increased traffic and development	3
Danger to recreational users of submerged trees toppled by bank erosion	1
Other Comments with Implications for Health and Safety	
Cumulative effect of discharges on river may offset water quality improvements	4
Instream sedimentation forming bars and causing vessel groundings	1
Need for examination of those licensed to operate recreational craft	1
Concern about ancillary movement of goods and services in emergencies, e.g., bridge destruction	1
Importance of coordination between Corps and Ohio River public water suppliers	1

8.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

Federal, state and local agencies broadly recognize the contribution of effective monitoring and response procedures to the protection of public H&S. As a result, numerous quantitative resources are available that can serve as indicators of the status of particular H&S concerns. Tracking these concerns over time permits an evaluation of H&S sustainability in the context of improving, stable, or declining conditions. Principal H&S concerns and available measures that address these concerns are presented in **Table 8-2.**

8.6 LAWS, REGULATIONS, ORDINANCES AND PROGRAMS

Spill response refers to emergency response activities to barge/tow spills or accidental discharges, or to industrial plant spills or accidental discharges, into the Ohio

River or its tributaries. The Ohio River Valley Sanitation Commission (ORSANCO) has a spill monitoring system in place.

TABLE 8-2
Indicators of Sustainability

Principal Health and Safety Concerns	Available Quantitative Measures to Address the Concerns
Spills of oil, fuel, and other hazardous or toxic materials.	USEPA Emergency Response Notification System (ERNS) spills database.
Potential sources of contamination associated with past or present activities – industrial sites, landfills, underground storage tanks.	USEPA databases for sites on the National Priority List (NPL); Resource Conservation and Recovery Act (RCRA) Corrective Action (CORRACTS) sites; and candidate NPL or CORRACTS sites under USEPA or state review. RCRA permitted treatment, storage and disposal (TSD) facilities; RCRA registered generators of hazardous waste; and state lists of leaking underground storage tanks (LUST), registered aboveground/underground storage tanks (AST, UST), and solid waste landfills, incinerators, or transfer stations (SWLF).
Accidents associated with commercial or recreational boating.	Boating accident records maintained by US Coast Guard (USCG) and states.
Health impacts of water quality – boating, swimming, fish consumption.	ORSANCO water quality data and indices for the Ohio River. State and federal fish consumption advisories.
Noise impacts from construction activity, commercial transportation, other sources.	USDOT/FHA Highway Construction Noise Methodology (DOT 1981).

Various states along the Ohio River and related federal agencies with pertinent responsibilities already have contingency plans in place to respond to spills or accidental discharges. Section 301 of the Clean Water Act (CWA) requires many industrial facilities to develop and maintain plans for preventing and responding to spills of oil and hazardous substances, such plans are called Spill Prevention Control and Countermeasure (SPCC) Plans (http://www.epa.gov/oilspill/respmgnt.htm).

Boating safety regulations refer to legislation and rules related to the operation of recreational watercraft, including personal watercraft, on the Ohio River. Such regulations are issued by the six states bordering the river, and also by the recreational boating safety program of the U.S. Department of Transportation and U.S. Coast Guard. Federal funding authorized by the Transportation Equity Act for the 21st century is used in conjunction with state revenues to support both educational and enforcement efforts. Marine Safety Offices of the U. S. Coast Guard are responsible for: Homeland Defense Activities, Port Safety & Security, Commercial Vessel Inspection, Pollution Response, Waterways Management & Marine Casualty Investigation.

ORSANCO monitors Ohio River water quality and aquatic ecology. River water quality monitoring for selected parameters is conducted at identified monitoring stations and fish monitoring is conducted via several research programs. ORSANCO also serves as

a repository for information on the quality of river water used for public water supplies. Monitoring data supports health advisories addressing water contact recreational activity.

Table 8-3 presents information on important federal, state, and local regulations and established programs, which directly or indirectly influence H&S (including noise) in the Ohio River study area.

In addition to noise related regulations described in **Table 8-3**, Federal legislation related to noise impacts include the Federal Aid Highway Act of 1970 and the Aviation Safety and Noise Abatement Act of 1979 (HUD, 1985). The Federal Aid Highway Act of 1970 and subsequent amendments established the requirement that noise control be a part of the planning and design of all federally aided highways. The Aviation Safety and Noise Abatement Act of 1979 focuses primarily on noise measurement, mapping, and reduction at airports (Canter, 1996).

TABLE 8-3
Laws, Regulations, Ordinance and Programs Relevant to Health, Safety and/or Noise

Law/Program	Key Components	Relevance to Health, Safety &/or Noise
Occupational Safety and Health Act (National Institute for Occupational Safety and Health)	• Requires employers to provide workers a place of employment free from recognized hazards to safety and health, such as exposure to toxic chemicals, excessive noise levels, mechanical dangers, heat or cold stress and unsanitary conditions • Created NIOSH to establish standards for workplace health and safety	Provides a comprehensive framework for worker and workplace safety
Emergency Planning and Community Right-to Know Act (a.k.a. SARA Title III) (USEPA and state and local emergency response agencies)	• Requires emergency planning and preparedness at state and local level • Section 304 establishes spill reporting requirements for facilities that release extremely hazardous substances • Section 312 requires certain facilities to file annual toxic chemical release forms.	Provides emergency planning and provides citizens, local governments and local response authorities with information on potential hazards in their community.
Pollution Prevention Act (US Environmental Protection Agency)	• Establishes the policy of pollution prevention, reduction and recycling in an environmental safe manner whenever feasible • Requires facilities filing annual toxic chemical release forms to also file a toxic source reduction and recycling report	Protects public safety by requiring pollution reduction or recycling of hazardous substances, toxic chemicals and toxic and radiological wastes at their sources
National Environmental Policy Act (NEPA) (Council on Environ-mental Quality and other federal agencies)	• Requires preparation of environmental impact assessments for new construction projects by private and governmental agencies • Includes federal government's responsibility to prevent environmental	Provides basic national charter for environmental protection , including efforts that promote human health and

Law/Program	Key Components	Relevance to Health, Safety &/or Noise
	degradation that could become a threat to public health or safety	welfare
Safe Drinking Water Act (SDWA) (U.S. Environmental Protection Agency)	• Provides for establishment of primary regulations for the protection of public health and secondary regulations related to taste, odor and appearance of drinking water	Helps protect public water supplies for approximately three million people who use the Ohio River as their source of drinking water
Oil Pollution Act (U.S. Environmental Protection Agency and U.S. Coast Guard)	• Strengthens governmental ability to prevent & respond to catastrophic oil spills • Requires oil storage facilities and vessels to submit plans detailing how they will respond to large discharges	Protects drinking water supplies and natural resources from pollution & damage from oil spills
Site Remediation Statutes (U.S. Environmental Protection Agency and state regulatory agencies)	• Includes the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), Superfund Amendments and Reauthorization Act (SARA), Resource Conservation and Recovery Act (RCRA) and related state programs that focus on cleanup and restoration of contaminated sites.	Protects human health and the environment and eliminates or reduces the generation of hazardous wastes
Toxic Substances Control Act (U.S. Environmental Protection Agency and state regulatory agencies)	• Designed to establish a system by which all chemicals are evaluated before use to ensure they pose no unnecessary risk to human health, other living organisms, or the environment • Intended to mitigate the hazards of other chemicals already in use	Tries to balance benefits and risks of chemicals in use to ensure human and environmental safety
Corps Permitting Statutes (U.S. Army Corps of Engineers)	• Section 10 of Rivers and Harbors Act (1899) relates to permits for physical obstructions to navigable U.S. waters. • Section 404 of CWA authorizes the Corps to issue permits for the discharge of dredged and fill materials into waters of the U.S.	Includes safeguards for public health and safety.
State Water Quality Certification (Appropriate state or interstate pollution control agencies)	• Section 401 of Clean Water Act requires applicants proposing activity, which may result in discharge to U.S. waters, to provide certification of compliance with state water quality standards.	Provides opportunity for state or interstate scrutiny of health related implications of such actions
Clean Water Act (CWA) (U.S. Environmental Protection Agency)	• Establishes structure for regulating pollution discharges into U.S. waters (NPDES permits) • Requires establishment of water quality standards • Section 301 requires many industrial facilities to develop and maintain plans	Provides a comprehensive framework for water quality protection that includes protecting public health and safety, as well as natural resources

Law/Program	Key Components	Relevance to Health, Safety &/or Noise
	for preventing and responding to spills of oil and hazardous substances, called Spill Prevention Control and Countermeasure Plans (SPCC).	
TMDL Program (U.S. Environmental Protection Agency)	• Increasingly important section (§303) of the Clean water Act; regulates maximum pollutant load a water body can receive and still attain water quality standards.	Helps protect public water supplies for approximately three million people who use Ohio River as their source of drinking water.
Phase 1 & 2 NPDES Program (U.S. Environmental Protection Agency)	• Also developed within the CWA, requires municipalities and certain industrial and construction sites to develop programs to control nonpoint sources of pollution.	Should reduce pollution characteristics of stormwater discharges from urban and industrial zones along the Ohio River.
National CSO Control Policy (U.S. Environmental Protection Agency)	• Published by USEPA, calls for communities to implement long-term plan for combined sewer overflows (CSOs) to comply with the CWA. • Administered through each state's NPDES permit program.	Should reduce pollution from a major urban source, including pathogens harmful to public health
Spill Response (ORSANCO and U.S. Coast Guard)	• Includes emergency response activities for river-related spills and accidental discharges and is related to the Oil Pollution Act and Section 301 of the Clean Water Act.	Minimizes adverse impacts of spills and discharges on mussels and other aquatic life and on water quality
Noise Control Act (USEPA, USDOT, FAA, GSA & state and local governments)	• Directs USEPA to set noise-level criteria and promote an environment free of noise that jeopardizes human health and welfare.	Protects hearing and fosters more orderly environmental conditions
Quiet Communities Act (State and local agencies)	• Amends the Noise Control Act to encourage noise-control programs at the state and community levels.	Extends noise control to local level to protect hearing and foster more orderly environmental conditions
Recreational boating safety regulations and programs (U.S. Coast Guard, U.S. Dept. of Transportation, and state agencies)	• Provides boater safety education and training • Establishes procedures for accident reporting	Enhances safety and enjoyment of recreational boat users on the Ohio River

8.7 PAST TO CURRENT BASELINE CONDITIONS

Project scoping suggested that the most important factors affecting the recent and current status of public H&S includes:

- Hazardous industrial activities

- Hazardous waste sites
- Spills or related accidental discharges
- Recreational boating accidents
- Water quality
- Commercial transportation

Industrial activities located or conducted in proximity to the river may pose one or more types of public risk. These can include pollution point sources, production and disposal of hazardous wastes, and spills of potentially hazardous or polluting materials associated with transfer, storage, and use of the materials. Past industrial activities have contributed to the creation of contaminated sites and landfills that pose ongoing threats to groundwater, surface water, or public health. Raw materials, products, and wastes associated with river oriented industrial activity are transported locally and regionally by barge, rail, and truck transport. These materials are subject to spillage while in transit and especially at material transfer points.

Recreational boating on the Ohio River may be subject to higher levels of risk than would normally be encountered on inland lakes and streams. Strong currents, water level fluctuations, and the presence of barge traffic may be more prevalent on the Ohio River than in other settings. Recreational boating on the Ohio River results in a number of injuries, fatalities, and associated property damage. Boating and other river oriented recreational activities appear to have grown significantly over the past several decades in conjunction with improving water quality. Continued growth of such activities may contribute to more crowded conditions and increased risk of additional accidents.

While overall water quality has improved to the point where almost all of the Ohio River can support recreational activities and consumptive uses most of the time, temporary impacts can still increase risks. Such impacts may include elevated fecal coliform counts in urban areas following wet weather or major spills that threaten drinking water supplies. Additionally, ongoing effects of past contamination are reflected in fish consumption advisories and remediation costs of contaminated sites.

In the context of H&S risks, commercial transportation on the river is most visibly connected with the potential for spills and for potential conflicts with recreational users of the river and adjoining property owners.

8.7.1 Hazardous Site/Spill Databases

Certain industrial activities, waste sites, and spill locations have been recorded in one or more databases. These include sites such as hazardous waste generators or underground storage tank operators that require a permit to operate contaminated sites such as Resource Conservation and Recovery Act (RCRA) listed sites, and sites where reportable spills of oil or hazardous materials have occurred. To obtain a perspective on the distribution of such sites along the full length of the Ohio River, the Corps collected information from all available databases. All records occurring on or within one mile of either bank of the river were selected and mapped. **Table 8-4** summarizes the federal and state databases that were searched and the number of records found for each database type.

This survey identified 3,579 mappable sites. Most sites are listed by more than one database. For example, site 950 in Pittsburgh includes records for a past leaking underground storage tank, current registration of underground tanks, and a reported spill. As would be expected, sites are concentrated in urban and major port areas, but numbers of sites are present along the length of the river. **Supplement 8-A** to this chapter includes an overview of mapped areas, Area Map 1, Detail Map 1 (Pittsburgh), and records for an example site (#950).

TABLE 8-4
Databases Searched to 1 mile of the Ohio River Mainstem

AGENCY	DATABASE	Type of Records	# cited
US EPA	NPL	National Priority List	13
US EPA	CORRACTS	RCRA Corrective Actions	104
STATE	SPL	State equivalent priority list	1
US EPA	RCRA-TSD	RCRA permitted treatment, storage, disposal facilities	27
STATE	SCL	State equivalent CERCLIS list	144
US EPA	CERCLIS/ NFRAP	Sites under review by US EPA	363
STATE/REG/CO	LUST	Leaking Underground Storage Tanks	1081
STATE/REG/CO	SWLF	Solid waste landfills, incinerators, or transfer stations	117
STATE/CO	UST	Registered underground storage tanks	2783
STATE	AST	Registered aboveground storage tanks	180
US EPA	GNRTR	RCRA registered small or large generators of hazardous waste	1526
US EPA/ STATE	SPILLS	ERNS and state spills lists	3069
Source: VISTA 10/25/01 (see Chapter References for complete list of databases).			

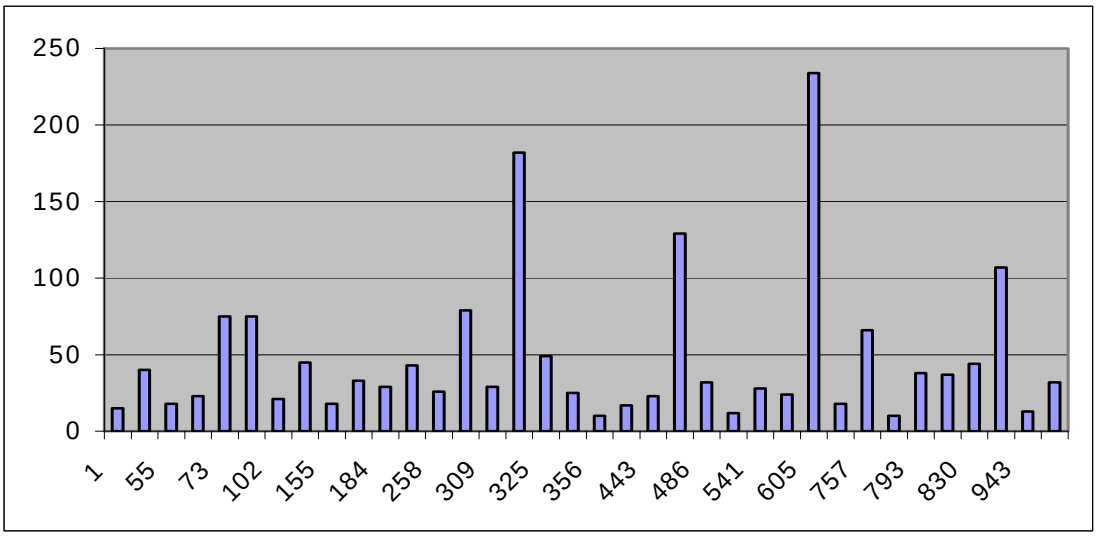
8.7.2 Spill Records

Spill records were difficult to interpret because of the extreme rates of record duplication. Records were collected for the period 1990 – 2000. Of the 3,069 records cited in Table 4, it appears that virtually all state records were duplicates of the national Emergency Response Notification System (ERNS). There were also numerous record duplications within ERNS; the initial total of 2,455 records was reduced to 2,123 after elimination of duplicates. Of this group, 1,700 records located the spill event by river mile.

ERNS is a national computer database system that is used to store information on the sudden and/or accidental release of hazardous substances, including petroleum, into the environment. The ERNS reporting system contains preliminary information on specific releases, including the spill location, the substance released, and the responsible party.

Spill events were not randomly distributed along the 981 miles of river. As might be expected, they are concentrated in the major port and industrial areas. The 1,700 spill records correspond to just 56 discrete River Mile (RM) point locations, ranging from a low of 4 records at Clarksville, IN (RM 605) to a high of 190 at Louisville, KY (also at RM 605). By clustering points that were close together (e.g., RM 602 – 608 for Louisville), spill locations could be summarized as just 36 points along the river. These points are summarized in **Figure 8-1**.

FIGURE 8-1
Distribution of Spill Events along the Ohio River Mainstem



From the above figure, the most frequent spills correspond to the following areas:

- Follansbee, WV area (75 spills, RM 71-75),
- Yorkville, OH to Wheeling, WV (75 spills, RM 85-90),
- Point Pleasant, WV area (79 spills, RM 265-270),
- Kenova, WV/South Point, OH/Catlettsburg, KY area (182 spills, RM 316-318),
- Cincinnati, OH area (129 spills, RM 468-473),
- Louisville, KY area (234 spills, RM 602-608),
- Owensboro, KY (66 spills, RM 757)
- Paducah, KY (107 spills, RM 935)

8.7.3 Recreational Boating and Accidents

Recreational boating accident statistics are compiled and published annually by the US Coast Guard. Data for the accident statistics come from two sources: (1) Boating Accident Report data forwarded to the Coast Guard by jurisdictions with an approved numbering and casualty reporting system and (2) reports of Coast Guard investigations of fatal boating accidents that occurred on waters under Federal jurisdiction. Recreational Boating Accident Investigation data are used if submitted to the Coast Guard and are relied

on as much as possible to provide accurate accident statistics. In the absence of investigations, information is collected from the accident reports filed by boat operators. Information is compiled in the Coast Guard's Recreational Boating Accident Report Database (BARD – see **Supplement 8-B**). Current regulations (33 CFR 173.55) require the operator of any vessel, numbered or used for recreational purposes to file a Boating Accident Report (BAR) when; as a result of an occurrence that involves the vessel or its equipment:

1. A person dies;
2. A person is injured or requires medical treatment beyond first aid, i.e., treatment at a medical facility or by a medical professional other than at the accident scene;
3. Damage to vessels totals $2,000 or more or there is a complete loss of any vessel (prior to July 2, 2001, the property damage threshold was $500);
4. A person disappears from the vessel under circumstances that indicate death or injury.

Users of these boating statistics need to be aware of the following facts that may affect results of analyses of accident report data:

1. The Recreational Vessel Casualty Reporting System does not include every accident involving a recreational vessel. Some accidents are not in the system because they are not required to be reported. Many more accidents are not reported because boaters may be unaware of the law and inherent difficulty in enforcing the law. It is believed that only a small fraction of all non-fatal boating accidents occurring in the United States are reported to the Coast Guard, state, or local law enforcement agencies.
2. Fluctuations from year to year in non-fatal accident statistics may be caused by factors other than the change in the total number of recreational boating accidents. A seemingly small change in the low reporting rate may cause a relatively large change in the statistics. Overall, the more serious the accident, the more frequent the reporting. Therefore, it is believed that nearly all fatal recreational boating accidents are reported (USCG, 2001).

8.7.4 Boating Accident Statistics

Boating accident totals for each state on the Ohio River are in **Table 8-5**. For the period 1997-2001, the six states accounted for 8.8% of all boating accidents nationwide. For the period 1995-2001, accidents on the Ohio River accounted for 4.7% of all boating accidents in the six states. Each state's share of Ohio River accidents varies from a low of 0.7% for Illinois to a high of 34.3% for West Virginia. These shares appear to be approximately consistent with each state's probable relative share of boating activity on the Ohio River. Illinois and Pennsylvania have significant boating opportunities available on other waterways and larger shares of population located away from the Ohio River, thus they would be expected to have the lowest proportions of boating activity on the Ohio River. By contrast, Kentucky and West Virginia, with the highest proportions of boating activity on the Ohio River, have large populations adjacent to the river and relatively fewer boating alternatives elsewhere.

For the Ohio River total of 235 accidents, collision with another vessel was the most common event, accounting for 80 accidents or 34% of the total. Other collisions (floating/sunken objects, docks, etc.) or groundings accounted for 47 events (20%), flooding/swamping, or capsizing the vessel accounted for 25 events (11%), and falling overboard or within the vessel accounted for 21 events (9%). Other types of accidents included fire/explosion (8%), sinking (7%), victims in water struck by boat or prop (4%), skier mishaps (3%), and miscellaneous other (4%).

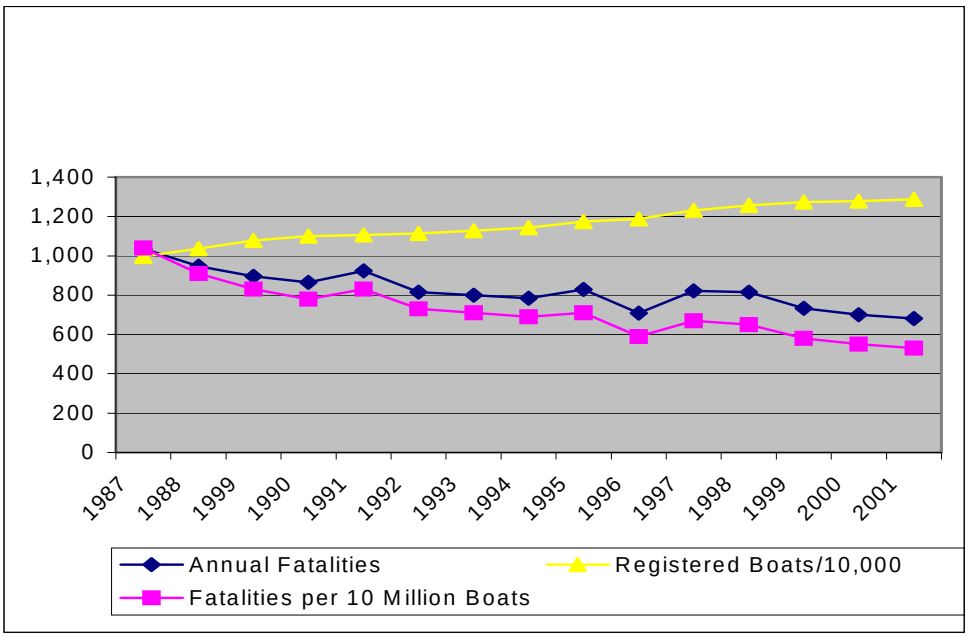
TABLE 8-5
Boating Accidents: State and Ohio River Totals

	1995	1996	1997	1998	1999	2000	2001	Totals (7 yrs)	State Share
Nat'l			8047	8061	7931	7740	6419		
IL-state	164	156	145	159	159	155	108	1046	
IL-OH R.	1	0	1	1	0	3	1	7	0.7%
IN-State	155	143	115	132	150	115	120	930	
IN-OH R.	6	6	10	4	10	6	10	52	5.6%
KY-State	83	95	79	63	75	98	71	564	
KY-OH r.	5	7	7	4	7	11	5	46	8.2%
OH-state	291	242	197	228	232	198	139	1527	
OH-OH R.	14	7	6	5	16	7	7	62	4.1%
PA-state	95	117	119	122	125	88	80	746	
PA-OH R.	4	2	2	2	5	4	0	19	2.5%
WV-state	27	18	20	18	25	20	15	143	
WV-OH R.	9	6	8	5	12	4	5	49	34.3%
Total-6 states	814	771	675	722	766	674	533	4955	
Total-OH R.	39	29	33	21	50	35	28	235	4.7%
Source: USCG, National Boating Statistics									

For the limited years of available data, there is no apparent trend in the annual average number of accidents on the Ohio River. Annual numbers vary widely, from a low of 21 in 1998 to a high of 50 in 1999. Anecdotal comments suggest that high water conditions during peak weeks of the boating season (mid-May through mid-September) significantly reduce the total amount of boating activity in those years and may likely contribute to similar declines in number of accidents in such years. This high annual variability, combined with the relatively small number of annual accidents on the Ohio River, makes it difficult to determine any trends over a limited period of time.

On a national scale, statistics for boating fatalities suggest that a trend towards improved boating safety is occurring. From 1987 through 2001, annual boating fatalities have declined by an average of 1.88% per year or a total of 28.2% over the 15 years of record. During this time, the number of registered boats has grown by a little under 30%. When fatality rates are adjusted for growth in the number of registered boats, fatalities decline by about 2.8% per year or 42.5% over the period of record. These trends are illustrated in **Figure 8-2**.

FIGURE 8-2
National Average Boating Fatalities and Adjusted for Number of Boats



Recreational boating activity and reported boating accidents on the Ohio River are highly concentrated on warm season weekends. The months of June through August account for 71.1% of all accidents, while May through September account for 89.7%. Saturday or Sunday accounts for 62% of all accidents. These figures can be compared to recreational boat lockage data recorded at Emsworth locks in 1999. June through August account for 71.9% of all recreational lockages, May through September account for 96.6% of lockages, and 73.3% of all activity occurs on Saturday or Sunday.

The boating accident reports include the primary cause of each accident and may also list other causes. The list of causal factors can be grouped under three primary categories: human behavior, boat equipment failure, and hazards in the boating environment. **Table 8-6** summarizes the primary causes of boating accidents on the Ohio River.

Human behavior is identified as the principle cause of over 60% of reported boating accidents on the Ohio River. These accidents often occur in good weather on boats in good operating condition. Equipment problems and environmental hazards each account for just fewer than 20% of all accidents. Note that overcrowded conditions (congested waters) is cited on only two occasions. The category for 'secondary causes' refers to additional contributing factors that are recorded on some accident records. These are also predominately related to human behavior and may typically refer to accidents where human mistakes compounded the initial problem of equipment failure or environmental hazards. Finally, the category for 'ambient conditions' records weather and water conditions at the time of the accident. For the Ohio River, 'rough water' often implies high water conditions. Note that accidents occurring during nighttime account for 74 of

223 reports (33%). Lockage data suggest that only about 21% of recreational boating traffic is on the river at night.

TABLE 8-6
Causes of Ohio River Boating Accidents

Principal Causes	1995	1996	1997	1998	1999	2000	2001	totals
Human Behavior								
Alcohol Consumption	4	3	6	1	8	4	2	28
Excessive Speed	3	5	7	4	5	4	0	28
Operator Inexperience	5	1	3	1	0	4	0	14
Operator Inattention	3	3	2	5	7	0	7	27
Careless/reckless operation	1	2	4	1	4	2	0	14
Rules of Road Infraction	1	0	0	0	1	0	0	2
No Proper Lookout	4	3	0	0	3	0	2	12
Over/improper Loading	2	0	0	0	0	1	0	3
Wake	0	0	0	0	2	0	2	4
Passenger/Skier Behavior	1	0	1	1	1	0	0	4
Improper Anchoring	0	0	0	0	0	1	0	1
Total Human Behavior	**24**	**17**	**23**	**13**	**31**	**16**	**13**	**137**
Total Human/223 reports								**61.4%**
Equipment								
Equipment/Mech. Failure	6	5	1	2	4	3	5	26
Ignition Fuel/vapor	0	0	1	0	2	0	0	3
Hull Failure	0	3	0	1	0	4	1	9
Total Equipment	**6**	**8**	**2**	**3**	**6**	**7**	**6**	**38**
Total Equip./223 reports								**17.0%**
Environment								
Hazardous Waters	2	3	4	2	6	4	2	23
Object in Water/submerged	1	0	0	0	1	0	2	4
Restricted Visibility	1	1	0	0	1	1	2	6
Weather	1	0	0	1	3	2	0	7
Congested Waters	0	0	0	0	1	1	0	2
Total Environment	**5**	**4**	**4**	**3**	**12**	**8**	**6**	**42**
Total Environ./223 reports								**18.8%**
Unknown Causes	0	0	1	0	2	1	2	6
Secondary Causes								
Excessive Speed	3	2	3	0	0	0	1	9
Operator Inexperience	2	3	3	4	4	2	1	19
Operator Inattention	3	8	5	2	7	4	2	31
Operator Other	4	2	1	1	6	5	6	25
Equipment Failure	2	1	1	2	0	2	2	10
Hazardous Waters	0	1	2	0	3	3	2	11
Environment Other	1	2	1	1	6	3	8	22
Ambient Conditions[1]								
Rough/Very Rough Water	2	3	5	4	10	8	5	37
Night-time	6	8	17	11	18	8	6	74
Poor Visibility	2	0	1	2	1	4	2	12

[1]Conditions at time of accident, not necessarily causal to accident.

Source: USCG, National Boating Statistics

8.7.5 Boating Accidents and Barge Traffic

Reported recreational boating accidents for the Ohio River from 1995 through 2001 included nine events out of 235 that involved a commercial vessel. Since the Coast Guard records only report accidents involving recreational vehicles, other types of accidents involving commercial vessels (running aground, striking a pier, etc.) would not be included. The nine accidents all involved recreational boats and barge/tow combinations that were underway at the time of the accident.

Three of the accidents resulted in a total of eight fatalities, including one accident that produced six deaths. The principal cause of this most spectacular disaster was listed as restricted vision due to fog and darkness. Improper loading was listed as a secondary factor; the six victims were sharing a 16 to 18 foot open motorboat. The barge/tow was not cited for contributory factors in this case.

For the total of nine accidents, alcohol use was cited as the primary cause of three events and a secondary factor in two additional events. Careless/reckless operation and operator inexperience were each cited as the primary cause of two accidents, while machinery failure and restricted vision were each identified for one accident. Operator inattention was recorded as a secondary factor in three cases and no proper lookout (attributable to the barge operator) was recorded for two cases. Six of the nine cases occurred at night. None of the cases indicated that a crowded condition on the waterway was a contributory factor.

8.7.6 Bacteria Contamination and Monitoring

To protect human health associated with contact recreation, ORSANCO monitors six urban areas (Pittsburgh, Wheeling, Huntington, Cincinnati, Louisville, and Evansville) five times per month from May – October for both fecal coliform and *E. coli*. In May 2001, ORSANCO added monitoring stations at both upstream and downstream locations at the six urban areas, increasing the total number of monitoring stations from six to nineteen. Data generated from the additional sites provide a valuable comparison between bacteria levels upstream and downstream of urban areas on the Ohio River.

From May – October, fecal coliform are not to exceed 400 Colony Forming Units (CFU) per 100 mL in more than ten percent of the samples at a given site, nor should they have a monthly geometric mean greater than 200 CFU per 100 mL. *E. coli* are not to exceed 240 CFU per 100 mL in any single sample, nor to exceed 130 CFU per 100 mL as a monthly geometric mean.

Nine water supply utilities perform analysis for fecal coliform bacteria on their raw intake water and provide these results to ORSANCO on a monthly basis. ORSANCO has adopted a criterion that specifies a maximum monthly geometric mean for fecal coliform of 2000 CFU per 100 mL to protect public drinking water supplies. These sites, added to the 19 urban sites, result in 28 monitoring points for fecal coliform.

There were no violations of the stream criterion to protect public drinking water supplies during calendar year 2001 (the latest year available). During May and June of 2001, five of the six cities recorded at least one violation of the contact recreation standards. From July – October 2001, all cities recorded at least one violation of the contact recreation standards. Additionally, stream criteria to protect human health associated with contact recreation were exceeded at 22 of the 28 sampling sites.

Records for 2001 reflect the general pattern in recent years for bacteriological exceedances in Ohio River urban areas. Exceedances occur annually in most urban areas and are generally associated with high flow conditions. Combined sewer overflows, leakage and overflow from sanitary sewer collection systems, and urban stormwater runoff are suspected as the primary sources of these biological contaminants.

8.7.7 Fish Consumption Advisories

Both federal and state agencies currently publish fish consumption advisories applicable to the Ohio River. The USEPA in 2001 issued a national mercury-based advisory that states: "If you are pregnant or could become pregnant, are nursing a baby, or if you are feeding a young child, limit consumption of freshwater fish caught by family and friends to one meal a week. For adults, one meal is six ounces of cooked fish or eight ounces of uncooked fish; for a young child, one meal is two ounces of cooked fish or three ounces of uncooked fish."

The USEPA advisory is similar to Ohio's statewide mercury advisory, issued in 1997, which advised women of child-bearing age and young children (age 6 and under) to eat no more than one meal per week of fish (any species) from any Ohio body of water or no more than the number of meals specified for the more restrictive advisories listed in the annual advisories. Although the one meal per week advice applies mainly to these sensitive populations, the current general advisory for Ohio, issued in 2003, recommends that everyone follow that advice.

All six of the states bordering the Ohio River have consumption advisories in place for certain species of fish from the river. These advisories primarily focus on the potential presence of certain contaminants and are derived from fish tissue sampling conducted by ORSANCO. This sampling program, initiated in 1976 and modified in 1987, allows appropriate state agencies to use data from the program as the basis for issuing fish consumption advisories. An advisory committee comprised of state health and environmental quality personnel is convened to discuss the data and the need for and basis of fish advisories. Fish advisories are issued, removed or modified by state agency personnel. ORSANCO also facilitates communication among the states to minimize differences in advisories issued for Ohio River fish. Current consumption advisories from USEPA and the six Ohio River states are presented in **Table 8-7**.

TABLE 8-7
Fish Consumption Advisories for the Ohio River

Authority	Fish Species	Applicable Population	Advisory	Contaminant
US EPA	All species	Women, pregnant or nursing	No more than one meal per week	Mercury
Ohio	All species	General population	No more than one meal per week	Mercury
	Freshwater drum, white bass, striped bass hybrid; walleye 17" & over.	General population	No more than one meal per month	PCBs
	Channel catfish under 17," flathead catfish	General population	No more than one meal per 2 months	PCBs, Mercury
	Channel catfish 17" and over, common carp	General population	Do not eat	PCBs
Pennsylvania	All species	General population	No more than one meal per week	Mercury
Pennsylvania, RM 0.0-31.7	Walleye, sauger, white bass, freshwater drum	General population	No more than one meal per month	PCBs
	Carp, channel catfish	General population	Do not eat	PCBs
Pennsylvania, RM 31.7-40.0 (Based on OH & WV advisories).	White bass, hybrid striped bass, freshwater drum, walleye 17" and over	General population	No more than one meal per month	PCBs
	Channel catfish under 17," flathead catfish	General population	6 meals/year	PCBs
	Channel catfish 17" and over, common carp	General population	Do not eat	PCBs
West Virginia	Smallmouth bass, largemouth bass, sauger	General population	No more than one meal per week	PCBs, Mercury, Dioxin*
	White bass, hybrid striped bass, freshwater drum	General population	No more than one meal per month	
	Channel catfish under 17," flathead catfish	General population	6 meals/year	
	Channel catfish 17" and over, common carp	General population	Do not eat	
Kentucky	All species	Special population[1]	No more than one meal per week	Mercury
	Paddlefish (and eggs)	Special population	No consumption	PCBs
		General population	6 meals/year	
	Sauger, black	Special population	One meal/month	PCBs

Authority	Fish Species	Applicable Population	Advisory	Contaminant
	basses, flathead catfish	General population	One meal/week	
	Carp, white bass, drum, hybrid striped bass	Special population	6 meals/year	PCBs
		General population	One meal/month	
	Channel catfish >21" (above Cannelton L&D)	Special population	No consumption	PCBs
		General population	6 meals/year	
	Channel catfish <21" (above Cannelton L&D)	Special population	6 meals/year	PCBs
		General population	One meal/month	
	Channel catfish, blue catfish > 14" (below Cannelton L&D)	Special population	6 meals/year	PCBs
		General population	One meal/month	
	Smallmouth buffalo (above Markland L&D)	Special population	6 meals/year	PCBs
		General population	One meal/month	
	Blue catfish <14," bigmouth buffalo (below Cannelton)	Special population	One meal/month	PCBs
		General population	One meal/week	
Indiana	Carp to 16"; channel catfish, freshwater drum, largemouth bass, Sauger/walleye/ saugeye, & spotted bass to 13," flathead catfish to 17," white/striped/hybrid bass to 9"	General population	One meal/week	PCBs
	Carp > 16," channel catfish 13"-21," flathead catfish 17"-20," drum, largemouth bass, spotted bass >13," sauger/walleye/saugeye 13"-23," smallmouth buffalo 15"-17," white/striped/hybrid bass 9"-20," paddlefish any size	General population	One meal/month	PCBs
	Channel catfish 21'-26," flathead catfish 20"-24," sauger/walleye/saugeye >23," smallmouth bass 13"-15," smallmouth buffalo >17," white/striped/hybrid bass >20"	General population	One meal/2 months	PCBs

Authority	Fish Species	Applicable Population	Advisory	Contaminant
	Channel catfish >26," flathead catfish >24," smallmouth bass >15,"	General population	Do not eat	PCBs
Illinois	Predator fish (fish eaters)	Special population[2]	One meal/week	Mercury
	Channel catfish >15," blue catfish any size, drum <14,"	General population	One meal/week	PCBs
	Drum >14," carp any size	General population	One meal/month	PCBs
	Sauger any size	General population	One meal/month	PCBs & mercury
	Largemouth bass	Special population[2]	One meal/month	PCBs
		General population	One meal/week	

[1]KY special population: women of childbearing age and children 6 years and younger.
[2]IL special population: pregnant or nursing women, women of childbearing age and children younger than 15 years of age
PCBs = Polychlorinated Biphenyls
Source: Ohio http://www.epa.state.oh.us/dsw/fishadvisory/overview.html
p://www.dep.state.pa.us/dep/deputate/watermgt/Wqp/WQStandards/FishAdvis/fishadvisory.htm
WV http://www.wvdhhr.org/fish/
KY http://water.nr.state.ky.us/dow/dwfish.htm
IN http://www.in.gov/isdh/dataandstats/fish/fish_adv_index.htm
IL http://www.idph.state.il.us/public/press03/fish.htm
US EPA http://www.epa.gov/waterscience/fish/

8.8 INTERACTIONS WITH OTHER VALUED ENVIRONMENTAL COMPONENTS (VECs)

Impacts of river-related health and safety on other resources, ecosystems, and human communities are most obviously related to the Transportation, Recreation, and Socioeconomic VECs. H&S issues are also related to Air and Water Quality and to biological resources (aquatic or riparian organisms, including Threatened and Endangered (T&E) Species). Current health and safety risk factors result from the scale of activities such as navigation or recreation and the level of success achieved by present efforts to reduce those risks. As river related activities continue to grow, additional measures will be needed to prevent any resurgence of risk factors. VEC interactions are illustrated in **Table 8-8**.

TABLE 8-8
Interactions of Health & Safety with Other VECs

VEC	Risk Factors & Impacts	Past/Present Trends	Future Trends	Comments
Transport-ation & Traffic	Source of fuel/oil spills, hazardous cargo spills, other cargo spills, boating accidents.	Reduced spills (all types due to regulatory standards and improved handling procedures. Boating accidents minimized through training & equipment upgrades.	Increases in commercial traffic contribute to additional risk factors.	Role of lock & dam projects and O&M activity to promote safe commercial use of the river.
Recreation	Boating accidents, fuel/oil spills.	Accidents/spills minimized through boater education, boat safety equipment standards, regulatory presence.	Increases in recreational traffic contribute to additional risk factors.	Role of Coast Guard, state & municipal authorities to establish & enforce safe boating standards, especially in congested use areas
Socio-Economic	Spills/discharge s from river oriented industry Also, from CSOs, urban stormwater, nonpoint sources.	Frequent exceedances of contact recreation standards (fecal coliform &/or E. coli) from CSO & urban stormwater sources. Reduced industrial spills/discharges per historic levels.	CSO, urban stormwater, nonpoint sources need further improvement to reduce discharge impacts.	Role of state EPAs to monitor & maintain stability/containment of former waste disposal sites, contaminated industrial sites, and contaminated fills in Ohio River.
Water Quality	Primary impacts are as described for Transportation and SocioEconomics .	Significant past improvements contribute to increased recreational uses & sustainability of drinking water sources and industrial and transportation uses.	Population growth & increased recreational use may offset some water quality improvements.	Role of ORSANCO to monitor water quality parameters on Ohio River mainstem and major tributaries.
Air Quality	Acid rain and ground-level ozone continue to pose health risks to local and down-wind populations.	Significant past improvements contribute to improved health, sustainability of coal utilities & other industrial activity.	Ongoing implementation of long term source reduction programs will contribute to reduced emissions and improve air quality.	More stringent ozone standards will require expanded local programs plus new programs in new areas.

VEC	Risk Factors & Impacts	Past/Present Trends	Future Trends	Comments
Biological Resources (aquatic, riparian, T&E).	Aquatic & riparian organisms are susceptible to same spectrum of impacts as described previously for people.	Significant past improvements contribute to recovering populations and sustainability of many Ohio River organisms.	Nutrients from non-point sources may be important risk factor for local and downstream impacts to biological resources.	Expansion & recovery of aquatic & riparian habitats may be more important than further pollution reductions to expanded populations, species diversity & sustainability.
Cultural Resources	Acid rain impacts affect historic structures, grave markers, etc.	Significant past improvements contribute to reduced impacts.	Continued air quality improvements should contribute to further reduction of impacts.	Less direct interaction than previous VECs.
Land Use	Health impacts of urban stormwater.	Risks from urban stormwater will increase with continued urban expansion.	Long term risks of increased travel associated with continued urban expansion.	Less direct interaction than previous VECs.

8.9 RELEVANT ACTIONS AFFECTING HEALTH, SAFETY, AND NOISE

RFFAs were evaluated utilizing the Matrix (see Exhibit A, Procedure and Methods, for discussion of the RFFA analysis methodology). The matrix evaluation process resulted in identification of 23 RFFAs with potentially high importance to future health and safety issues and 46 RFFAs with medium importance. Completion of a separate RFFA matrix for noise related issues identified 8 RFFAs with potentially high importance and 19 with medium importance. These RFFAs are presented in **Table 8-9**, which combines the results of the health and safety and noise matrices.

Following the summation of RFFA findings, H&S issues are discussed in the context of the continued operation of the Ohio River navigation system. Further discussion addresses activities that are dependent upon continued operation of the new system and other actions that are less directly related to continued operation of the system.

8.9.1 Health and Safety RFFAs

RFFAs that are likely to be of high importance to future H&S issues include: new locks or extensions, levees and floodwalls, and several key regulatory activities. RFFAs that constitute important risks to health and safety include: port development and dredging, pool maintenance, commercial navigation in general, marina development, on-water recreation, hazardous waste sites, floods, and severe storms.

TABLE 8-9
RFFA Cumulative Effects Matrix for Human Health, Safety & Noise VECs

RFFA[1]	Time Period[2]	Occurrence	Location on River[4]	Impact-H & S	Importance- H&S	Impact-Noise	Importance- Noise
Navigation Investment Actions							
Lock Extensions/New Locks/Replacement or Rehabilitation	A	H	SL	+	H	-	M
L&D operation and maintenance	A	H	SL	+	M	-	L
Non-structural navigation improvements	A	H	E	+	H	+	M
Dam replacement and rehabilitation	A	H	SL	+	M	-	M
Other Corps Actions							
Channel dredging/dredged material disposal	A	H	E	0	M	-	L
Navigation aids - Construction and O&M	A	H	E	+	M	-	L
Flood damage reduction projects							
levees/floodwalls	A	L	SL	+	H	-	L
dry dams, other projects off mainstem	A	L	SL	+	M	-	L
channel modifications	A	H	SL	+	M	-	L
nonstructural measures (e.g., relocation)	A	H	SL	+	L	+	M
Emergency streambank stabilization (Sec. 14)	A	H	SL	+	M	-	L
Modification of Corps structures for environmental improvements (Sec. 1135)	A	M	SL		L	-	L
Environmental restoration of aquatic ecosystems (Sec. 206)	A	M	SL	+	L	-	M
Recreation facilities - Construction and O&M	A	H	SL	+	M	-	M
ERP Projects - 5 categories	A	M?	SL	+	L	-	M
Port development (Sec. 107) and maintenance dredging	A	H	SL	-	H	-	M
Pool maintenance	A	H	E	-	H	-	L
"But for" Actions							
Commercial Navigation							
barge queuing	A	H	SL	-	H	-	L
fleeting areas/barge storage	A	H	SL	-	H	-	M
terminals	A	H	SL	-	H	-	M
multi-modal sites	A	H	SL	-	H	-	H
increased traffic	A	H	E	-	H	-	M
dispersed barge traffic	A	H	E	-	H	-	L
barge/tow tech/"green" design	A	H	E	+	M	?	
accidents/spills	A	H	E	-	H	-	L
Coast Guard Nav. Aids - Construction, O&M	A	H	E	+	M	-	L
Instream sand and gravel mining	A	H	SL	-	M	-	H
Floodplain sand and gravel mining	A	H	SL		L	-	H
Limestone aggregates mining	A	H	SL		L	-	H
Coal utilities	A	H	SL	-	M	-	H

RFFA[1]	Time Period[2]	Occurrence	Location on River[4]	Impact- H & S	Importance- H&S	Impact- Noise	Importance- Noise
Other coal industries	A	M/L?	SL	-	M	-	H
Hydropower on dams	A	M	SL	-	M	?	
Water intakes	A	M?	SL	0	M	-	L
Industrial users, excluding coal-related	A	H	SL	-	M	-	H
Recreation facilities - Construction and O&M	A	H	SL	+	M	-	M
Actions by Others							
Park development and operations	A	H	SL	+	L	+	L
Public forest development and operations	A	H	SL	+	L		
Floodplain development							
residential	A	H	SL	-	M	-	L
commercial	A	H	SL	-	M	-	M
industrial	A	H	SL	-	M	-	H
Crossings							
bridges	A	H	SL	-	H	-	M
utility	A	H	SL	-	M	-	L
industrial	A	H	SL	-	M	-	L
Riverbed crossings	A	H	SL	-	M	-	L
Marina development & operation	A	H	SL	-	H	-	M
Water -based recreation							
boating	A	H	E	-	H	-	L
fishing	A	H	E	-	H	?	
PWCs	A	H	E	-	H	-	L
hunting	A	H	SL	0	M	?	
wildlife watching	A	H	E		L	?	
sight-seeing	A	H	E	-	L	?	
Silviculture	A	H	R	-	L	-	L
Agriculture	A	H	R	-	M	?	
WWTP discharges							
municipal	A	H	U	-	M	?	
industrial	A	H	U	-	M	?	
onsite systems	A	H	E	-	M	?	
Stormwater discharges	A	H	U	-	M	?	
Brownfields redevelopment	A	H	U	+	M	-	L
Trail/bikeway development	A	H	E	+	L	-	L
Casinos	A	H	SL	-	L	-	M
Hazardous waste sites	A	H	SL,U	-	H	-	L
Natural Climatic Events							
floods	A	H	E	-	H		
droughts	A	H	E	-	M		
severe storms	A	H	E	-	H		
earthquakes	A	L	E	-	M	-	L
ice	A	H	E	-	M		
Regulatory Environment							
Phase I & 2 NPDES program	A	H	SL,	+	M	?	

RFFA[1]	Time Period[2]	Occurrence	Location on River[4]	Impact- H & S	Importance- H&S	Impact- Noise	Importance- Noise
			U				
TMDLs	A	H	E	+	M	?	
Site remediation	A	H	SL	+	M	-	L
More stringent quality standards for environmental media	A	H	E	+	M	+	M
Pollutant source control	A	H	E	+	M	?	
Wetland Mitigation Banking	A	H	SL	+	L	-	L
Carbon sequestration	2,3	M	E	+	M	+	L
Farmland preservation	A	H	SL, R	+	M	?	
Effluent trading	A	H	SL	+	M	?	
Agricultural discharges	A	H	SL, R	-	M	?	
Pollution Prevention	A	H	SL, U	+	L	+	M
Emissions trading	A	H	SL	+	M	?	
COE permitting programs	A	H	E	+	L	+	M
Small navigation projects	A	H	SL, U	-	M	-	L
Boating safety regulations	A	H	E	+	H	?	
ORSANCO monitoring program	A	H	E	+	H	?	
Spill response	A	H	E	+	H	?	
Information and FOIA	A	H	E	+	L	+	L
Environmental Awareness Education	A	H	E	+	M	+	L
ESA (Endangered Species Act)	A	H	SL	+	L	+	L
Environmental sustainability practices	2,3	M	E	+	M	+	L

[1] Reasonably Foreseeable Future Actions
[2] Time period in which the RFFA may occur
1 = within 10 years, 2 = in 10 - 25 years, 3 = in 25 - 60 years, A = all time periods
[3] Occurrence probability or likelihood RFFA will happen
H = high M = medium L= low
[4] Location or setting on river where RFFA is expected to occur
U = upper (Pittsburgh - Huntington), M = middle (below Huntington - Louisville)
L = lower ((below Louisville - mouth), E = along entire length of river
SL = specific location, e.g., locks and dams, U = urban setting, R = rural setting

New locks or extensions would provide increased capacity for commercial and recreational lockages and would relieve congestion associated with queuing, particularly when the main lock chambers are closed for maintenance. This would facilitate safer, more efficient movement of river traffic (see Chapter 10 - Transportation and Traffic, for a more complete discussion of congestion-related impacts). Potential accidents, injuries, and environmental impacts are important H&S risks associated with all major construction

projects. Strict enforcement of onsite safety regulations (OSHA, plus state standards) for workers and the public and proper disposal of all construction materials, effluents, and other wastes would minimize risks. River congestion/conflicts during construction could be alleviated through effective notification of navigation industry and other river users and also alleviated with helper boats near L/Ds.

Levees and floodwalls provide flood protection for adjacent communities. However, depending on levee design, they may limit emergency access to the river.

Key regulatory activities include boating safety regulations, ORSANCO monitoring, and spill response. More stringent boating regulations, better educational programs, and consistent enforcement should result in safer boating on the Ohio River. Efforts to standardize regulations and programs along the entire river (through a consortium of states or through federal leadership) would be more effective than state-by-state efforts. ORSANCO's various ongoing monitoring programs provide environmental and human health information and are now widely accessible on the ORSANCO website. Awareness of ORSANCO and its programs seems to have increased in recent years. Measures currently in place by ORSANCO, Coast Guard, USACE, USEPA, and various state agencies should continue to reduce accidental spills and their adverse effects on water quality, particularly on drinking water and edible fish. Spill detection and notification systems along the river have become increasingly sophisticated in the last 20 years.

Various activities related to commercial navigation have the potential to negatively affect recreational use, safety, and water quality. These include queuing, fleeting operations, and activities at terminals or multi-modal sites. Ongoing negative safety concerns include traffic congestion and spills during transfer of materials at these facilities. Continued growth of commercial traffic, activities such as operations outside the navigation channel, and periods of extreme high or low flows can increase these associated risks.

Spills of hazardous or toxic materials are an ongoing problem associated with commercial navigation and river-oriented industry. Areas of particular concern include vessel fueling operations (including midstream), barge loading/off-loading operations, queuing areas and river reaches with heavy debris. Short to long-term impacts are associated with exposure of spills and public drinking water intakes. Spills also may damage or contaminate shoreline areas.

Pool maintenance is also closely related to maintenance and growth of the commercial navigation system. Significant H&S issues are related to the maintenance of existing pool elevations. These include maintenance of the nine-foot minimum depth for navigation, safety of operations and prevention of spills at barge loading/off-loading operations, and maintenance of minimum depths at water intakes and discharge outfalls. Potential raising/lowering of pool levels would have health and safety impacts of very high importance to affected populations.

Port development and dredging involves potentially significant safety concerns and user conflicts, depending on levels of activity and management. These issues also would

increase with future growth of commercial traffic. Development of recreational marinas also suggests potential conflicts with commercial vessels and related safety concerns depending on carrying capacity of particular river reaches.

On-water recreation includes fishing from boats, other recreational boating, and operation of personal watercraft (PWC). Conflicts between these activities and other non-recreational river users cause safety concerns that become more critical as localized crowding increases. Season, time of day, and popularity of individual river reaches add to these risk factors. Continued growth of recreational activities will broaden applicability of these issues.

Hazardous waste sites, if not properly managed and regulated, pose continuing threats to public health and safety related to water pollution, air pollution, and quality of life.

Floods and/or severe storms can be extremely dangerous to river users because of heavy precipitation, high winds, rising water, swift currents, heavy debris, and lightning. These can increase the potential for river-related accidents, including vessel casualties, barge breakaways, and pollution incidents. Although these occurrences cannot be prevented, better forecasting, improved communications, and enhanced boater education can help prevent injuries and deaths as well as minimize environmental impacts.

RFFAs judged likely to be of medium importance to future health and safety issues include: various activities associated with maintenance of the commercial navigation system, numerous regulatory activities, development of recreational facilities, and redevelopment of brownfields. RFFAs that constitute potentially moderate importance risks to H&S include: various river-oriented industrial activities, instream sand/gravel mining, floodplain development, crossings, agriculture, waste water treatment plant discharges, stormwater discharges, and other severe climatic events.

Maintenance of the commercial navigation system includes L&D operation and maintenance (O&M), non-structural navigation improvements, lock and dam replacement/rehabilitation, channel dredging, navigation aids, flood damage reduction projects, and emergency streambank stabilization. O&M activities ease congestion, maintain a safe operating environment for commercial traffic and other river users, warn of hazards, and facilitate efficient movement of traffic. This group of activities was assigned medium importance since most effort focuses on maintenance of existing conditions.

Important or potentially important regulatory activities include NPDES programs, TMDLs, site remediation, more stringent future quality standards for environmental media, pollutant source control, carbon sequestration, farmland preservation, effluent trading, agricultural discharges, emissions trading, small navigation projects, environmental awareness education, and environmental sustainability practices. These programs may benefit or maintain water, air, or soil quality and thus contribute to a more healthful environment.

Development of recreational facilities includes riverfront parks, trailways, bikeways, playgrounds, picnic areas, etc., in addition to fishing and boating access. Positive long-term health benefits are related to such increased recreational opportunities. Brownfields redevelopment creates general long-term benefits for public health and safety, as well as for land use and socioeconomics.

Various river-oriented industrial/commercial activities include instream sand/gravel mining, coal utilities, other industries, hydropower on dams, water intakes, floodplain commercial/industrial development, agriculture, WWTP discharges, and bridge, utility, and industrial crossings. Issues related to these activities may include ongoing safety concerns related to traffic and spills during transfer of materials at these facilities, potential impacts of point source pollutants on water quality and related health conditions, and increased risk factors during severe weather or periods of extreme high or low flows. Temporary risk factors also occur during construction or major repair activity at these sites.

8.9.2 Noise RFFAs

RFFAs that are likely to be of high importance to future noise issues are associated with general industrial activities that may produce significant, ongoing, or frequent noise impacts. These include mining activities, coal utilities, other river-oriented industries, and future industrial developments. Noise impacts of potentially medium importance include construction activity at large project sites such as lock extensions, dam rehabilitation, various other Corps activities, and major construction activity conducted by others. In all cases, the potential importance of noise impacts is a function of the population, including sensitive groups, living in close proximity to the source of the noise. With respect to Corps activities, initiatives such as nonstructural navigation improvements or nonstructural flood damage reduction programs can have a moderate positive impact by reducing or eliminating some construction activity and its noise related impacts.

8.9.3 Continued Operation of the Ohio River Navigation System

This section addresses H&S impacts that may result from continued operation of L&D projects on the Ohio River. These direct actions include lock construction and maintenance, navigation system operation and maintenance, commercial navigation, recreation, and other activities. Such actions meet the “but for” criteria to the extent they are dependent on continued operation and maintenance of the navigation system. Potential impacts from each class of activities are summarized.

8.9.3.1 Construction of Auxiliary Lock Chamber Extensions

Temporary H&S impacts would occur at the lock site as a result of auxiliary lock chamber expansion projects. Temporary impacts would also occur on the Ohio River above and below the site. Following completion of auxiliary lock chamber expansions, increased capacity for commercial and recreational lockages would relieve congestion when the main chamber is closed for maintenance and would facilitate safer, more efficient movement of river traffic.

Potential impacts from construction of the lock chamber extensions include:

- Impacts to human H&S of the public from construction activities
- Noise impacts from construction activities
- The risk of spills during construction activities and increased queuing.
- Impacts to human H&S of recreational boaters and commercial navigation from increased towboat congestion.

Procedures to protect human H&S would be similar at each of the potential lock chamber extension sites. Variations would be required to meet local site conditions, address site-specific construction/demolition requirements, and comply with individual state regulatory standards. The following excerpts from the Environmental Impact Statement (EIS) for J.T.Myers and Greenup Locks Improvement illustrate these H&S procedures ($USACE_a$):

> During lock construction, several safety procedures would be in place. All existing recreation areas would be restricted from public access during the construction period. A notice of construction activity would be given to the navigation industry. Helper boats would be used to assist navigation traffic. Dive plans and blasting plans would be developed and coordinated with the lockmaster. On-site safety personnel would oversee safety procedures and enforce provisions of Environmental Manual (EM) 385-1-1 *Safety and Health Requirements Manual*, US Army Corps of Engineers. Any blasting would require approval of a blasting plan by the appropriate state agency.
>
> To help prevent harm to workers or the public from accidental spills during construction, a control and disposal plan would be in effect. The plan would include procedures for addressing the filling and disposal of hydraulic oil, manner of draining pipe, disposition of valves, pipe and related construction debris, manner of collection and storage of used or spilt oil, and the manner of collection, storage and disposal of used absorbent or absorbent pads. Records would be provided to confirm that work was performed in the approved manner.
>
> All transportation operations associated with the project would take place in accordance with the EM 385-1-1 *Safety and Health Requirements Manual*. A plan for transporting materials and equipment to the site would indicate haul routes, method of transportation, safety precautions, and method of handling and storage. Materials kept on the construction site would be stored in accordance with manufacturer instructions as well as with EM 385-1-1 *Safety and Health Requirements Manual*.
>
> The approved drilling and blasting plan would show the location and depth of holes, inclination of wedge-cut holes, amount and strength of explosives per round and per hole, sequence of firing and time delays, and estimated length of pull per blast. All work would be done in accordance with EM 385-1-1 *Safety and Health Requirements Manual* and applicable state and federal regulations. This plan would also address the required communication, coordination and monitoring efforts with

the lockmaster regarding the impacts of the blasting on navigation and day-to-day operation of the existing locks and dam.

Operations during the construction process would require periodic closures of the main and/or auxiliary chambers. Associated towboat traffic safety issues would be the same as during any emergencies or planned closures without construction. Closures would cause area towboat densities to increase, posing additional risks to tow crews and pleasure craft operators. Timing of main chamber closures and minimizing individual closure duration would minimize increased towboat densities and associated risks.

Fencing and warning signs would be used to minimize the risk of public exposure to or interference with construction activities. Signs would be provided where needed to regulate traffic, warn of hazardous conditions, establish restrictions and restricted areas, and to direct and inform the public. Disposal of all construction materials, effluents, and other wastes would be handled in accordance with EM 385-1-1 *Safety and Health Requirements Manual*. Any materials that might be burned throughout the construction process (i.e., cleared trees and shrubs) would follow applicable state procedures or permit requirements for open burning.

All diving performed under the proposed action would be in accordance with the rules and regulations prescribed by the Department of Labor's Occupational, Safety and Health Administration (OSHA), as per commercial diving operations: Part 1910 of Title 29 of the code of Federal Regulations, Subpart T; the Corps *Safety and Health Requirements Manual*, EM 385-1-1; Corps of Engineers Diving Regulations and ER 385-1-86. All diving activities would be conducted with full knowledge and close coordination with an authorized Corps representative. Divers would not enter the water or move from the prescribed location without the approval of the lockmaster and an authorized Corps representative.

A distance of approximately one mile from the site to the nearest sensitive receptors would primarily mitigate noise levels from construction activities. Maximum noise levels were calculated not to exceed 101.85 dBA at the site, according to the FHA's Highway Construction Noise Methodology (USDOT 1981). At one mile from the site, noise levels would not exceed 62 dBA, a "normally acceptable" level for sensitive receptors such as nursing homes or schools.

If sensitive receptors are significantly closer to the construction site at other locks, additional measures such as sound barriers may be required to reduce noise impacts.

8.9.3.2 Lock Maintenance, Repair, and Rehabilitation.

Ongoing commercial use of the L&D facilities will require periodic upkeep and maintenance. This will include major and minor repairs of both primary and auxiliary locks. As existing locks age, the need for such repairs will become more frequent. The frequency of repairs increases in proportion to ongoing increases in the amount of commercial traffic (and resultant use of the lock chambers) on the Ohio River. For the 60-

year study period, these repair events are expected to occur on an average of once every five years for each L&D project ($USACE_a$). Effects from major lock rehabilitation would be similar to those of repairs, but would likely occur less frequently and would be of longer duration.

Each lock repair event will produce similar but smaller scale temporary health and safety risks in the vicinity of the construction activities. Repair events would include temporary lock closures and the H&S risks associated with barge queuing. Measures to protect H&S would closely resemble those described above for lock extension activity.

Completion of auxiliary lock chamber extensions will reduce the need for some major and minor repair events and would contribute to reduced repair activities and associated H&S risks in three ways:

- It may be feasible to schedule each lock extension so as to eliminate one complete auxiliary chamber repair event.
- Each extension creates a lock in new condition, allowing for a longer time interval between auxiliary chamber repair events.
- Finally, the original full-sized lock will be used less, since total lockages can be shared equally between the two full sized locks allowing for a longer time between the main chamber repair events ($USACE_a$-1, Sept. 2000).

8.9.3.3 Nonstructural Navigation Improvements

Nonstructural navigation improvements refer to project alternatives that do not involve L&D infrastructure. These include efficiency measures such as vessel scheduling and prioritization, self-help coordination among towboat coordinators, and expanded mooring facilities near locks and dams. Some measures, such as expanded mooring facilities, may require modest, temporary health and safety risks during construction and installation. Other measures such as vessel scheduling may require improved communication and position tracking systems, but would involve no installation risks. It is expected that nonstructural navigation improvements will be implemented wherever they prove to be feasible.

Nonstructural navigation improvements offer a great opportunity to reduce risks associated with commercial traffic in the vicinity of the locks. Reduced congestion, queuing, toe-ins, and groundings would facilitate safer, more efficient movement of river traffic.

8.9.3.4 Other Direct Actions by U.S. Army Corps of Engineers

The Corps conducts a wide variety of other activities within the Ohio River study area. Activities with potentially significant H&S impacts include: major rehabilitation of the dams, channel maintenance dredging, construction of levees or floodwalls, channel modifications for flood control, nonstructural flood reduction programs such as relocation of threatened housing, emergency streambank stabilization (Sec. 14), modification of Corps projects for environmental improvement (Sec. 1135), environmental restoration of

aquatic ecosystems (Sec. 206), construction and operation of recreation facilities, ecosystem restoration projects, and port development and maintenance dredging.

The largest of these activities involves major rehabilitation of the dams (as opposed to rehabilitation of lock chambers). While the timing of rehabilitation projects is subject to numerous variables, this activity primarily corresponds to the useful life cycle of the dam. Of the 20 dams currently on the river, six have been rehabilitated in the past two decades, at an average age of 60 years following their initial construction. Assuming a life cycle of 60 years, all of the dams currently on the Ohio River may require major rehabilitation during the 60-year cycle of the study period.

H&S impacts from dam rehabilitation projects will be similar to construction site impacts described previously for lock extension projects. The activities will require similar measures to reduce risks to public health and safety.

Channel maintenance dredging involves removal and disposal of sand and gravel deposits from the navigation channel of the Ohio River to maintain a nine-foot depth. Notices to navigation, warning signs in the vicinity of active dredges, and operational plans in conformity with EM 385-1-1 *Safety and Health Requirements Manual* are routinely employed to protect public health and safety in the vicinity of dredging operations ($USACE_d$). Effective maintenance of the nine-foot navigation channel is a critical part of assuring safe operating conditions for commercial traffic on the Ohio River. Maintenance of navigation aids that are the responsibility of the Corps is also important to the provision of safe operating conditions.

8.9.3.5 Commercial Navigation

The full spectrum of commercial navigation activities constitutes a significant source of H&S impacts within the Ohio River floodplain. Barge traffic is potentially subject to accidents in the form of collisions with other watercraft, collisions with fixed objects such as bridge abutments, and spills of fuel, oil, or cargo. The scope of such risks was illustrated during January, 2005 when two accidents occurred within days of each other during high water conditions on the upper Ohio River. At Montgomery Lock and Dam, four crew members' lives were lost when strong currents pushed their tugboat and six barges of coal through the dam following an attempt to lock through upbound. At Belleville Lock and Dam, nine coal barges broke away from their tug and were swept into the dam. Four of the barges became trapped against the dam abutments, preventing closure of the dam gates and contributing to a partial dewatering of the pool until salvage workers were able to remove the barges following nearly 3 weeks of effort. Additional risks of accidental spills are associated with fleeting areas, terminals, other port related facilities, and industrial activities that utilize commercial navigation services. These facilities store, transfer, or process petroleum products, chemical stocks, and other toxic or hazardous materials.

Congestion adds to these transportation-related risks. Congestion occurs in the form of urban or commercial concentrations of port activity, barge queuing, seasonal and daily peaks of recreational boating, and the ongoing growth of barge traffic. The quantity of

materials shipped on the Ohio River grew steadily from the 1920's through the early 1990's, leveled off during the past decade, and is expected to continue to grow at a slower pace for the foreseeable future. This continued growth will require new terminals, expanded capacity at existing terminals, and expanded land based storage and transfer facilities, all of which will contribute to increased H&S risks along the Ohio River.

Continued expansion of existing facilities and establishment of new facilities can be expected to occur in response to general economic/population expansion and subsequent growth in loads carried by barge transport. Traffic projections prepared by the Corps indicate that barge traffic growth will occur independently of navigation improvements addressed by this study. The second generation of high-lift L&D projects, which was largely completed in 1980, provides sufficient capacity to meet most of the projected barge traffic growth ($USACE_a$-3). However, completion of lock extensions, nonstructural improvements and other upgrades to the navigation system can improve safety conditions by reducing congestion impacts associated with lock maintenance activities.

Barge queuing is an aspect of commercial navigation that is an important factor to several VECs (including Air, Fish, Mussels, and Water Quality)) because of the environmental impacts of such activity. Queuing occurs as a result of both lock extension and lock repair activities, which are referred to as construction delay queuing. Queuing also occurs during heavy traffic when locks are in normal operation (operational delays).

8.9.3.6 Mining Activities

Mining activities along the Ohio River contribute to general H&S risks; including navigation hazards and potential spills of equipment, fuel, or other pollutants. Instream sand and gravel mining poses the greater risk, with lesser risks from floodplain sand and gravel mining and floodplain limestone aggregates mining. Continued growth of such activities is expected to occur in proportion to ongoing population and urbanization/development growth along the Ohio River. These mining activities tend to congregate along the river in areas proximate to growing metropolitan areas or in support of major construction projects such as Olmsted dam or major highway or bridge projects.

Mining activity along the Ohio River benefits directly from the availability of barge transport. If such transport were not available, some mining activity would be replaced by mine sites in other locations. Thus, mining activity at least partially meets the 'but for' criteria. However, capacity within the existing navigation system is adequate to accommodate any anticipated growth of mining activity and no additional growth would be expected as a result of the navigation improvements addressed by this study.

8.9.3.7 Industrial Activities

A number of industrial activities congregate along the Ohio River or its major tributaries and benefit directly from the availability of barge transport and/or availability of water supplies associated with maintenance of the navigation pools. While some of these activities are conducted within major urban centers, much is dispersed through less populated areas along the length of the floodplain. These include coal-fired electric

utilities, other industries utilizing coal as a fuel and/or process material, and other industries with bulk transport needs. Continued growth of these industries is expected to occur in proportion to ongoing population and urbanization/development growth within the broader economy of the Ohio Valley region or the nation at large.

Ongoing safety concerns related to these facilities include the risk of spills during transfer of materials and traffic congestion in the vicinity of barge terminals. Some activities, such as refineries or oil storage/transfer, pose important point source spill risks.

These industrial activities account for the majority of projected growth in barge transport on the Ohio River system. In fact, coal transport alone currently accounts for more than 55% of all barge traffic on the Ohio River and is projected to account for a large percentage of traffic for the foreseeable future.

8.9.3.8 Recreational Activities

Recreational boating and related activities and the infrastructure of marinas, parks, and other support facilities compete with commercial navigation for use of the Ohio River. Other facilities supporting boating and non-boating activities include urban or rural riverfront parks, riverfront hotel/restaurant complexes, and casino boat/resort complexes.

Although boating and related recreational activity occurs throughout the river, the greatest concentrations can be found in urban riverfront settings. These areas frequently coincide with concentrations of commercial navigation in the vicinity of urban port facilities and industrial activities. The recent rate of growth of recreational activity appears to outpace population and development growth rates and is expected to continue to do so for the foreseeable future. See Chapter 9, Recreation, for additional discussion and study findings related to these issues.

While potential conflicts between recreational and commercial navigation are an important H&S concern, it is also important to recognize that recreational use of the river imposes H&S impacts independently of commercial navigation activities. Indeed, the vast majority of boating accidents involve only recreational vessels. Dockside or shoreline fueling of recreational boats also poses a significant risk of fuel and oil spills.

8.9.4 Indirect Action Sources of Impacts on River-Related Health and Safety

Indirect actions include activities which may derive some benefit from existence of the improved navigation system, but would likely have developed regardless of navigation system improvements and would be expected to persist with or without maintenance or additional improvements to navigation. These include:

1) Bridges and other crossings - New bridges across the Ohio River may occur at the rate of one or two per decade during the next 60 years. Two bridges are currently proposed for the Louisville area that may be constructed within the next twenty years (KYINbridges). Associated H&S risks include potential accidental spills or release of contaminants in sediments during construction, potential collisions between

vessels and construction structures, noise impacts, and general public safety risks in the vicinity of construction sites. Public communications, fencing, warning signs, construction plans, and accident or spill contingency plans similar to those discussed previously for lock extension construction would be required for this type of project.

2) Brownfields redevelopment - The availability of funding support for redevelopment of brownfields and other former contaminated sites is contributing to reutilization of some of these formerly abandoned sites. Limited availability of undeveloped land within some areas of the floodplain further reinforces reuse of formerly developed sites. These abandoned or underutilized sites represent an important portion of historic urban/commercial development patterns and are an important component of many redevelopment programs. Successful redevelopment of such sites should include removal or stabilization of buried contaminants and thus contribute to reduced public health risks.

3) Transportation - Highways and railroads constitute a significant land use pattern throughout the Ohio River floodplain. In some portions of the upper river, roads and track are in place along both banks. Just as industrial growth is expected to occur in proportion to ongoing population and urbanization/development, expansion of transportation capacity can be expected to grow proportionally.

4) Natural climatic events - Original settlement patterns along the Ohio River were directly influenced by flood patterns and indirectly influenced by periodic events such as severe storms or drought. Completion of the L&D navigation system, in conjunction with levees and floodwalls on the main stem and flood control reservoirs throughout the watershed, has significantly reduced the impact of flooding events. Additionally, the 100 and 500-year floodplains are fairly well defined along the main stem. Current and potential future improvements in environmental monitoring and communications technologies should continue to contribute to reduced H&S risks associated with flood events, and

5) The regulatory environment - Several regulatory programs are critically important to H&S issues on the Ohio River. These include the spill prevention and response requirements of Section 301 of CWA, boating safety regulations administered by states and the Coast Guard, and system-wide monitoring activities of ORSANCO. Regulatory programs of secondary importance include CWA amendments addressing storm water, non-point sources, and TMDL standards; site remediation standards under RCRA, CERCLA, and SARA; and future emission standards under CAA, CWA, and other regulations.

8.10 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve environmental sustainability (ES). ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the

quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of CE can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An Analysis of Environmental Sustainability (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps: (1) identification of "common effects" on health and safety parameters from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix; (2) selection of indicators for ES for health and safety, and their grouping, as appropriate; and (3) consideration of the "connections" between the common effects and the indicator groups. The output of the AES consists of a qualitative (descriptive) discussion of the "connections," with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for health and safety, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – the composite conditions for the selected indicators of ES for H&S do not reflect conditions that would facilitate attainment of acceptable standards or would not maintain existing standards in concert with rising risk factors associated with increasing activity.

- Marginally sustainable – the composite conditions for the selected indicators of ES for H&S are such that the attainment of acceptable standards is accomplished for the majority, but not all, of the river miles in the Ohio River: however, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of H&S for the Ohio River).

- Sustainable – the composite conditions for the selected indicators of ES for H&S are such that the attainment of acceptable standards is accomplished for essentially all of the river miles in the Ohio River, and such standards are maintained in concert with rising risk factors associated with increasing activity. Further, the conditions of the indicators exceed regulatory thresholds and various governmental programs are in place to control point and nonpoint pollution sources, to emphasize pollution reduction in the river, to prevent and/or respond to spill events, and to regulate risk factors associated with boating activity on the river.

Common effects of multiple actions have been previously discussed in the sections entitled "Interactions with Other VECs" and "Relevant Actions Affecting Health, Safety and Noise." These common effects result in groups of actions (risk factors) affecting worker health and safety, boating safety, and public health concerns related to water quality (drinking water, contact recreation, and fish consumption).

Indicators or groups of indicators of ES were identified earlier in the section entitled "Indicators of Environmental Sustainability," and relevant information on them have been presented in the section entitled "Past to Current Baseline Conditions." Regarding their relevance for ES, the following rationale is appropriate:

- measures of key water quality parameters

  - fecal coliform – related to fecal matter contamination from humans or other animals, whether from point or nonpoint sources at specific locations along the river; can also be used as a threshold indicator since the standard is 2000 fecal coliforms/100 ml for drinking water and 400/100 ml for contact recreation.
  - *E. coli* – related to fecal matter contamination from humans or other animals, whether from point or nonpoint sources at specific locations along the river; can also be used as a threshold indicator since the standard is 240/100 ml for contact recreation.

- measures of fish tissue contamination and resultant fish consumption advisories – guidelines for fish consumption are based on risk factors applied to the general population and to more sensitive subpopulations such as young children. They reflect relative progress in long-term efforts to remove pollutants or prevent their introduction to aquatic systems.

- level of conformance with state and federal water quality standards, including attainment of permissible use designations – water quality standards are based on various use designations, with the level of conformance representing a composite indicator of a sustainable aquatic resource for human use including contact recreation

- level of conformance with state and federal air quality standards (Chapter 7 - Air Quality) – these standards include ambient air quality standards, point source controls, industry or group source emission caps, and equipment performance standards

- boating accident statistics can indicate relative risk factors of boating at various locations on the river – trends in accident statistics reflect effectiveness of educational and regulatory efforts to promote and enforce safer boating practices

- effectiveness of spill response, monitoring programs, and related precautionary measures – these represent both direct and indirect programs which are focused on more effective management of health and safety impacts through prevention or minimization

- level of conformance with state and federal worker health and safety standards, including noise management at construction sites, accident prevention, use of protective equipment, and monitoring and enforcement actions

- effectiveness of oversight of permitted activities such as RCRA hazardous waste generators and monitoring of recovery processes at inventoried sites – these represent ongoing programs to minimize discharges from production of hazardous materials or wastes and efforts to clean up previously contaminated sites contributing to reduced risk factors associated with these sites and activities.

For the purposes of this analysis, the above indicators are grouped into three tiers for the AES. The three tiers are as follows:

- first tier – "scientific measures of quality or risk factors"

  (1) water quality parameters (fecal coliform and *E. coli* bacteria, and fish tissue analysis for specified contaminants)

  (2) conformance with air, water quality, and other regulatory standards

- second tier – "positive actions related to minimization of risk factors"

  (1) point source control and nonpoint source control programs

  (2) boating safety programs, education, and enforcement

  (3) spill response, monitoring programs, and related precautionary measures

- third tier – "composite indicators of health and safety sustainability;" this includes measures developed from multiple indicators

  (1) attainment of permissible use designations

  (2) sustain acceptable standards for public health risks

Finally, the indicators and tiers are displayed into three tables, with each coinciding with the three groups of actions with common effects. **Tables 8-10 through 8-12** are on the following pages.

Table 8-10 relates to RFFAs affecting worker/workplace H&S, plus populations affected by construction or other workplace activities. Measures to protect the safety of workers and others affected by these actions are well documented and are discussed in some detail in the section titled "Relevant Actions Affecting Health, Safety, and Noise." These measures have contributed to significant improvements compared to past levels of risk. Further, spill-related programs and precautionary measures are expected to reduce accidental releases from construction sites and other workplace activities. As a result of these current and anticipated future efforts, it is expected that acceptable standards for public health risks will continue to be consistently attained.

Table 8-11 relates to RFFAs associated with commercial and recreational traffic on the Ohio River. Federal and state efforts have focused on: (1) higher standards for boating

safety equipment, (2) improved education for both commercial and recreational boaters, (3) establishment and enforcement of prohibitions of alcohol consumption by boaters, and (4) improved operational rules such as no wake zones in crowded areas. Further improvements to lock and dam infrastructure, navigation aids, as well as other components of the river navigation system can be expected to contribute to improved safety conditions for all boaters. Additionally, comprehensive efforts to minimize transportation-related spills and respond effectively to spills that do occur have significantly reduced H&S impacts of these sources. Continued improvements through broader education requirements, equipment/technology/communication improvements, and implementation of higher standards should achieve sustainability, even with anticipated future increases in commercial and recreational boating traffic.

Three public health concerns that are affected by water quality issues are illustrated in **Table 8-12**. These include drinking water supplies, contact recreation, and fish consumption. Water quality issues are discussed in detail in Chapter 3, Water Quality and Sediment Quality, and much of that discussion regarding the benefits of improving water quality is applicable to these public health issues. The discussions clearly demonstrate the fundamental improvements in water quality from the unsustainable conditions of the recent past.

With respect to present day conditions, availability of threshold water quality parameters for drinking water and contact recreation along with consumption advisories for fish adds further detail specific to human health impact concerns. Water quality monitoring records indicate that coliform levels rarely exceed safety thresholds for drinking water supplies, while these same monitoring efforts further protect drinking water sources by facilitating timely closure of intakes whenever contamination is detected. However, coliform and *E. coli* levels in urban areas frequently exceed threshold levels for contact recreation. Sources associated with these contaminants, such as combined sewer overflows (CSO), sanitary sewer overflows (SSO), and urban stormwater are proving to be difficult and expensive to clean up. While the levels of some fish tissue contaminants such as PCBs and chlordane are continuing to decline in samples from the Ohio River, levels of mercury appear to be more persistent even as risk factors associated with consumption of mercury tainted fish are being elevated. Conflicting fish consumption advisories between some of the states bordering the Ohio River adds an additional layer of doubt to the public consumer. These trends suggest that the safety of drinking water supplies is sustainable, but that contact recreation and fish consumption should be considered only marginally sustainable at the present time.

With respect to future trends for contact recreation and fish consumption, current regulatory programs appear not to be making as much progress as they should. Phase I and II NPDES programs for stormwater runoff have been implemented. Clear demonstrations of runoff water quality improvements are difficult to substantiate. Problems associated with CSOs and SSOs stem from older wastewater collection systems that are often in severely degraded condition. High costs associated with upgrading or modernizing these systems contribute to the lack of progress. Efforts to implement more effective regulatory standards such as TMDLs for aquatic resources or air emission standards for mercury may be years or decades from demonstrated effectiveness. Given the uncertainties of future

TABLE 8-10 AES Tiers for Risk Factors Affecting Workplace Health and Safety			
Actions Affecting Workplace Health and Safety	Scientific Measures of Quality	Positive Actions Related to Source Control	Composite Indicators of Aquatic Ecosystem Sustainability
• Lock extensions/new locks/ replacement or rehabilitation (H) • Dam replacement and rehabilitation (H) • Channel dredging (M) • Flood damage reduction projects (all types, M) • Commercial navigation (all categories, M/H) • Mining activities (H) • General industrial activities (M/H) • Other construction/industrial maintenance (M)	• Water Quality Parameters • Conformance with Air and Water Quality Standards	• Point source control and nonpoint source control programs • Boating safety programs, education and enforcement • Spill Response, Monitoring, and Precautionary Measures	• Attainment of Permissible Use Designations • Sustain acceptable standards for public health risks

TABLE 8-11 AES Tiers for Risk Factors Affecting Commercial and Recreational Boating Safety			
Actions Affecting Boating Safety	Scientific Measures of Quality	Positive Actions Related to Source Control	Composite Indicators of Aquatic Ecosystem Sustainability
• Navigation investment actions (all types – improved safety, M) • Navigation maintenance: dredging, buoys & markers, M) • Commercial navigation (all categories, M/H) • Instream mining, (M) • Marina development & operations (h) • Water-based recreation (all types, H) • Floods, severe storms (H) • Boating safety regulations (H) • Spill prevention/response (H)	• Water Quality Parameters • Conformance with Air and Water Quality Standards	• Point source control and nonpoint source control programs • Boating safety programs, education and enforcement • Spill Response, Monitoring, and Precautionary Measures	• Attainment of Permissible Use Designations • Sustain acceptable standards for public health risks

TABLE 8-12 AES Tiers for Water Quality Factors Affecting Public Health – Drinking Water, Contact Recreation, Fish Consumption			
Actions Affecting Public Health	Scientific Measures of Quality	Positive Actions Related to Source Control	Composite Indicators of Aquatic Ecosystem Sustainability
• Urban Stormwater, CSOs, SSOs (H) • Accidents/spills (H). • Hazardous waste sites (H). • Dredging/instream mining (H). • WWTP discharges (M). • Agricultural runoff (M). • Phase I & II NPDES (H). • TMDL standards (H). • Water quality monitoring (H).	• Water Quality Parameters • Conformance with Air and Water Quality Standards	• Point source control and nonpoint source control programs • Boating safety programs, education and enforcement • Spill Response, Monitoring, and Precautionary Measures	• Attainment of Permissible Use Designations • Sustain acceptable standards for public health risks

progress in these areas, contact recreation and fish consumption should be considered marginally sustainable for the foreseeable future.

8.11 CONCLUSIONS

In the time period prior to 1920 and continuing into the 1960-70s, H&S issues on the Ohio River represented a broad spectrum of risk factors. Construction and workplace conditions were generally more dangerous than at present; spills and discharges from commercial navigation, river oriented industries, and untreated municipal effluents contributed to a variety of public health risks; and little or no information was available to advise the public of ambient risk levels associated with river oriented activity.

While individual risk factors no doubt varied significantly from time to time, most H&S related issues for the period are categorized in **Figure 8-3** as 'marginally sustainable.' However, activities that involved more direct exposure to water quality risk factors are categorized as 'not sustainable' in **Figure 8-4**.

Improvements to water quality, reduced risks of spills and faster response, improved workplace safety standards, and effective safety standards for recreational boating have all combined to make the Ohio River a safer place to work, live, and play. These improved present day conditions result in a 'sustainable' classification in **Figure 8-3**. Improved conditions have also contributed to reduce risk factors associated with contact recreation and fish consumption. However, problems associated with continued exceedances of biological standards, persistence of some contaminants associated with fish consumption, and mixed signals regarding fish consumption standards result in a present time classification of 'marginally sustainable' for these activities.

With respect to the future, most H&S issues are expected to remain in the 'sustainable' rankings. It is important to note, however, that continued growth of commercial navigation, recreational activity, river oriented industries, and other uses of the river will require continued improvements in management and regulation of H&S issues just to maintain the status quo.

While improvement of risk factors associated with contact recreation and fish consumption is expected to continue, these factors are kept in the 'marginally sustainable' category as a conservative estimate of potential trends. Some of the efforts required to achieve continued improvement, such as rehabilitation of sanitary sewer systems to eliminate CSO and SSO, or reduction of mercury emissions from coal combustion will require significant investments and long periods of time to achieve results.

FIGURE 8-3.
Health & Safety for Workplace and Boating Activities

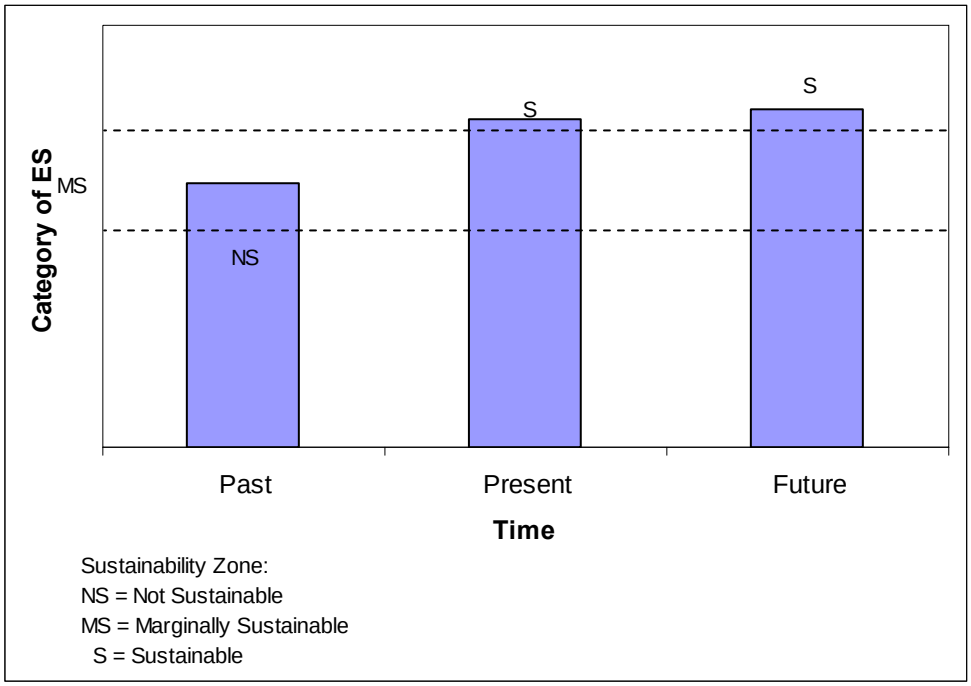
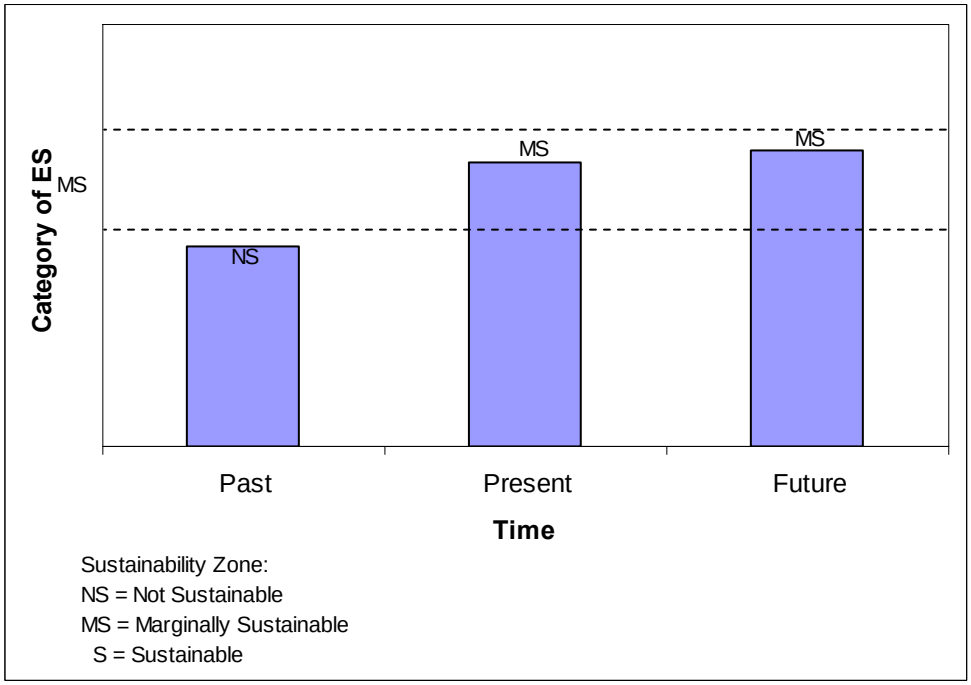


FIGURE 8-4
Health & Safety for Contact Recreation and Fish Consumption



8.12 REFERENCES

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Council on Environmental Quality. 1997. "Considering Cumulative Effects under the National Environmental Policy Act." Executive Office of the President, Washington, D.C.

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USArmy Corps of Engineers[a], J.T. Myers and Greenup Locks Improvements, Ohio River Mainstem Systems Study (ORMSS):
Interim Feasibility Report, US Army Corps of Engineers, April, 2000

1) Document MR Main Report & EIS
2) Document EC Economics Appendix
3) Document EC Attachment 3 – ORS Traffic Demand Forecast
4) Document ED-2 Greenup L&D Engineering Site Appendix

_____[b], Ohio River Ecosystem Restoration Program Final Integrated Decision Document and Environmental Assessment, Oct. 2000.

_____[c], Ohio River Main Stem Context Study, Pittsburgh District, US Army Corps of Engineers, Sept. 2001.

_____[d], Safety and Health Requirements Manual, EM 385-1-1, US Army Corps of Engineers.

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U.S. Department of Housing and Urban Development. 1985. The Noise Guidebook. Washington, D.C.

U. S. Department of Transportation. 1981. Federal Highway Administration's Highway Construction Noise Methodology.

Additional sources of information include databases searched by Fidelity National Information Solutions (formerly VISTAinfo) in Fall 2001:

NPL
The agency release date for National Priorities List was July, 2001.

The NPL Report is the US EPA's registry of the nation's worst uncontrolled or abandoned hazardous waste sites. NPL sites are targeted for possible long-term remedial action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980.

SPL
The agency release date for Category List was June, 1997.
This database is provided by the Illinois Environmental Protection Agency. The agency may be contacted at: 217-782-6762.

SPL
The agency release date for Hazardous Waste Response Sites was May, 2001.
This database is provided by the Department of Environmental Management, Office of Environmental Response. The agency may be contacted at: 317-308-3052.

SPL
The agency release date for Annual Report of Hazardous Waste Disposal Sites was May,
2001.
This database is provided by the Department of Natural Resources, Superfund Section. The agency may be contacted at: 573-751-3176.

SPL
The agency release date for Hazardous Sites Cleanup Program Site List was July, 2001.
This database is provided by the Department of Environmental Protection, Bureau of Waste Management. The agency may be contacted at: 717-783-7816.

CERCLIS
The agency release date for Comprehensive Environmental Response, Compensation and Liability Information Sys was July, 2001.
The CERCLIS database is a comprehensive listing of known or suspected uncontrolled or abandoned hazardous waste sites. These sites have either been investigated, or are currently under investigation by the U.S. EPA for the release, or threatened release of hazardous substances. Once a site is placed in CERCLIS, it may be subjected to several levels of review and evaluation, and ultimately placed on the National Priorities List (NPL).

NFRAP
The agency release date for No Further Remedial Action Planned was July, 2001.
The No Further Remedial Action Planned Report (NFRAP), also known as the CERCLIS Archive, contains information pertaining to sites which have been removed from the U.S. EPA's CERCLIS database. NFRAP sites may be sites where, following an initial investigation, either no contamination was found, contamination was removed quickly without need for the site to be placed on the NPL, or the contamination was not serious enough to require federal Superfund action or NPL consideration.

SCL
The agency release date for Site Remediation Program List was August, 2001.
This database is provided by the Illinois Environmental Protection Agency, Remedial Project Management Division. The agency may be contacted at: 217-782-0462.

SCL
The agency release date for Voluntary Cleanup List was June, 2001.
This database is provided by the Department of Environmental Management. The agency may be contacted at: 317-308-3023.

SCL
The agency release date for State Cleanup List was January, 1999.
This database is provided by the Department of Environmental Management. The agency may be contacted at: 317-308-3023.

SCL
The agency release date for State Leads List was October, 2000.
This database is provided by the Department of Environmental Protection. The agency may be contacted at: 502-564-6716. The Kentucky State Leads List is an inventory of potential hazardous substance and waste disposal sites located within the state. In addition, Kentucky uses the U.S. EPA CERCLIS database as an additional source of known or potentially contaminated sites in the State, and for the purpose of tracking sites to be investigated under the Preliminary Assessment/Site Investigation program for potential Superfund listing.

SCL
The agency release date for Master Sites List was March, 1999.
This historical database is provided by the Ohio Environmental Protection Agency. The agency may be contacted at: 614-644-2924.

SCL
The agency release date for Land Recycling Program was July, 2001.
This database is provided by the Department of Environmental Protection, Bureau of Waste Management. The agency may be contacted at: 717-783-7816.

CORRACTS
The agency release date for RCRIS Corrective Action Sites was June, 2000.
The CORRACTS database contains information concerning RCRA facilities that have conducted, or are currently conducting a corrective action. A Corrective Action Order is issued pursuant to RCRA Section 3008 (h) when there has been a release of hazardous waste or constituents into the environment from a RCRA facility. Corrective actions may also be imposed as a requirement of receiving and maintaining a TSDF permit.

ERNS
The agency release date for Emergency Response Notification System was December, 2000.
ERNS is a national computer database system that is used to store information on the sudden and/or accidental release of hazardous substances, including petroleum, into the environment. The ERNS reporting system contains preliminary information on specific releases, including the spill location, the substance released, and the responsible party.

RCRIS-TSD
The agency release date for RCRIS Treatment, Storage and Disposal Facilities was June,
2000.
The EPA's Resource Conservation and Recovery Act (RCRA) Program identifies and tracks hazardous waste from the point of generation to the point of disposal. The RCRA Facilities database is a compilation by the EPA of facilities which report generation, storage, transportation, treatment or disposal of hazardous waste. RCRA TSDs are facilities which treat, store and/or dispose of hazardous waste.

RCRIS-TSDC
The agency release date for RCRIS TSDs Subject to Corrective Action was June, 2000.
The EPA's Resource Conservation and Recovery Act (RCRA) Program identifies and tracks hazardous waste from the point of generation to the point of disposal. The RCRA Facilities database is a compilation by the EPA of facilities which report generation, storage, transportation, treatment or disposal of hazardous waste. RCRA TSDCs are treatment, storage and/or disposal facilities that are subject to corrective action under RCRA.

RCRA-LQG
The agency release date for RCRIS Large Quantity Generators was June, 2000.
The EPA's Resource Conservation and Recovery Act (RCRA) Program identifies and tracks hazardous waste from the point of generation to the point of disposal. The RCRA Facilities database is a compilation by the EPA of facilities which report generation, storage, transportation, treatment or disposal of hazardous waste. RCRA Large Generators are facilities which generate at least 1000 kg./month of non-acutely hazardous waste (or 1 kg./month of acutely hazardous waste).

RCRIS-SQG
The agency release date for RCRIS Small Quantity Generators was June, 2000.
The EPA's Resource Conservation and Recovery Act (RCRA) Program identifies and tracks hazardous waste from the point of generation to the point of disposal. The RCRA Facilities database is a compilation by the EPA of facilities which report generation, storage, transportation, treatment or disposal of hazardous waste. RCRA Small Quantity Generators are facilities which generate less than 1000 kg./month of non-acutely hazardous waste.

SWLF
The agency release date for USGS Solid Waste Landfills was December, 1991.
This database is provided by the United States Geological Survey. The agency may be contacted at: 703-648-5613.

SWLF
The agency release date for Special Waste Site List was January, 1990.
This database is provided by the Illinois Environmental Protection Agency. The agency may be contacted at: 217-524-3306.

SWLF
The agency release date for Active Permitted Municipal Waste Transfer Stations was September, 1996.
This database is provided by the Illinois Environmental Protection Agency. The agency may be contacted at: 217-524-3865.

SWLF
The agency release date for Land-Based Disposal Sites was July, 1998.
The Landfill Sites of Illinois (Land Based Disposal Sites) database was assembled from several sources including the U.S. EPA, the Illinois Environmental Protection Agency and studies sponsored by WMRC. The GIS coverage includes data for over 3000 waste sites of various types.

SWLF
The agency release date for Storage, Treatment, Recyclers, Incinerators Processors was
October, 1998.
This database is provided by the Illinois Environmental Protection Agency. The agency may be contacted at: 217-524-3306.

SWLF
The agency release date for Solid Waste Landfill Subject to State Surcharge was January,
2000.
This database is provided by the Illinois Environmental Protection Agency. The agency may be contacted at: 217-782-6761.

SWLF
The agency release date for Special Waste Disposal Sites was September, 2000.
This database is provided by the Department of Environmental Management, Office of Solid and Hazardous Waste Mgmt. The agency may be contacted at: 317-232-0066.

SWLF
The agency release date for Permitted Solid Waste Facilities was March, 2001.
This database is provided by the Department of Environmental Management. The

agency may be contacted at: 317-232-0066.

SWLF

The agency release date for Inactive Solid Waste Landfills was January, 1999.

This database is provided by the Department of Environmental Management. The agency may be contacted at: 317-232-0066.

SWLF

The agency release date for Active Solid Waste Disposal Facilities was September, 1999.

This database is provided by the Natural Resources Environmental Protection Division of Waste Management. The agency may be contacted at: 502-564-6716.

SWLF

The agency release date for All Sites List was October, 2000.

This database is provided by the Natural Resources Environmental Protection Division of Waste Management. The agency may be contacted at: 502-564-6716.

SWLF

The agency release date for Inactive Solid Waste Facilities List was July, 1995.

This database is provided by the Department of Natural Resources, Waste Management Program.

SWLF

The agency release date for Certified Hazardous Waste Resource Recovery Facilities was June, 2001.

This database is provided by the Department of Natural Resources. The agency may be contacted at: 573-751-5401.

SWLF

The agency release date for Permitted Solid Waste Facilities was May, 2001.

This database is provided by the Department of Natural Resources, Waste Management Program. The agency may be contacted at: 573-751-5401.

SWLF

The agency release date for Closed Solid Waste Landfills was March, 1995.

This database is provided by the Ohio Environmental Protection Agency (One time only list).

SWLF

The agency release date for Licensed Solid Waste Facilities was May, 2001.

This database is provided by the Ohio Environmental Protection Agency, Division of Solid Infectious Waste. The agency may be contacted at: 614-728-5326.

SWLF
The agency release date for Delisted and Closed Landfills was May, 2001.
This database is provided by the Ohio Environmental Protection Agency, Division of Solid Infectious Waste.

SWLF
The agency release date for Solid Waste Transfer Stations was August, 1991.
This database is provided by the Department of Environmental Protection, Bureau of Waste Management. The agency may be contacted at: 717-783-7816.

SWLF
The agency release date for Inactive Solid Waste Facilities was July, 1994.
This database is provided by the Department of Environmental Protection, Bureau of Waste Management. The agency may be contacted at: 717-787-7381.

SWLF
The agency release date for Solid Waste Inventory was August, 1998.
This database is provided by the Department of Environmental Protection, Bureau of Waste Management. The agency may be contacted at: 717-787-7381.

SWLF
The agency release date for Priority Waste Tire Piles List was July, 2001.
This database is provided by the Department of Environmental Protection, Bureau of Waste Management. The agency may be contacted at: 717-787-7381.

SWLF
The agency release date for Certificate of Approval for Disposal was June, 1992.
This database is provided by the Division of Natural Resources, Waste Management Section.

SWLF
The agency release date for Class D1 Processing Facilities was May, 1998.
This database is provided by the Division of Natural Resources, Waste Management Section. The agency may be contacted at: 304-558-6350.

SWLF
The agency release date for Industrial Landfills was September, 1998.
This database is provided by the Division of Natural Resources, Environmental Protection. The agency may be contacted at: 304-759-0515.

SWLF
The agency release date for Municipal Solid Waste Landfills was February, 1999.
This database is provided by the Division of Natural Resources, Solid Waste Management Office. The agency may be contacted at: 304-558-6350.

SWLF
The agency release date for Transfer Stations was June, 2001.
This database is provided by the Division of Natural Resources, Waste Management Section. The agency may be contacted at: 304-558-6350.

SWLF-REG
The agency release date for Solid Waste Landfills was March, 1988.
This database is provided by the Northeastern Illinois Planning Commission. The agency may be contacted at: 312-454-0401.

SPILLS
The agency release date for Spills was May, 2001.
This database is provided by the Department of Environmental Management. The agency may be contacted at: 317-308-3023.

SPILLS
The agency release date for Spills was April, 1999.
This database is provided by the Ohio Environmental Protection Agency. The agency may be contacted at: 614-644-2084.

LUST
The agency release date for Leaking Underground Storage Tanks was August, 2001.
This database is provided by the Illinois Environmental Protection Agency, Division of Land Pollution Control. The agency may be contacted at: 217-782-6762.

LUST
The agency release date for Leaking Underground Storage Tanks was May, 2001.
This database is provided by the Department of Environmental Management. The agency may be contacted at: 317-308-3023.

LUST
The agency release date for Leaking Underground Storage Tanks - Active and Inactive was April, 2001.
This database is provided by the Department of Natural Resources, LUST Program. The agency may be contacted at: 573-751-6822.

LUST
The agency release date for Leaking Underground Storage Tanks was June, 2001.
This database is provided by the Department of Commerce, Division of State Fire Marshall. The agency may be contacted at: 614-752-7926.

LUST
The agency release date for List of Confirmed Releases was May, 2001.
This database is provided by the Department of Environmental Regulation. The agency may be contacted at: 717-772-5599.

LUST
The agency release date for Leaking Underground Storage Tanks - Active and Inactive was May, 2001.
This database is provided by the Division of Natural Resources, Division of Waste Management. The agency may be contacted at: 304-759-0515.

UST
The agency release date for Underground Storage Tanks was February, 2001.
This database is provided by the Office of the Illinois Fire Marshall. The agency may be contacted at: 217-528-8936. Be advised that some states do not require registration of heating oil tanks, especially those used for residential purposes.

UST
The agency release date for Underground Storage Tanks was May, 2001.
This database is provided by the Department of Environmental Management, UST Section. The agency may be contacted at: 317-308-3023. Be advised that some states do not require registration of heating oil tanks, especially those used for residential purposes.

UST
The agency release date for Underground Storage Tanks was January, 2001.
This database is provided by the Department of Environmental Protection, Division of Waste Management-UST Section. The agency may be contacted at: 502-564-5174. Be advised that some states do not require registration of heating oil tanks, especially those used for residential purposes.

UST
The agency release date for Underground Storage Tanks was April, 2001.
This database is provided by the Department of Natural Resources. The agency may be contacted at: 573-751-6822. Be advised that some states do not require registration of heating oil tanks, especially those used for residential purposes.

UST
The agency release date for Underground Storage Tanks was June, 2001.
This database is provided by the Department of Commerce, Division of State Fire Marshall. The agency may be contacted at: 614-752-7926. Be advised that some states do not require registration of heating oil tanks, especially those used for residential purposes.

UST
The agency release date for Underground and Aboveground Storage Tanks was June, 2001.
This database is provided by the Department of Environmental Protection, Bureau of Water Quality Mgmt. The agency may be contacted at: 717-772-5599. Be advised that some states do not require registration of heating oil tanks, especially those used for

residential purposes.

UST

The agency release date for Underground Storage Tanks - Active and Inactive was June,
2001.

This database is provided by the Division of Natural Resources, Division of Waste Management. The agency may be contacted at: 304-759-0515. Be advised that some states do not require registration of heating oil tanks, especially those used for residential purposes.

AST

The agency release date for Aboveground and Underground Storage Tanks was July, 1999.

This database is provided by the Department of Environmental Protection, Bureau of Water Quality Mgmt. The agency may be contacted at: 717-772-5599.

AST

The agency release date for Aboveground Storage Tanks was June, 2001.

This database is provided by the Department of Environmental Protection, Bureau of Water Quality Mgmt. The agency may be contacted at: 717-772-5599.

AST

The agency release date for Aboveground Storage Tanks was April, 2001.

This database is provided by the Department of Natural Resources. The agency may be contacted at: 573-751-6822.

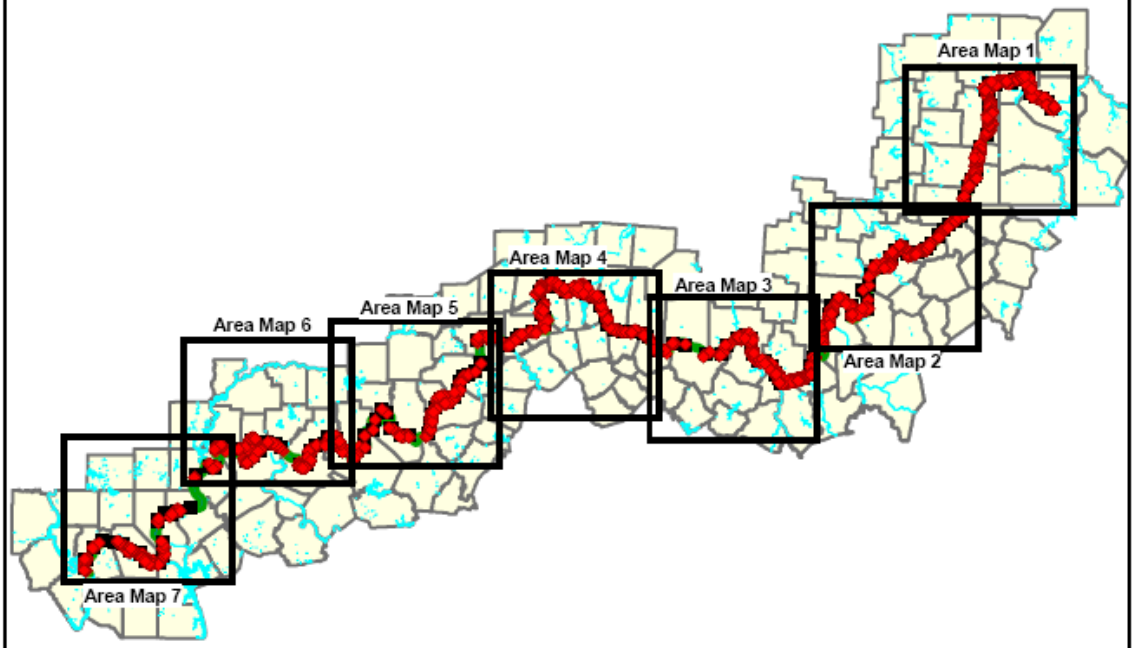
SUPPLEMENT 8-A

EXAMPLE MAPS AND RECORDS FROM

SITE DATABASE SEARCH

SITE ASSESSMENT - SPECIAL PROJECT (ALL DATABASES SEARCHED TO 1 MILE)

Overview Map



Subject Centerline

Search Area

Risk Sites

Risk Sites Plotted as Polygons

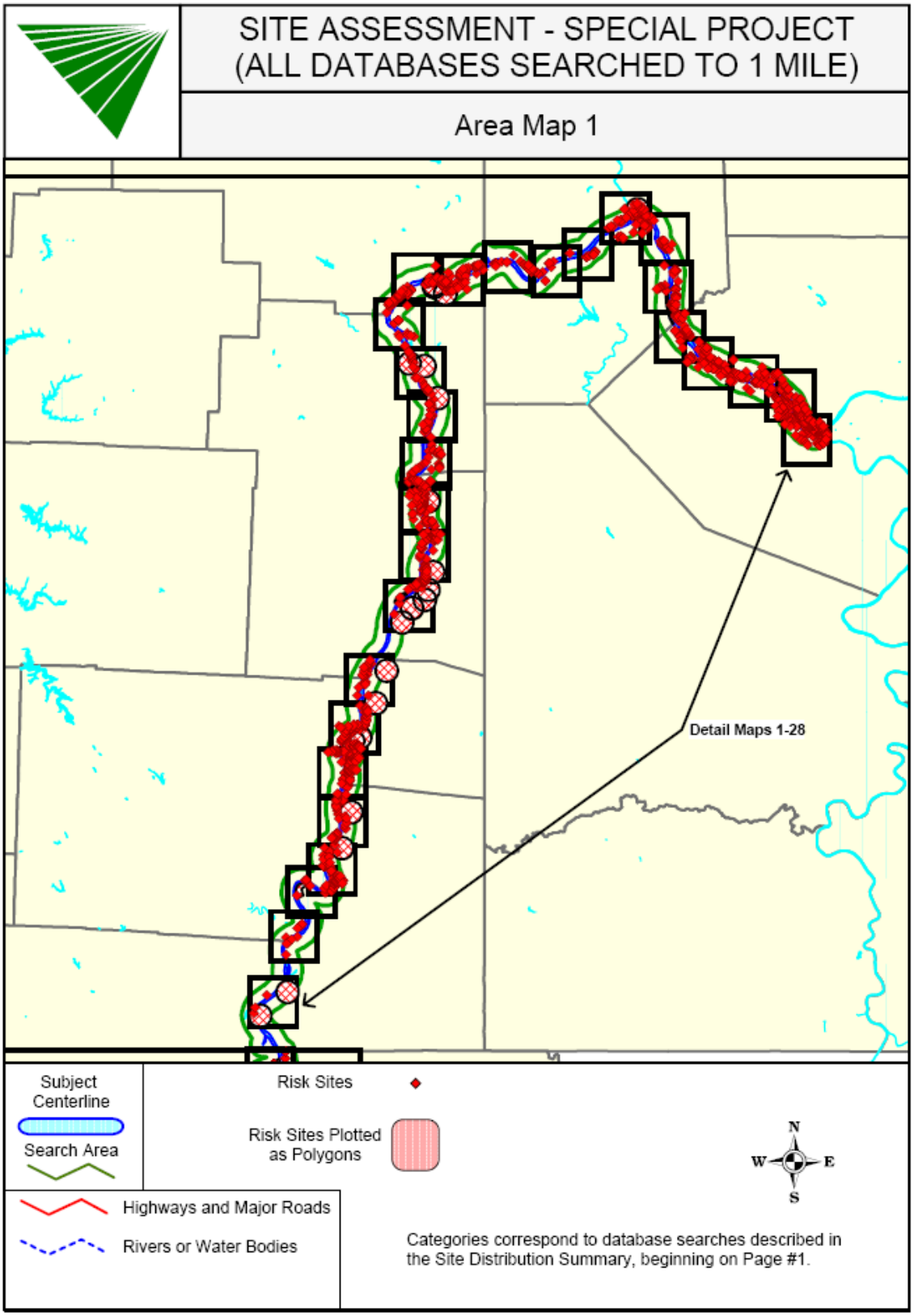
N
W
E
S

Highways and Major Roads

Rivers or Water Bodies

Categories correspond to database searches described in the Site Distribution Summary, beginning on Page #1.

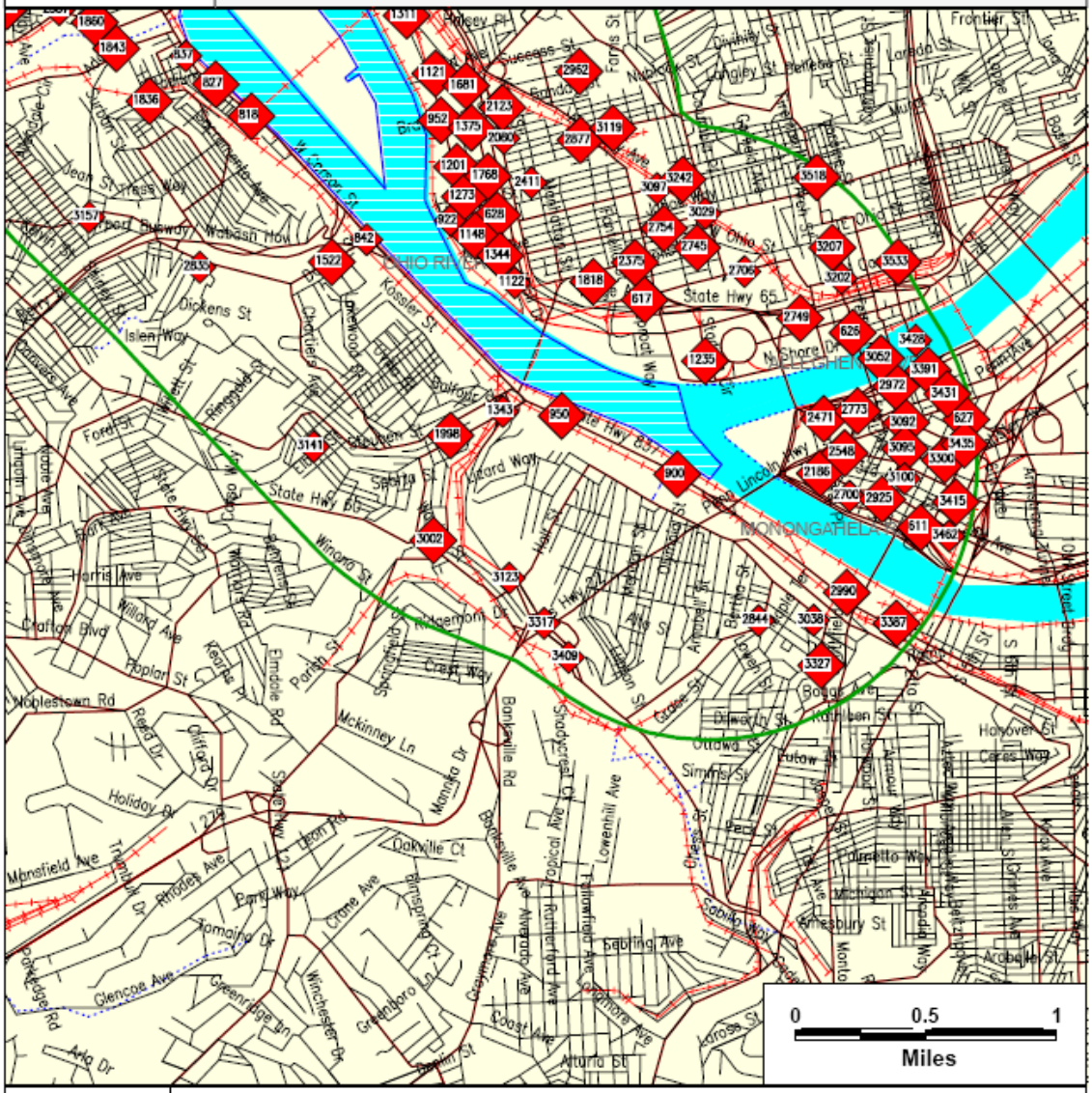
For More Information Call VISTA Information Solutions, Inc. at 1 - 800 - 767 - 0403
Report ID: 436489001 Date of Report: October 25, 2001



For More Information Call VISTA Information Solutions, Inc. at 1 - 800 - 767 - 0403
Report ID: 436489001 Date of Report: October 25, 2001

SITE ASSESSMENT - SPECIAL PROJECT (ALL DATABASES SEARCHED TO 1 MILE)

Detail Map 1



Subject Centerline

Search Area

Category:	A	B	C	D
Single Sites	◆	■	▲	○
Multiple Sites	◆	■	▲	○

Risk Sites Plotted as Polygons

Highways and Major Roads
Roads
Railroads
Rivers or Water Bodies
Utilities

Categories correspond to database searches described in the Site Distribution Summary, beginning on Page #1.

For More Information Call VISTA Information Solutions, Inc. at **1 - 800 - 767 - 0403**
Report ID: **436489001**
Date of Report: **October 25, 2001**

Incident Reports for Site 950 (page 1 of 3)

VISTA Address*:	1686 W KARSON PITTSBURGH, PA 0	VISTA ID#:	66130614
		Distance/Direction:	0.06 MI / E
		Plotted as:	Point
ERNS - Emergency Response Notification System / SRC# 8		Agency ID:	530590

Agency Address:	SAME AS ABOVE
NRC Report #:	530590
Location	1686 W KARSON PITTSBURGH PA
County:	ALLEGHENY
Discharger Last Name:	UNKNOWN
Discharger Company	GUTTMAN OIL
Discharger Organization Type	PRIVATE ENTERPRISE
Discharger Address	1686 WEST KARSON PITTSBURGH PA
Discharger Phone #	4122552935
Date/Time Reported:	30-MAY-00
Date/Time Completed:	30-MAY-00
Call Taker:	JLC3759
Cause of Incident:	UNKNOWN
Date/Time of Incident:	30-MAY-00
Description of Incident:	COMPLAINT OF DIESEL FUEL SPILL AT A GAS STATION
Incident Type:	FIXED
Air Release:	NO
Land Release:	NO
Water Release:	YES
Ground Release:	NO
Facility Release:	NO
Other Release:	NO
Media Affected	WATER
Source:	UNAVAILABLE
Comments	NEUTRALIZED MATERIAL,INVESTIGATION UNDERWAY
CAS #:	000000-00-0
CHRIS Code:	OTD

Material Spilled:	OIL, FUEL: NO. 2-D
Material Quantity:	4
Unit Of Measuere:	GALLON(S)
Fields Not Reported by the Source Agency for this Site:	Name(1), Location II(1), Location III(1), Discharger First Name(1), Discharger Secondary Address(1), Additional Medium Information(1)

Incident Reports for Site 950 (page 2 of 3)

VISTA Address*:	WEST CARSON STREET EXXON 1686 W CARSON ST PITTSBURGH, PA 15219	VISTA ID#:	2418934
		Distance/Direction:	0.06 MI / E
		Plotted as:	Point
STATE UST - State Underground Storage Tank / SRC# 450		EPA/Agency ID:	N/A

Agency Address:	SAME AS ABOVE
Facility Name:	WEST CARSON STREET EXXON
Facility Address:	1686 W CARSON ST PITTSBURGH, PA 15219
Facility ID #:	02-03574
Total Underground Tanks:	5
Total Aboveground Tanks:	NOT REPORTED
Total Tanks Removed:	NOT REPORTED
Owner ID #:	21838
Owner Name:	GUTMAN OIL CO
Owner Address:	200 SPEERS ST BELLE VERNON, PA 15012
Owner Phone #:	6372448335
Tank ID #:	952
Tank Sequence:	001
Tank Installation Date:	19781201
Tank Capacity (G):	00008000
Tank Contents:	DIESEL
Tank Status:	CURRENTLY IN USE
Tank ID #:	953
Tank Sequence:	002
Tank Installation Date:	19811201
Tank Capacity (G):	00008000
Tank Contents:	GASOLINE
Tank Status:	CURRENTLY IN USE
Tank ID #:	954
Tank Sequence:	003
Tank Installation Date:	19781201
Tank Capacity (G):	00010000
Tank Contents:	DIESEL
Tank Status:	CURRENTLY IN USE
Tank ID #:	955
Tank Sequence:	004
Tank Installation Date:	19811201
Tank Capacity (G):	00010000

Incident Reports for Site 950 (page 3 of 3)

Tank Contents:	GASOLINE
Tank Status:	CURRENTLY IN USE
Tank ID #:	956
Tank Sequence:	005
Tank Installation Date:	19811201
Tank Capacity (G):	00010000
Tank Contents:	GASOLINE
Tank Status:	CURRENTLY IN USE
Fields Not Reported by the Source Agency for this Site:	Facility Secondary Address(1)

STATE LUST - State Leaking Underground Storage Tank / SRC# 453	EPA/Agency ID:	N/A

Agency Address:	WEST CARSON STREET EXXON 1686 W CARSON ST PITTSBURGH, PA 0
Site Name:	WEST CARSON STREET EXXON
Site Address:	1686 W CARSON ST
Site City:	PITTSBURGH
Site State:	PA
Site County:	ALLEGHENY
Site Region:	SOUTHWEST
Class:	CLEANUP OF UNDERGROUND STORAGE TANKS AT FEDERALLY REGULATED PETROLEUM FACILITIES
Substance Leaked:	LEADED GASOLINE
Media Affected:	NOT REPORTED
Discovery Date:	NOT REPORTED
Class:	CLEANUP OF UNDERGROUND STORAGE TANKS AT FEDERALLY REGULATED PETROLEUM FACILITIES
Date Closed	2/16/96
Substance Leaked:	UNLEADED GASOLINE
Media Affected:	NOT REPORTED
Discovery Date:	NOT REPORTED
Fields Not Reported by the Source Agency for this Site:	Date Closed(1)

SUPPLEMENT 8-B

EXAMPLE OF RECREATIONAL BOATING ACCIDENT REPORT DATABASE

(BARD)

2001

State	Name of Body of Water	County	Nearest City or Town	Location	Accident Report No#	Date	Time
IL	Bangs Lake	Lake	Wauconda		2001-IL-0101	09/02/2001	11:32 AM
IL	Bangs Lake	Lake	Wauconda	Wauconda park dist.	2001-IL-0074	07/22/2001	10:06 AM
IL	Calumet River	Cook	Chicago	5/8 on Cal River under 130th bridge	2001-IL-0021	06/10/2001	5:30 PM
IL	Carlyle Lake	Clinton	Boulder	Boulder Marina	2001-IL-0013	05/19/2001	7:15 AM
IL	Carlyle Lake	Clinton	Carlyle	Dam East Boat Ramp	2001-IL-0014	05/19/2001	4:15 PM
IL	Carlyle Lake	Clinton	Carlyle		2001-IL-0069	10/20/2001	5:15 PM
IL	Carlyle Lake	Clinton	Keyesport	1/2 mile northeast of Keyesport boat ramp	2001-IL-0112	11/30/2001	6:45 AM
IL	Carlyle Lake	Clinton	Carlyle	Between Pooint 1 and Eldon Hazlet Campground	2001-IL-0025	06/12/2001	3:00 PM
IL	Carlyle Lake	Clinton	Boulder	Island north of Boulder Marina	2001-IL-0055	07/01/2001	10:00 AM
IL	Carlyle Lake	Clinton	Keyesport	Harbor Light Bay - Private Boat Dock	2001-IL-0087	08/12/2001	1:30 PM
IL	Chicago River	Cook	Chicago	about 31st St. Lowest bridge	2001-IL-0109	10/18/2001	1:00 AM
IL	Chicago River	Cook	Chicago	Lake Michigan Locks	2001-IL-0091	01/22/2001	
IL	Chicago Sanitary and Ship Cana	Cook	Lemont	Egan Marine Corp. barge repair ship	2001-IL-0108	10/17/2001	6:00 PM
IL	Clinton Lake	DeWitt	Clinton	Hot water discharge area	2001-IL-0006	04/29/2001	3:30 PM
IL	Clinton Lake	Dewitt	Clinton	Houseboat Cove	2001-IL-0020	06/09/2001	7:00 PM
IL	Clinton Lake	DeWitt	Lane	Peninsula Day Use Area	2001-IL-0102	09/03/2001	5:25 PM
IL	Clinton Lake	DeWitt	Fullerton	Rt. 48 Bridge	2001-IL-0103	09/03/2001	4:00 PM
IL	Clinton Lake	Dewitt	Lane	1 mile southwest marina	2001-IL-0023	06/10/2001	11:30 AM

IL	Des Plaines River	Will	Channahon	mile marker 282	2001-IL-0036	06/17/2001	7:30 PM
IL	Des Plaines River	DuPage	Burr Ridge	Madison and Jeans	2001-IL-0082	10/13/2001	6:30 PM
IL	Forbes State Park Lake	Marion	Omego, IL		2001-IL-0007	05/05/2001	1:30 PM
IL	Fox Lake	Lake	Lake Villa	Columbia Bay	2001-IL-0068	09/30/2001	4:29 PM
IL	Fox Lake	Lake	Fox Lake	Mineola Bay, 200 yards off of Mineola Marina	2001-IL-0065	09/22/2001	8:57 PM
IL	Fox River	McHenry	Cary	North of Rt. 14 & west of the county line	2001-IL-0092	09/22/2001	8:40 PM
IL	Fox River	McHenry	Cary	1/4 mi. north of Rawson Bridge Rd.	2001-IL-0010	05/04/2001	1:30 PM
IL	Fox River	McHenry	Island Lake	1 mi. so. of Rt. 176	2001-IL-0009	05/20/2001	4:45 PM
IL	Fox River	Kane			2001-IL-0107	09/08/2001	2:00 PM
IL	Governor Bond Lake	Bond	Greenville	200 yards Southwest of Ski Club boat dock	2001-IL-0041	06/22/2001	1:30 PM
IL	Grass Lake	Lake	Antioch	South of Grass Lake Rd.	2001-IL-0079	07/29/2001	2:30 AM
IL	Holiday Shores Lake	Madison	Edwardsville	Near dam	2001-IL-0059	07/04/2001	2:38 PM

139	OH
120	IN
15	WV
71	KY
80	PA
108	IL
533	

Chapter 9
RECREATION

9.1 TABLE OF CONTENTS

Definition of River-Related Recreational Impacts

Objectives and Scope of the Recreation Study

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Relevant Actions Affecting Recreation

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Summary and Conclusions

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9.2 DEFINITION OF RIVER-RELATED RECREATIONAL IMPACTS

River-based recreation activities on the Ohio River mainstem include, but are not limited to, recreational fishing and hunting, pleasure boating, water-skiing, and swimming. Pleasure boating includes use of privately owned or rented motorboats, personal watercraft (PWC), and non-powered watercraft (canoes, etc.) as well as sightseeing/dining and related activities aboard commercial watercraft. Additionally, the Ohio River and its riparian environs provide a setting for a broad range of 'shore oriented' activities that include hiking, biking, picnicking, camping, scenic drives, sightseeing, birdwatching, bank fishing, riverfront dining, and special events such as festivals, regattas, or fireworks displays. Both on-the-water and shore oriented recreational activities may have the potential to create crowding conditions at certain times or places that may conflict with other recreational activities or with commercial uses of the river.

Recreational activity contributes to development and/or preservation of a broad spectrum of public and privately funded recreational support features. These include

individual boat launching ramps, riverfront parks, trail and greenway corridors, marinas and moorage facilities, and floating restaurants. In addition to river oriented recreational activities, riverfront settings are also popular locations for sports stadiums, museums, concert facilities, casinos, on-shore dining-shopping-entertainment complexes, hotel and convention centers, and residential developments. Opportunities for further enhancement of recreation and tourism oriented facilities are prominent features in virtually all riverfront oriented planning among individual communities and public/private regionally focused groups along the Ohio River.

These activities are expected to increase on the Ohio River mainstem due to increased leisure time, overall improvements in river water quality, and increased access via boat ramps, marinas, river oriented parks and other developments. Recreation oriented riverfront developments may compete with or displace other uses along the river. Conversely, the process of planning and providing publicly funded or subsidized recreational facilities has the potential to contribute to long term protection of those resources (e.g., greenways, viewscapes, and public access) that in turn heighten demand for such recreational opportunities.

Potential health and safety (H&S) impacts can occur to recreational users due to the proximity of these activities to navigational uses (barge traffic) or other uses of the river. Further, potential conflicts over river use can occur between navigation, recreation, and other stakeholders. For example, increased levels of navigation could lead to pressures to reduce recreational boating in some congested areas.

9.3 OBJECTIVES AND SCOPE OF THE RECREATION STUDY

9.3.1 Objectives

This chapter provides an overview of recreational activities and trends throughout the Ohio River mainstem. Additionally, this chapter assesses the system-wide Cumulative Effects (CEs) to recreation of all likely major navigation improvements along the mainstem of the Ohio River from 2000 - 2070. Impacts that are directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFAs) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFAs. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, non-governmental entities, and predictions of general economic expansion and development.

The results of the Cumulative Effects Assessment (CEA) are intended to contribute to two topics of subsequent public debate: (1) whether the impacts of the RFFAs constitute acceptable outcomes for the affected resources and (2) how the proposed navigation improvements contribute to those outcomes.

9.3.2 Geographic Scope

The geographic focus for this study of Ohio River recreation includes those areas most directly impacted by operation and maintenance of the navigation system. In order to reflect influences of the navigation system in the context of broader business and economic forces, as well as to maintain consistency with the scope of other chapters (e.g., Socioeconomics, Health and Safety), counties adjacent to the Ohio River mainstem are defined as the geographic focus for impacts related to recreational activities. Where such counties are part of a Census-defined Metropolitan Statistical Area (MSA), all counties in the MSA are included in the geographic focus.

9.3.3 Time Frame

The established time frame for this assessment is 1920 to 2070. The earlier date approximates the initiation of modern Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the Ohio River Main Stem System Study (ORMSS).

9.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during the Summer, 2001, in communities along the Ohio River. The meetings created opportunities for the public, state, and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. More detailed discussions of the scoping meetings are presented in Exhibits A and B of this report.

A total of 185 people attended the meetings and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Comments that directly or indirectly addressed recreational issues are presented in **Table 9-1.**

TABLE 9-1
Comments from Public Scoping Meetings

Direct Comments on Recreation Oriented Impacts or Issues	Total	Impact[1]
Need more public access ramps in each pool to reduce recreational crafts' usage of locks	5	R-M
Effects on fishing caused by water level fluctuations	3	-
Degradation of recreational value of river caused by increased industrialization	2	-
Interest by Ohio to promote Ohio River as a vacation destination	2	+
Increased development of scenic byways and bikeways	2	+
Under-representing of fishermen in ORMSS scoping process	1	Q
Increase in barge loading/unloading facilities limiting fishing access from shore	1	-
Danger to recreational users of submerged trees toppled by bank erosion	1	-

Direct Comments on Recreation Oriented Impacts or Issues	Total	Impact[1]
Need for examination of those licensed to operate recreational craft	1	R-M
Suggestion of greater use of levees for passive recreation	1	R-M
Effects on recreation and heritage sites in Illinois, including Tower Rock Recreation Area	1	-
Include recreational facilities as design components of L/D revitalization & construction projects	1	R-M
Need for long-term plan for replacement & maintenance of existing recreational launch ramps	1	R-M
Need more access ramps in each pool for emergency response and boating safety officials	1	R-M
Other Comments With Implications for Recreation	**Total**	**Impact**
Health and safety concerns related to increased traffic and development	3	-
Eligibility of locks for classification as historic structures	1	+
Effects on recreation and quality of life of raising Montgomery pool level	1	-

[1]Impact codes:
"+, -, +/-" Comments that suggest positive, negative or mixed impacts to recreation activities or opportunities.
"R-M, R-S" Comments recommending an action for management of river resources (M) or as a topic in the CEA study (S).
"Q" General questions.

9.5 INDICATORS OF SUSTAINABILITY

Three principal factors that contribute to the sustainability of recreational activities in a local or regional setting are opportunity, availability, and experience. Any general class of recreational activity (e.g., river oriented boating) can be interpreted as an optional use of leisure time. Opportunity to engage in such activity derives from the general socioeconomic prosperity of the population living in the study area. Accessibility refers to the general ease of access to the resource. Experience refers to the likelihood that people will continue to engage in a particular activity.

Socioeconomic trends that contribute to recreational opportunity within a given population include employment and income statistics that are routinely collected by the U.S. Bureau of the Census. A population with better than average employment and income has more opportunity for recreational activity than a population that is less affluent. Over time, population growth in concert with continued growth of economic prosperity will contribute to expanding opportunities for recreational activity. Socioeconomic factors are addressed in Chapter 11 of this report.

Accessibility refers generally to ease of access to a given recreational resource. Individuals living close to the Ohio River have easier access than individuals living an hour's travel time away. The presence of boat launch ramps, community parks, or public access to shoreline fishing sites provides improved access in comparison to areas without such facilities. The type of facility provided may also differentially benefit certain groups (e.g., boat ramps likely provide little value to hiking/biking interests). This chapter addresses past to present trends of boat ramps, marinas, and other recreation facilities mapped on Corps' Navigation Charts. Other types of access facilities and future needs/consumer demands were assessed through interviews with selected stakeholders.

Experiences gained from participation in a recreational activity will directly influence future recreational choices. Not only are individuals more likely to repeat pleasurable recreational experiences, they are likely to encourage others through word-of-mouth. The collective activity and experiences of a given population can provide a good indicator of future activity and may be able to shed light on how the population would respond to changes in the recreational resource.

9.6 LAWS, REGULATIONS, ORDINANCES AND PROGRAMS

9.6.1 Agency Guidelines

Chapter 3 of the Planning Guidance Notebook (PGN) of the Corps of Engineers (ER1105-2-100; published on April 22, 2000) contains some information related to river-based recreation. The following two items are especially pertinent:

- Statement – The U.S. Army Corps of Engineers is one of the nation's largest providers of outdoor recreation opportunities. Although known primarily for the opportunities managed at its lake projects, the Corps also participates in the planning, design and construction of recreation facilities at a wide variety of other types of water resource projects.

- Policy – Lakes, or reservoirs, are impoundments created behind dams, or behind navigation locks and dams, if lands not subject to navigation servitude are needed for water storage. Recreation policies applicable to lakes are not applicable to dry dams, that is, those dams not providing permanently impounded water. The Federal government may participate in basic recreation facilities on project lands or separable recreation lands if a non-Federal sponsor will participate and cost share. Economically justified recreation facilities are cost shared 50 percent Federal and 50 percent non-Federal. The same conditions apply to separable lands acquired for future recreation development.

9.6.2 Federal Laws and Programs

The Corps' role in the development and support of recreational opportunities along the Ohio River is addressed through a number of laws and related authorizations. In addition to rulemaking that directly references recreational activities, other ordinances address stewardship of resources that indirectly contribute to the quality and variety of recreational opportunities. Examples of such direct and indirect mandates are described in **Table 9-2**.

TABLE 9-2
Laws, Regulations, Ordinances, And Programs Relevant to Ohio River Recreation

Law/Program	Key Components	Relevance to Recreation
Directly Relevant to Recreation at Corps Projects or Cost Sharing With Other Sponsors		
Federal Water Project Recreation Act (16 U.S.C. 460*l*-12).	Establishes policy that consideration be given to opportunities for outdoor recreation and fish and wildlife enhancement in the investigating and planning of Federal navigation, flood control, reclamation, hydroelectric or multi-purpose water resource projects, whenever any such project can reasonably serve either or both purposes consistently. May include recreation & wildlife benefits in project cost/benefit analysis.	On Ohio River, basis for boat ramps and shore fishing access to project pools, other facilities cost shared with state/local operators.
Reclamation Projects Authorization and Adjustments Act of 1992 Title XXVIII (16 U.S.C. 460*l*-31 - 460*l*-34), the *Reclamation Recreation Management Act*	Amends provisions of the Federal Water Project Recreation Act regarding cost sharing requirements for the provision of new recreation facilities, for recreation and fish and wildlife enhancement, and for the expansion or modification of existing recreation facilities.	Requirement for sponsor to assume 100% of operations, maintenance, and replacement costs is changed to "not less than one half the costs (16 U.S.C. 460*l*-13(a))." *These amendments extend to the Corps as well. Civil Works policy continues to require 100% non-Federal operations, maintenance, and replacement costs.*
National Trails System Act 16 U.S.C. §§ 1241 - 1251	Acknowledges the increasing popularity of outdoor recreation, the need to promote access to and enjoyment of outdoor areas of the Nation, both near urban areas and in more remote scenic areas.	Corps recognizes that the aesthetic attractiveness of scenic corridors available on project lands can be enhanced by incorporation of trails or trail systems.
Flood Control Act of 1944	Authorizes the Corps, to construct, maintain and operate public park and recreational facilities at water resources development projects (includes non-reservoir projects). Local interests also permitted to construct, operate and maintain such facilities.	Water areas of all such projects shall be open to public use for general recreational purposes, includes public access.
Relevant to Protection of Natural Resources for Recreational and Other Values		
Fish and Wildlife Conservation Act	Act declares that fish and wildlife are of ecological, educational, esthetic, cultural, recreational, economic and scientific value to the Nation.	May provide financial and technical assistance to States to conduct inventories and conservation plans for non-game wildlife.
Fish and Wildlife Conservation and Water Resource Developments-Coordination (16 U.S.C. § 661 et	Recognizes contribution of wildlife resources to national interests, provides that wildlife conservation receive equal consideration and be coordinated with other features of water-resources development programs.	Requires consultation with F&WS, state wildlife agencies from early planning to project completion. Provides for the use of

Law/Program	Key Components	Relevance to Recreation
seq.)		Civil Works projects for conservation, maintenance and management of fish and wildlife resources and wildlife habitat.
Emergency Wetlands Resources Act of 1986 (16 U.S.C. §§ 3901-3932)	Purpose is to promote the conservation of wetlands to maintain the public benefits they provide, and to fulfill international obligations contained in various migratory bird treaties and conventions (16 U.S.C. 3901 (b)). The means for this identified in the Act include: cooperative management and conservation efforts among private interests, local, state and Federal governments; and acquisition in fee, easements or other interests and methods.	Regional offices of the USFWS develop Regional Wetland Concept Plans, which may be useful in identifying significant opportunities for ecosystem restoration. Maps and other information from the National Wetlands Inventory may be useful in Civil Works planning and natural resources management initiatives.
Relevant to Protection of Historic Resources for Recreational and Other Values		
National Historic Preservation Act of 1966 (16 U.S.C. §§ 470 et seq.)	Act establishes preservation as a national policy and directs the Federal government to provide leadership in preserving, restoring and maintaining the historic and cultural environment of the Nation.	Corps has the opportunity to provide leadership in the preservation of cultural resources and to protect sites and structures as part of the operation and maintenance of Corps projects.
Archeological Resources Protection Act of 1979 (16 U.S.C. § 470 et seq.)	Enacted to preserve and protect resources and sites on Federal and Indian lands. Prohibits the removal, sale, receipt, and interstate transportation of archaeological resources obtained illegally (i.e., without permits) from public or Indian lands	Authorizes Federal agency permit procedures for investigations of archeological resources on public lands under the agency's control.

9.7 PAST TO CURRENT BASELINE CONDITIONS

9.7.1 Early Recreational Activities

Popularity of the Ohio River as a setting for recreational activity dates back to well before the beginning date (1920) for this assessment. The advent of steamboat transportation in the early 19th Century introduced luxury travel to the Ohio River for those that could afford it. First class accommodations featured luxury staterooms, fine dining, gambling, music and live entertainment, whether traveling for business or pleasure (Blake, 1981). Before long, some steamboats were entirely converted for use as floating entertainment centers. William Chapman's *Floating Theater*, built in Pittsburgh and launched on the Ohio River, made its initial trek to New Orleans in the summer of 1831 (Baldwin, 1981). Showboats provided a variety of entertainments, including dining, jazz, blues, popular music, theater, and vaudeville, for over a century. The showboat *Majestic*, built in Cincinnati in 1923, was by 1939 the last floating theater operating on the Ohio River (Baldwin, 1981). Now moored at the Cincinnati Public Landing, the *Majestic* still offers a summer theater series on the river.

Commercial steamboat transportation declined through the mid 19th Century due to competition from the railroads, but the entertainment value of traveling by steamboat survived. Vacation travel on steamboats offered all the luxuries of business travel during the earlier era and remained popular well into the 20th century. In addition to this overnight travel service, numerous excursion boats began operating on the river. While some provided transportation to a specific destination such as Cincinnati's Coney Island, most simply provided 2 or 3 hour tours on the river. These boats were designed to carry 1,000 to 5,000 people for the purpose of providing a floating platform for dining, sightseeing, and other entertainment (Blake, 1981).

By the turn of the 20th century, individual and family oriented activities such as pleasure boating, fishing, swimming, and picnicking were all highly popular pastimes on the Ohio River. Prior to completion of the low-level navigation dams (1929 or earlier, depending on location), summer low water in the Cincinnati area would reveal miles of smooth sandy beaches. On weekends, they were a popular site for family outings, where people could boat, fish, swim, and picnic (Roberts, 1981).

As completion of the low-level dams progressed through the 1920s, a variety of factors began to influence recreational activities on and around the river. The nature of such changes varied significantly at different locations along the river. Along the heavily industrialized reaches from Pittsburgh through Wheeling, steel mills, other industry, and railroad lines crowded out residential and commercial uses of the floodplains while also discharging their industrial process effluents to the river. The combination of pollution and restricted access eliminated most recreational activities and contributed to negative perceptions of the river's recreational potential that persisted well into the 1970s (Muller, 1972). Downstream from the industrialized reaches; acidic mining wastes destroyed aquatic life and rendered much of the river unusable for recreational activities. By contrast, significant recreational activity in the Cincinnati area persisted well into the 1930s and began to come back (concurrently with improving water quality) during the 1960s. Downstream from Cincinnati, rural stretches of the river were less impacted by industrial, mining, or municipal wastes and recreational patterns probably persisted with relatively less disruption.

The navigation dams had mixed impacts on some recreational patterns. The low water beaches were eliminated and fisheries associated with shallow riffles were restricted to tailwater areas immediately downstream of the dams. However, most references cited in this chapter suggest that changes in water quality engendered the most dramatic impacts to recreational activities. Coordinated efforts to clean up the Ohio River date from the establishment of the Ohio River Valley Sanitation Commission (ORSANCO) in 1948, and early successes in many areas contributed to reestablishment of traditional recreational uses from approximately the mid-1960s. This period roughly corresponds to the era of completion of the high lift lock and dam projects that replaced the earlier wicket dams. Thus, at least for the upper and middle reaches of the river, the recovery and expansion of river oriented recreation occurred in the relatively stable environment of the long pools behind the high lift dams.

Graydon DeCamp, a *Cincinnati Enquirer* reporter and frequent boater during the early years of recovery, has written of trips to relatively unspoiled reaches of the Ohio mainstem during that time. He estimated that in 1981 about 2,000 boats were moored all

summer at marinas and docks near Cincinnati. Most boats were small houseboats and cabin cruisers (20-25 ft. in length), a few were yachts (≥ 65 ft.), and many were smaller cabin boats and runabouts (16-20 ft. in length). A typical marina at the time consisted of a "headboat", essentially an old barge moored to the shore by heavy steel cables and to the river bottom with massive concrete "deadmen". Two long strings of floating docks were attached to the headboat and extended downstream a few hundred feet. Both the headboat and docks rose and fell with the river levels and were anchored by steel posts called "spuds". At the end of the boating season in late fall, the headboats were hauled close to shore and the floating docks were taken out of the river. Because of the winter hazards of high water, driftwood, and, possibly, ice, only a few harbors in protected embayments and tributaries remained afloat all year (DeCamp, 1981).

9.7.2 Present Status and Recent Trends

Over the past 30 years or more, the popularity of the Ohio River as a setting for recreational activities has experienced tremendous growth. People participate in a broad spectrum of river oriented activities both on and around the river. Despite this broad and apparently expanding spectrum of recreational interests, most readily available studies of Ohio River recreation have focused on boating and fishing activities. This is partly due to their status as primary on-the-water forms of recreation, partly the result of boat registrations and fishing licenses that facilitate tracking these activities, and partly the existence of state agencies responsible for managing these activities. Although narrowly focused, such studies do illustrate recent trends in boating and fishing that may be applicable to analysis of the broader spectrum of recreational activities.

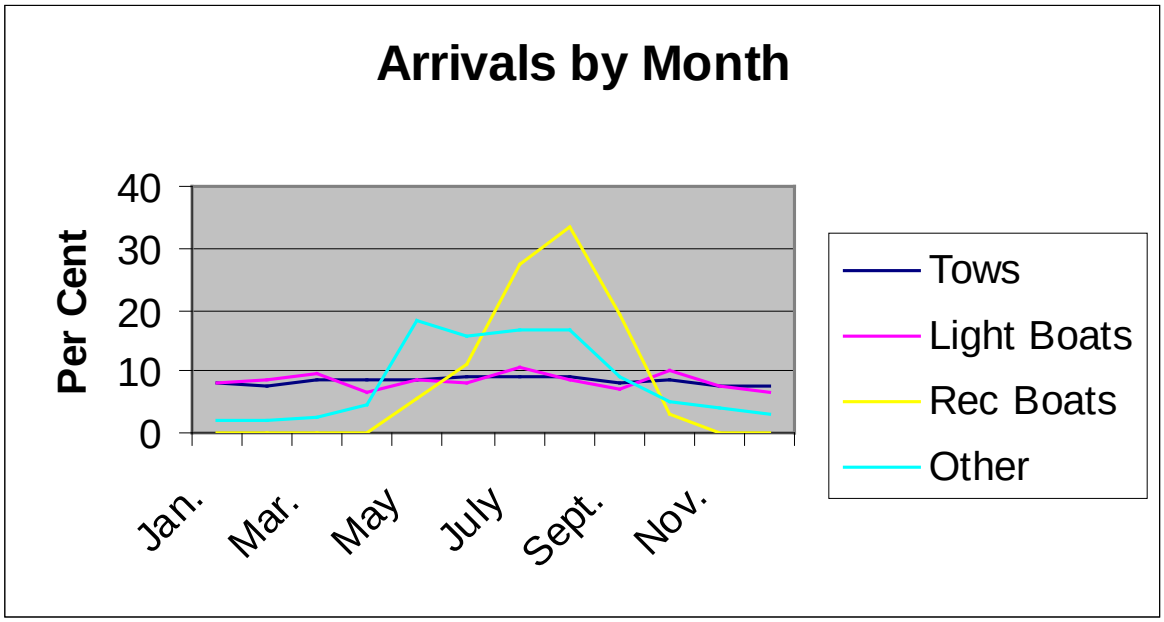
9.7.2.1 Recreational Boat Lockage Data

The Corps maintains records of all boat traffic that utilizes its locks on the Ohio River. Every boat that transits a lock is classified as a tow, light boat (other commercial boats), recreational boat, or other (includes excursion boats). Comparison of lock arrival times for commercial and recreational boats illustrates the basic patterns of boating activity on the Ohio River. Recreational boats are generally operated during daylight hours, on weekends, in the warm season of the year. **Figures 9-1-through 9-3** illustrate the extent to which recreational boats adhere to this pattern at Emsworth Lock and Dam. Tows and other commercial boats operate year-round, 24 hours per day, resulting in lock arrival times that approach a flat line. Arrival patterns for 'other' boats at this location (Emsworth Lock, 1998) illustrate the May-August season and Monday-Saturday, mid-day operations of the excursion boats.

Figure 9-4 summarizes total recreational boat lockages at all 20 Ohio River lock and dam projects for the last six years of record. Lockage records do not directly reflect all boating activity on the river because the relatively large size of Ohio River pools and general availability of access and boater services makes 'same pool' boating a feasible option. However, many pleasure boaters choose to include lock transits in their boating itinerary. The highest numbers of boats lock through Meldahl, with Markland a close second. Cincinnati is located approximately midway between these projects and likely contributes to the high numbers of boats using these locks. By contrast, McAlpine Lock and Dam is located in downtown Louisville, allowing boaters to launch either above or below the dam and thus minimize use of these locks. Additionally, construction of a new

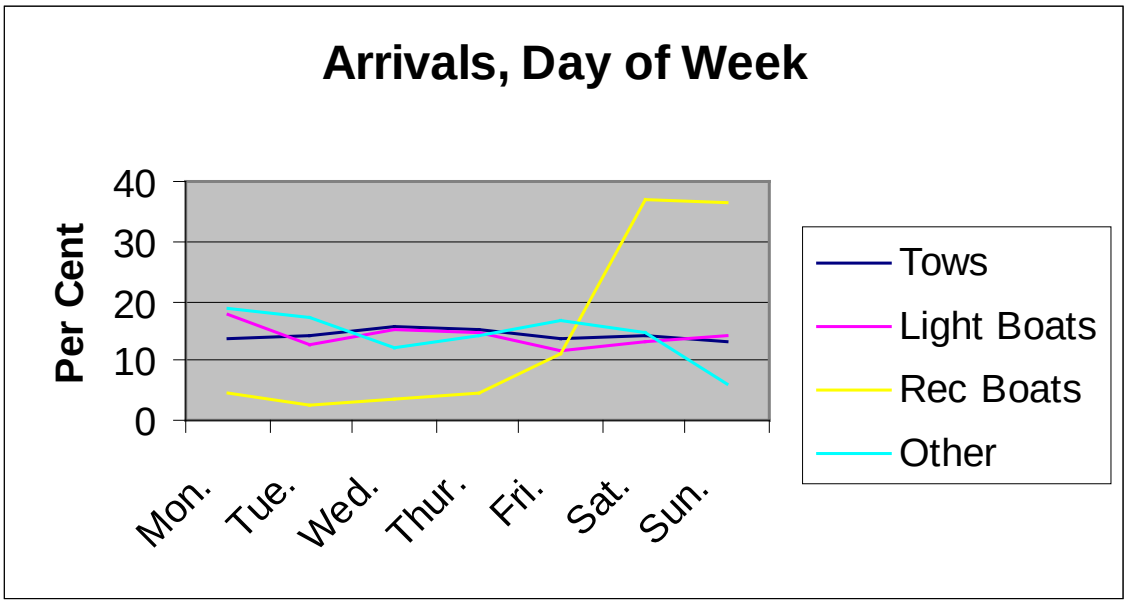
1200-foot lock extension at McAlpine during this record period may have reduced recreational use of these locks. The high numbers of lockages at the upper four projects (Emsworth, Dashields, Montgomery, and New Cumberland) reflect boating activity in the Pittsburgh area. Pools at these locations are also much shorter than downstream pools, which contributes to more frequent lockages.

FIGURE 9-1
Lock Arrivals by Month, Emsworth Dam, 1998



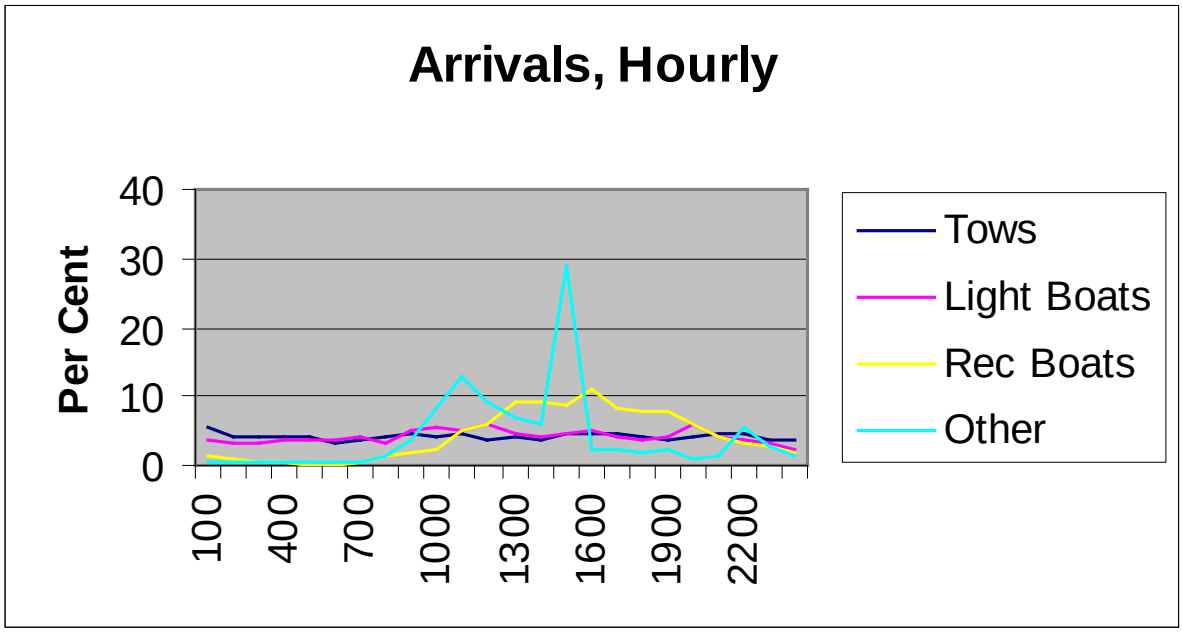
Source: U.S. Army Corps of Engineers

FIGURE 9-2
Lock Arrivals by Day of Week, Emsworth Dam, 1998



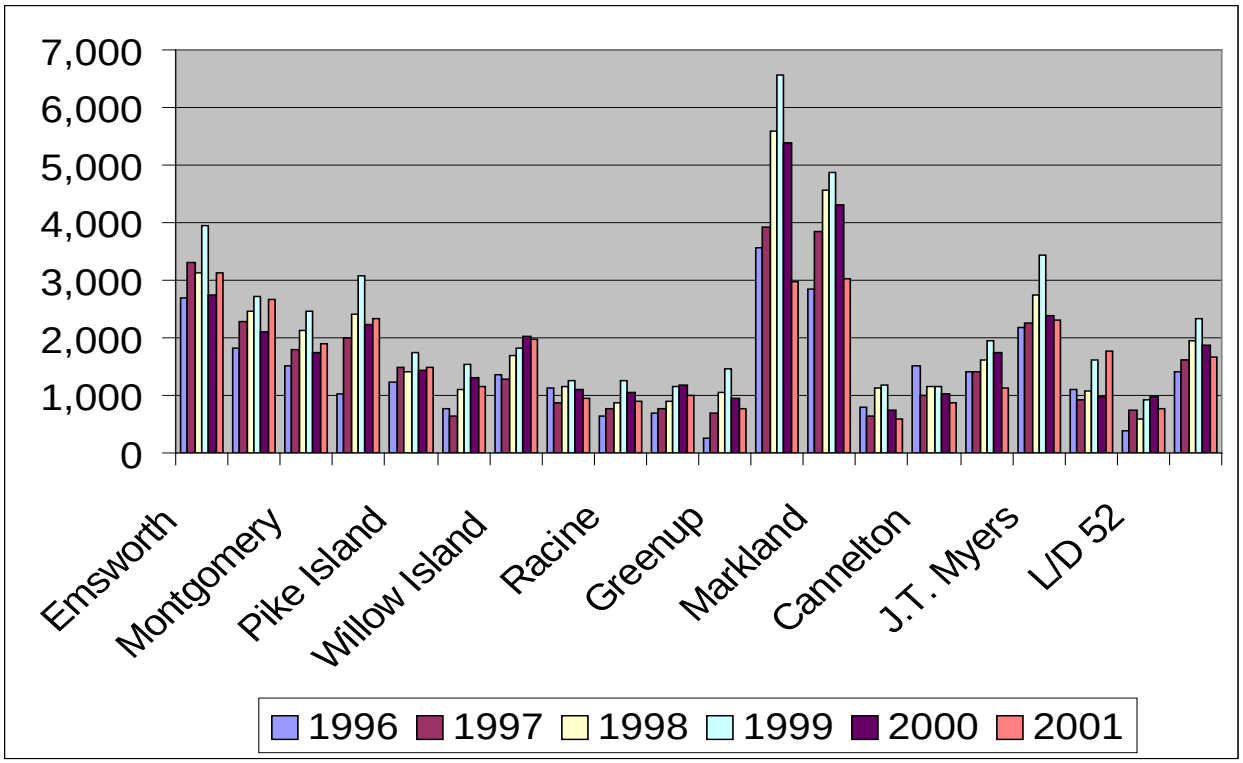
Source: Source: U.S. Army Corps of Engineers

FIGURE 9-3
Lock Arrivals by Time of Day, Emsworth Dam, 1998



Source: Source: U.S. Army Corps of Engineers

FIGURE 9-4
Total Recreational Boat Lockages on Ohio River



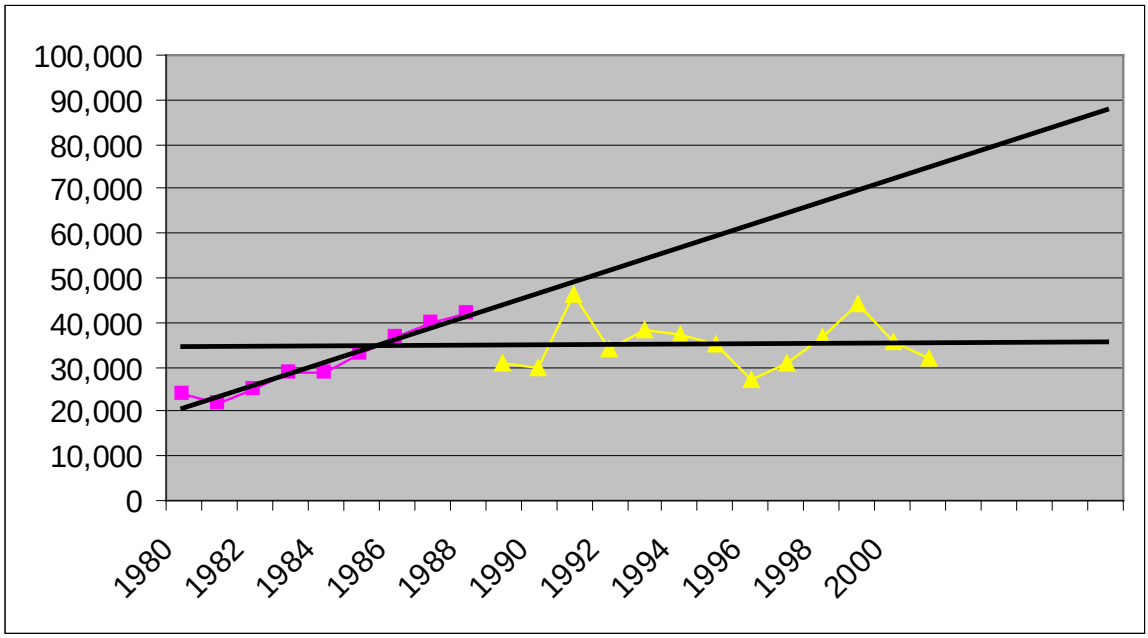
Source: U.S. Army Corps of Engineers

Lockage patterns illustrated in **Figure 9-4** also reflect annual variations in recreational boating opportunity associated with weather and water conditions during the

May-September peak season. Both good (1999) and bad (1996) years exhibit fairly consistent patterns at locations up and down the river. High water and inclement weather generally affect the full length of the river and, consequently, preclude traveling up or downstream to less impacted locations.

When aggregated for the total river and tracked for the long term, recreational lockages reflect a steady growth trend for boating on the Ohio River from 1980 through 1988 and almost no growth from 1988 through 2001. Total lockages for the two periods are illustrated below in **Figure 9-5**. The rapid growth of lockage activity from 1980 to 1988 may reflect renewed interest due to improved water quality. The trend from 1988 to 2001 could be influenced by a variety of factors, including annual variations in river water levels, changes in boating travel patterns or improved availability of launch ramps (which could reduce the need to lock through from available ramps to preferred pools). The latter trend may also reflect the end point for rediscovery of the river, i.e., all boaters in the region are aware of opportunities on the river and the level of interest has stabilized.

FIGURE 9-5
Total Recreational Boat Lockages and Trends on the Ohio River



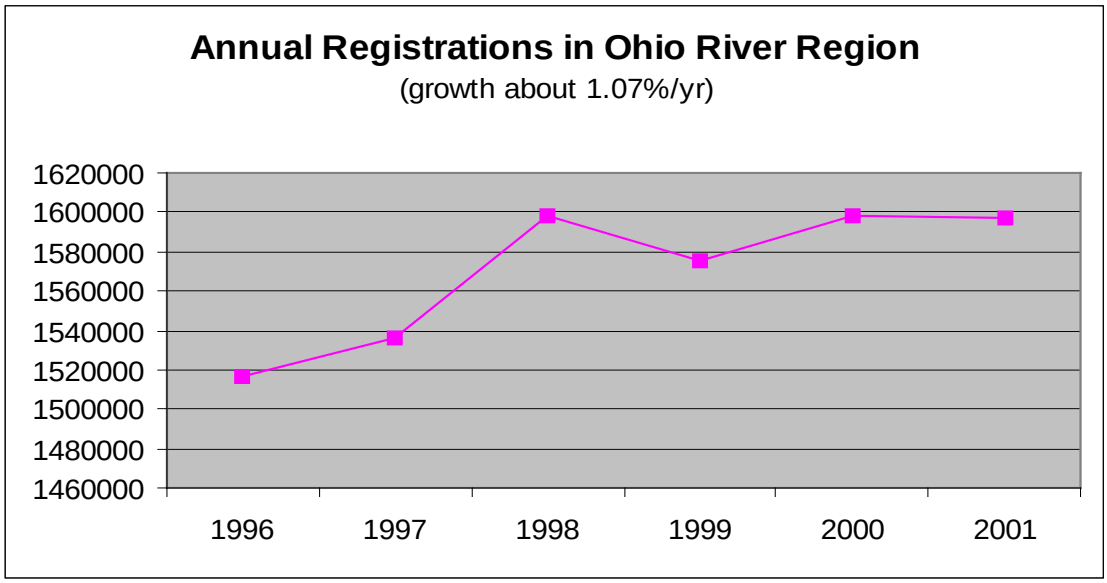
Source: U.S. Army Corps of Engineers

9.7.2.2 Boat Registration Data.

Nationwide annual recreational boat registrations have climbed steadily from a total of approximately 7,976,000 in 1977 to about 12,876,000 in 2001. This represents an average annual growth of 2.7 percent. However, the rate at which boat registrations have increased has declined over the more recent periods of record. Growth during the past 20 years averaged 2.3 percent annually, during the past 10 years averaged 1.9 percent annually, and fell to an average annual growth of 1.1 percent during the past 5 years (USCG, 2002).

Recent annual registration data (1996-2001) are available for individual states in the Ohio River region and recent county data are available for Ohio (1995-2001) and Pennsylvania (1992-2001). The states generally reflect both the national average boat registrations per capita and the recent national trend towards a slower rate of growth, with an average annual growth for the region of 1.1 percent during the past 6 years. Growth rates for individual states range from a low of 0.04% for Indiana to a high of 2.8% annually for West Virginia. **Figure 9-6** presents recent boat registrations for the six states bordering the Ohio River and **Figure 9-7** presents similar data for Ohio and Pennsylvania counties adjacent to the river.

FIGURE 9-6
Recent Trend in Boat Registrations for States in Ohio River Region



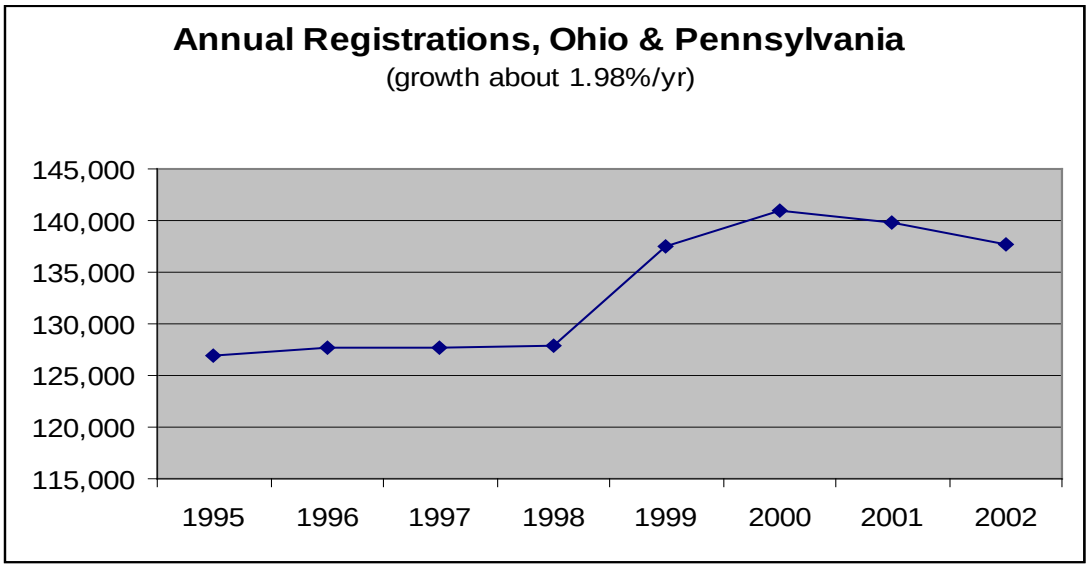
Source: USCG 2001

9.7.2.3 Studies of Boat Owners

The Ohio Department of Natural Resources (ODNR), Division of Watercraft has recently completed a series of boating studies that help to illustrate boater activity on the Ohio River. In 1998, a survey of 5,544 boater households resulted in 2,339 responses for a response rate of 42 percent. The typical boat owning household took 15.7 boating trips to Ohio sites during the survey period (Oct. 1, 1997 through Sept. 30, 1998) and 2.1 trips outside of Ohio. About 81 percent of the Ohio trips were single day outings, while 19 percent were overnight or longer. Of the trips within Ohio, 4.3 out of 15.7 were to Lake Erie, 1.3 to the Ohio River, 8.7 to inland lakes and reservoirs, and 1.5 to inland rivers or streams. These averages suggest that about 8.3 percent of statewide boating activity occurred on the Ohio River during the study period **(see Figure 9-8)**.

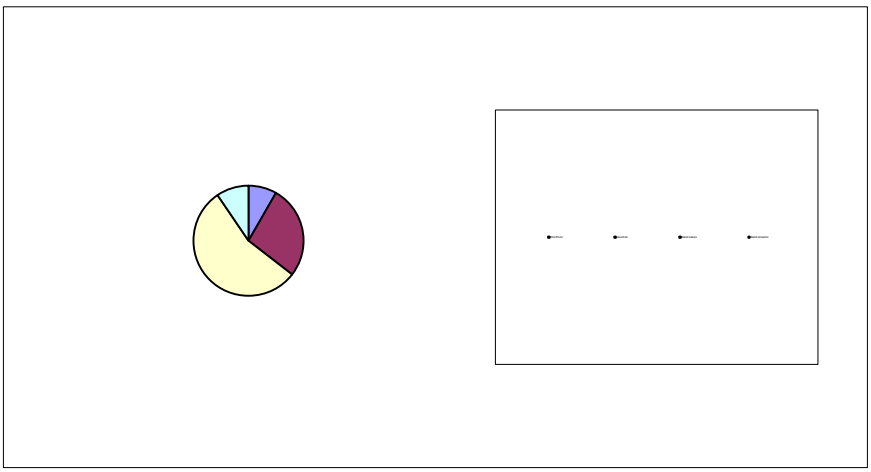
Boat ownership averaged 1.74 boats per household. Approximately 70 percent of boats were kept at home during the boating season and about 75 percent at home during the off-season. Thirteen percent were docked at a marina or club during the boating season and 3 percent were kept in dry-rack storage. The average one-way distance from home to the boating site was 38 miles.

FIGURE 9-7
Recent Trend in Boat Registrations for Counties Adjacent to Ohio River



Source: Ohio DNR, 2003; PA Fish and Boat Commission, 2003.

FIGURE 9-8
Destinations of Boat Trips Taken in Ohio by Ohio Boaters - 1998



SOURCE: ODNR, Division of Watercraft

Boater households spent an average of $134.30 per trip, for total expenditures of $2,104 per household for trips within Ohio during the study period. There were an estimated 234,303 boat-owning households in Ohio, resulting in an estimated $493 million in total household trip expenditures for trips within Ohio. When all costs of purchasing, repairs and maintenance were added to trip expenditures, total expenditures for boating households in Ohio added up to $1,387.3 million (Husak, 1999).

The Ohio Division of Watercraft completed a follow-up survey of boater households in 2002 (ODNR 2003). This survey was designed from focus group studies completed by the Division in 1991 and was intended to develop further information about boaters' experiences with issue areas identified in the focus groups. The survey collected information from 1,126 boater households that had actually boated on an Ohio waterway in

2002. Among these respondents, 5.8 percent listed the Ohio River as the waterway that they frequented most often.

The ODNR Division of Watercraft provided the ORMSS project with a breakdown of selected variables that identified the responses of Ohio River boaters. These variables included satisfaction with availability of launch ramps, experiences with silt and natural debris accumulations, overnight boating trips, and perceived need for speed limits.

A total of 18 of the 65 Ohio River boaters (27.7%) reported staying overnight on their boat while traveling on the river. Also, 100 of the 348 Lake Erie boaters (28.7%) and 30 of the 705 boaters on inland waters (4.3%) reported staying overnight while boating. Many Ohio River boaters (7 of 18 = 38.9%) tied up along the shoreline, but not in a designated boat camping area. Others were about equally divided among anchored in open water, tied up at a transient rental dock, tied up at a private dock (such as friend or relative), and use of a designated boat camping area. On Lake Erie, 73% stayed at transient docks.

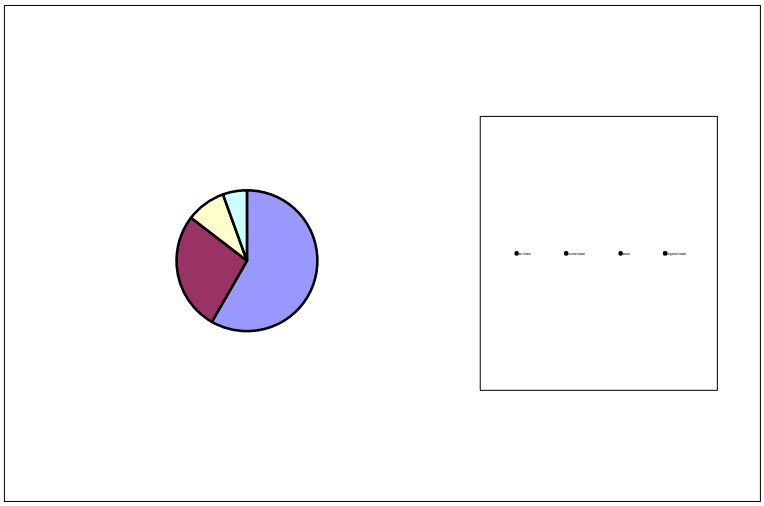
On the Ohio River, 50% of overnight boats traveled alone while 50% traveled in small groups of two to five boats. The most important destination features for overnight travel include 'suitable draft for boat' and experiencing a 'back to nature atmosphere'. Of secondary importance were nearby restaurants and short-term rental docks. Least important were city atmosphere, nearby tourist attractions, and nearby shops.

Of Ohio boaters in general, Ohio River boaters were least likely to report a need for speed limits. About 58 percent reported 'no need', 27 percent saw 'some need', 9 percent agreed to 'need', and 5.5 percent felt there was an 'urgent need' **(Figure 9-9)**. Those reporting 'no need' on other waterways ranged from 15 to 52 percent.

Also in Ohio, Ohio River boaters reported a lower satisfaction (12 of 59 respondents) with the availability of launch ramps compared to boaters using other Ohio waterways. Survey respondents rated their satisfaction on a scale of 1 (completely satisfied) to 5 (completely dissatisfied). Ohio River boaters in Southwest Ohio scored 2.81 while boaters from Southeast Ohio scored a somewhat more positive 2.39. The statewide average for the Ohio River was 2.61, while the statewide score for Lake Erie was 2.32. Scores for inland lakes averaged approximately 2.2.

Also, proportionally more Ohio River boaters (48.3%) reported negative impacts from accumulation of silt in the waterways. In other areas, problems were reported by 30.5% to 47.3% of respondents. Further, proportionally more Ohio River boaters (62.5%) reported negative impacts from accumulation of natural debris in the waterways. Problems reported for other areas ranged from 27.8% to 51.5% (ODNR, 2003).

FIGURE 9-9
Ohio River Boaters' Responses Regarding Need for Speed Limits



SOURCE: ODNR, Division of Watercraft

9.7.2.4 Boating/Fishing Studies

The ODNR, Division of Wildlife conducted a recreational use survey for Ohio's portion of the Ohio River in 1992 and 1993 (Schell et al., 1996). The primary objective of this survey was to provide direction and prioritization in developing fisheries strategies, resource protection, recreational facilities development, and public perceptions of the resource.

West Virginia had conducted a similar survey in 1981 of recreational activity on the eight Ohio River counties that border the state (Pierce et al. 1983). When Ohio prepared to conduct the 1992 survey, the Division of Wildlife coordinated with West Virginia to insure comparability of findings from the two surveys. As a result, comparisons can be made for several types of activity on the eight pools addressed by both surveys.

Two survey procedures were employed by both studies. Aerial surveys provided counts of boats and shore anglers and are summarized below in **Table 9-3**. The 1981 data collected by West Virginia is based on 66 aerial surveys – one weekend and one weekday flight per week, including holidays over more than 30 weeks. The 1992 data resulted from 90 aerial surveys – one weekend day and two weekday flights per week, excluding holidays during the approximately 30 week recreation season. While these counts are not directly comparable, they do illustrate strong growth for all activities observed.

On-the-water observations and surveys of shore and boat anglers were employed to augment the aerial surveys and generate estimates of fishing effort, including length of time spent fishing, species sought, and catch rates. Comparison of the surveys indicated that the total angler hours for the Ohio River bordering West Virginia increased 110% between 1981 and 1992. Most of the growth was accounted for by boat fishing, which more than tripled between 1981 and 1992, (Schell et al., 1996). **Table 9-4** provides additional details of angler hours by areas fished.

TABLE 9-3

Comparison of Boats and Shore Anglers during 1981 and 1992 Surveys

	Total Shore Anglers	Total Boat Anglers	Total Anglers	Total Fishing Boats	Total Recreation Boats	Total Boats
1981 (WV)	9,797	3,352	13,149	1,687	8,201	9,888
1992 (OH)	12,429	13,306	25,735	7,217	10,200	17,417

Fishing Boats: Actively fishing or such use was imminent.
Recreational Boats: Motorized and non-motorized recreational craft (not fishing).

SOURCE: Schell et al., 1996

TABLE 9-4
Comparison by Angler Hours of Areas Fished during 1981 and 1992 Surveys

Anglers	Pools		Embayments		Tailwaters	
	1981	1992	1981	1992	1981	1992
Shore	438,000	373,586	34,600	23,686		
Boat	133,500	403,299	27,400	29,569		
Total	571,500	776,885	62,000	53,255	84,700*	675,608*

*90-95% of the tailwater fishery during these surveys was shoreline fishing, due to boating access restrictions in the tailwaters.

SOURCE: Schell et al. (1996)

Comparison of the data from Ohio and West Virginia for this portion of the river suggests that pleasure boating may have declined less or recovered earlier from the mid-20th century era of heaviest pollution. Fishing may require a relatively higher level of water quality than pleasure boating or may have been delayed during the years required for fish stocks to become reestablished in response to improving water quality.

Boating and fishing data collected by the ODNR survey in 1993 (Schell et al., 1996) suggests that urban boaters may be somewhat less likely to include fishing in their boating activities. The 1993 survey looked at the lower 3 pools adjacent to Ohio: Greenup, Meldahl, and Markland. The 1992 study looked at the upper pools from New Cumberland to Greenup. Greenup was studied in both years to help address potential seasonal differences between the two study years. On the upper pools in 1992, fishing from boats accounted for 40.8 percent of all boating activity. On the lower pools in 1993, fishing from boats accounted for only 18.4% of all boating activity.

Seasonal variability in fishing success and in non-fishing recreational activity may account for some of the observed differences. The ODNR study recorded significantly better fishing success in 1992 compared to 1993. On the Greenup pool, fishing activity increased by 6.8 percent from 1992 to 1993, but all other boating activity rose by 55.2 percent. Fishing activity in 1993 accounted for 25.7 percent of all boating activity on the Meldahl pool and 14.5 percent on the Markland pool. Additionally, all boating activity on Markland pool accounted for 53.3 percent of all boating activity observed on Greenup, Meldahl, and Markland pools in 1993.

Cincinnati is located at the approximate midpoint of the Markland pool and provides boaters with numerous marinas and boat launching facilities. As indicated in Figure 9-4, the locks immediately upstream (Meldahl) and downstream (Markland) of Cincinnati are by far the busiest locks for recreation boats on the Ohio River. This suggests that Cincinnati also contributes a significant number of boaters to these neighboring pools. The

popularity of fishing in the Meldahl pool may be due in part to Cincinnati boat anglers desire to avoid crowds and/or perceptions of relative fishing quality between the pools.

In 1992, a recreational use survey was conducted on the Ohio River in the Pittsburgh area (TES, Inc. et al. 1996). The study examined and interviewed recreationists on 40 miles of the Ohio River, 14.5 miles on the Allegheny, and 23.8 miles on the Monongahela. The purpose of this study was to characterize and quantify the various recreational uses of the rivers in the study area for planning and managing the future recreational development of the rivers.

The survey and interviews were used to calculate total recreational activity in the study area for calendar year 1992. The study estimated 110,000 user days of bank fishing activity, 16,500 user days of boat fishing, 113,000 user days of general boating activities other than fishing, and 264,000 user days of park utilization. All of these estimates are conservative; the study identifies various factors that contributed to undercounting of the studied activities. The relative proportion of boat fishing activity in the Pittsburgh study, 12.7 percent of all boating activity, may be comparable to the 14.5 percent found on Cincinnati's urban pool by the ODNR study in 1993.

Recreational activity on rivers in the Pittsburgh study area was strongly influenced by seasonal weather. About 67 percent of all boating and 55 percent of all fishing activity occurred during the June-August summer season. Park usage was more year-round, with 28% of the activity during spring, 39% in summer, 24% in fall, and 8% in winter.

Recreationists in this study area consisted primarily of local residents utilizing a close-to-home resource. Anglers traveled a median round-trip distance of 12 miles, boaters averaged 20 miles, and park users traveled 6 miles. While virtually all anglers and boaters traveled to their recreation site by car, van, or truck, about 53 percent of the park users walked or jogged. An additional 8.2 percent took the bus. The survey of park recreationists included Point Park in downtown Pittsburgh, where users traveled a median 8 miles round-trip. Median travel to other parks was as low as 1 or 2 miles.

Despite fairly high catch rates averaging just over three fish per hour, anglers near Pittsburgh generally rated fishing quality as 'poor' (about 38%) or 'fair' (28%). This was primarily due to concerns with water quality (pollution, dirty or unclear water, debris in river, can't eat the fish). Over 80 percent of anglers indicated that river problems affected their enjoyment of fishing.

About 18 percent of boating activity near Pittsburgh involved contact recreation, including water-skiing, swimming and tubing. Most boats had motors (89%) and most were 14 to 21 feet in length (72%). About 6 percent of boats surveyed traveled through a lock during their outing. River problems were of concern to over 88 percent of boaters. Unpolluted water and absence of debris were the characteristics of greatest importance. While 70 percent of boaters rated easy access as very important, only 17% mentioned lack of public access as a problem.

The majority of park users were there to walk or relax (63%). Other activities included physical activity (15%), eating (10.5%), playground use (5.5%), and other passive activities (6%). Compared to the longer time commitments required of fishing and

boating, park visits averaged just 55 minutes. Only about 27 percent of park users felt that river problems affected their enjoyment of park activities. Items rated as 'very important' to park user's enjoyment included easy access (73%), scenic beauty (65%), and unpolluted water (63%) (TES, Inc; et al. 1996).

9.7.2.5 Comparison with Other Studies

Some comparisons are possible between recreational activity on the Ohio River and recent studies conducted on the Upper Mississippi River-Illinois Waterway (UM-IWW). The UMR-IWW system has less commercial traffic, but more recreational boating than the Ohio River. The busiest individual locks for recreation on UMR-IWW had recent annual averages (1994-1997) of 19,202 (Lock#3, UMR), 12,404 (Lock#7, UMR), and 18,381 (Peoria, IWW). These numbers represent total recreational vessels locked through, which is the same enumeration method used for the Ohio River data. Data for the busiest recreational locks on the Ohio River are illustrated in **Table 9-5**.

TABLE 9-5
Total Recreational Vessels Locking Through at the Busiest Ohio River Locks, 1998-2001

Lock	Average No. of Vessels Locking Through	No. of Vessels for Busiest Year, 1998-2001
Meldahl	5,133	6,564
Markland	4,193	4,880
Emsworth	2,519	3,939

The UMR-IWW study found no conflict between commercial navigation and recreational boating. There was little or no correlation between delay times for commercial traffic and the number of recreational lockages. Locks accommodated heavy recreational traffic by increasing the number of boats per lockage. There was plenty of capacity for additional recreational lockages, with the busiest locks averaging 4.2, 3.3, and 3.7 recreational boats per lockage (U.S. Army Corps of Engineers, 1999).

A second study of the UMR-IWW system provided an estimate of total recreational boating activity for year 2000 by pool. Total boating days on the UMR-IWW were estimated to be 2.7 million, with the large majority of this activity (2.37 million) on the Upper Mississippi River. Comparison of the two UMR-IWW studies allows calculation of the ratio of boats locked to the total of boats in the system. For the total UMR-IWW system, about one boat in 17 locked through (U.S. Army Corps of Engineers, 2000b).

If one assumes the same ratio applies, on average, for the Ohio River, one can estimate total days of recreational boating from the recreational boat lockage data. This results in an estimated 535,239 recreational boating days on the Ohio River during 2001, based on 31,725 recreational boat lockages recorded. For the busiest year on record (1991), 46,347 recreational boat lockages would result in an estimate of 781,568 recreational boating days.

9.7.2.6 Riverfront Enhancement Trends

As this document reiterates, measurable improvements in water quality of the Ohio River mainstem have led to the rediscovery of the river as an asset to communities along the entire river corridor. During the earlier water quality recovery phase (1970s and 1980s), specific sites began to be developed for recreation and entertainment, for example, riverfront parks, major league stadiums, and riverboat restaurants. Within the past decade, however, riverfront projects have become much more comprehensive in scope. Large and small-scale efforts to integrate residential and commercial development, shoreline and river recreation, heritage tourism, and ecological protection/restoration are underway in many communities along the Ohio mainstem.

All three of the river's major metropolitan areas have organizations dedicated to regional visions for the river corridor:

- River Fields, Inc. (www.riverfields.org) is the oldest such organization, founded in 1959. It promotes management, protection, and development of land and water resources along both sides of a 50-mile reach of the river near Louisville from the community of Westport in Oldham County, KY (RM 580) to West Point in Hardin County, KY (RM 630). River Fields has played a key role in the reclamation of Louisville's waterfront and in the development and implementation of a master plan for a 39-mile greenway system along the Ohio River and four tributaries near Louisville.

- The more recently founded Ohio River Way (www.ohioriverway.org), based in Cincinnati, focuses on a 150-mile reach of the river from Maysville in Mason County, KY (RM 408-409) to Madison in Jefferson County, IN (RM 558-559). Ohio River Way's focal areas include recreation, commerce, ecology, heritage, and the arts. Among its long-term goals is the development of a 300-mile, multi-state greenway loop along the river corridor.

- The Pittsburgh Riverlife Task Force (www.pittsburghriverlife.org) was founded in 1999 to develop a compelling vision for the city's waterfront, an area encompassing portions of the Ohio, Allegheny, and Monongahela rivers. "*A Vision Plan for Pittsburgh's Waterfront*", presented in 2001, focuses on providing "continuous public access to the rivers and along the edges, connecting and expanding on the parks that now punctuate the shoreline in a continuous flow of trails, bridges, green space and waterfront amenities". The series of interconnected places and destinations is envisioned to comprise a grand public space called "Three Rivers Park". Concurrently, the Western Pennsylvania Field Institute (www.wpfi.org) supports a program promoting outdoor recreation of all types on and along Emsworth Pool (Ohio RM 0-6.2).

Several smaller communities along the river have developed comprehensive planning processes or implemented plans that combine recreation, heritage tourism, and economic growth. Examples of such efforts include:

1) Designation of the 106-sq. mi. Wheeling National Heritage Area (WNHA), WV – This National Park Service program permits designation of heritage areas "where

natural, cultural, historic, and recreational resources combine to form a cohesive nationally distinctive landscape" (www.cr.nps.gov/heritageareas/). An important component of the Wheeling project has been the development of the Heritage Port, a 20-acre landing/entertainment complex, serving as a concert and festival venue.

2) Development of Marietta, OH, as a heritage tourism base – Marietta has capitalized on its river location and status as Ohio's first city to become a center of heritage tourism. The downtown riverfront offers specialty shops, historic lodging, museums, and trolley transportation. Nearby places of interest include Blennerhassett Island State Park and the Ohio River Islands National Wildlife Refuge.

3) Greenway planning near Evansville, IN – Progress is being made on the Pigeon Creek Greenway Passage, a 42-mile greenway encircling Evansville with portions of the route following the Ohio River levee and traversing the renovated downtown. Additional plans include connections with the river town of Newburgh and with Angel Mounds Historic Site.

4) Renaissance of Paducah, KY – Historic building restoration, live entertainment downtown on Saturday nights (May-September), riverboat visits, museums, and self-guided walking tours attract visitors to the most downstream sizeable community on the Ohio River in Kentucky. A $40 million, year-round performing arts center opened in February, 2004, at the downtown floodwall. A series of floodwall murals depicting Paducah's history has become an interesting visitor attraction. The mural artist is painting a similar series on the floodwall in Covington, KY.

5) Comprehensive planning in Southwestern Illinois – The Southern Five Region, which includes Alexander, John, Massac, Pulaski, and Union counties in the Ohio River corridor in Southwestern Illinois, has recently completed a regional economic development plan. The plan's strategies include protecting, enhancing, and creating tourism and outdoor recreation areas as well as developing new service areas and recreation infrastructure. Just east of the Southern Five Region a river taxi connects tourists visiting river towns in Gallatin and Hardin counties.

Many other smaller communities along the river are developing docking facilities, rejuvenating their downtowns, and hosting river-based festivals focusing on regional music, art, food, and other local attractions (e.g., the Superman festival in Metropolis, IL). Widespread Internet access has become increasingly important in publicizing recreation and entertainment offerings of smaller river communities.

The Ohio River Scenic Byway (www.byways.org/browse/byways/2286) connects communities and points of interest along the 943-mile north bank of the Ohio mainstem through the states of Ohio, Indiana, and Illinois. Like other routes in the National Scenic Byways system, the Ohio River Scenic Byway markets and promotes all types of recreational, natural, scenic, and cultural features within at least one to two miles of the route. Maps and details on places of interest and amenities for motorists, bikers, and hikers are available on the web site above. This web site also features links to individual state web sites.

9.7.2.7 Recreation Support Facilities

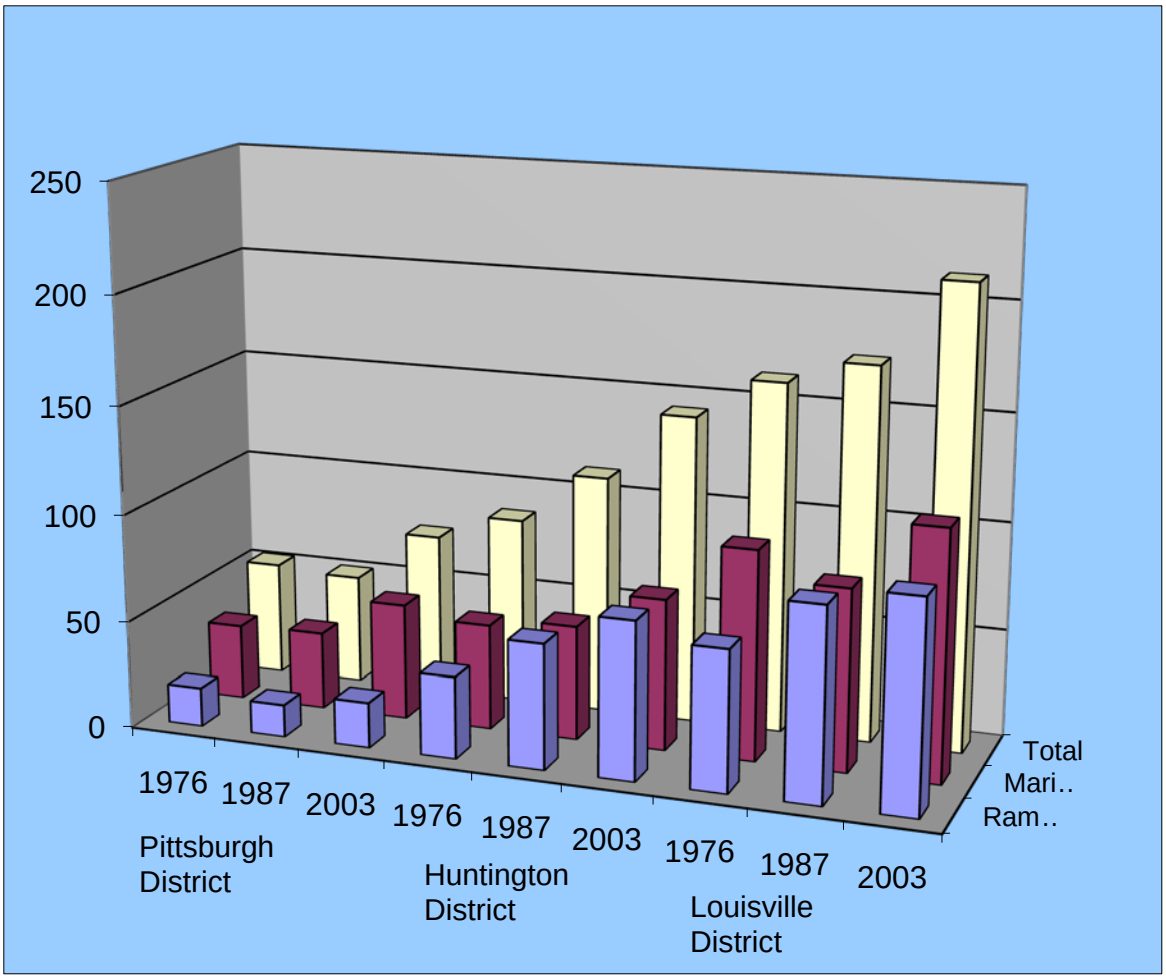
The growth and diversification of recreational activities on the Ohio River create demands for a variety of support facilities and services. Informal and qualitative data collected for this study suggest that steady growth is occurring in riverfront dining, camping, marinas, shopping, boat launching ramps, parks, and related services in response to this demand, although quantitative data for most of these trends is not readily available. However, numbers of marinas and public boat launching ramps can be tracked from Corps of Engineers Navigation Charts for the Ohio River. Data for the three past decades are presented in **Figure 9-10**.

The numbers of public ramps and marinas were primarily derived from Appendix B, Inventory of Small Boat Harbors, Ramps and Landings, published in the 2003 Ohio River Navigation Charts (U.S. Corps of Engineers, 2003). Facilities were classified as a private marina if they were described as a marina, boat club, harbor, or similar class of service, or if they provided services such as private launching ramp, fuel, or overnight mooring. Facilities that provided only restaurant or food sales were excluded, as were excursion boat terminals. Facilities were classified as a public ramp if described as such and owned by a public entity such as riverfront town, state wildlife agency, or the Corps. Listings that described privately owned docks or launching ramps were excluded. The list of facilities identified from Appendix B was then compared to the 2003 Navigation Charts. A few additional facilities that were clearly labeled on the charts as marinas or public ramps were added to the enumeration. A number of launching ramps appeared on the charts that were not listed in Appendix B. These were excluded from enumeration if unlabeled or if identified by the name of an individual or corporation. Additionally, mapped facilities that were labeled as closed or abandoned were excluded.

The 2003 Ohio River Navigation Charts included marinas and ramps located on tributaries to the Ohio River. These were included if located within 5 miles of the Ohio River or below the first lock and dam on the tributary river. In a few cases, the 1976 and 1987 charts did not include mapping of such tributaries. Where this occurred, facilities from the 2003 charts were excluded.

While this enumeration tracks the number of marinas operating on the Ohio River, it probably under-represents the overall service capacity provided. The enumeration does not address expansion of capacity at individual marinas. A few cases were noted where adjacent marinas shown on earlier charts appear to have merged into a single operation. The total count was thus reduced even though net service likely was not.

FIGURE 9-10
Ohio River Marinas and Public Ramps



Source: U. S. Army Corps of Engineers

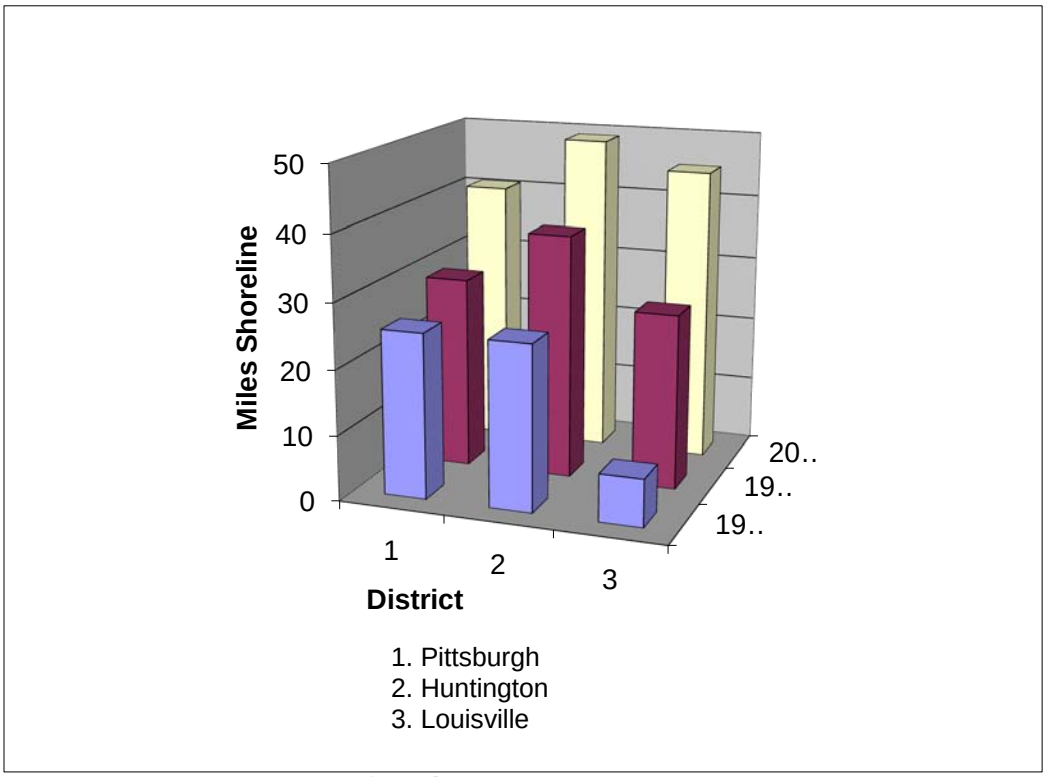
9.7.2.8 Fleeting Areas and Competing Uses of Ohio River Resources

Recreationists on the Ohio River must share the resource with commercial navigation. In addition to the size and number of barges and towboats on the water, the industry requires space for terminals and fleeting activities. Barge and tow activity is reflected in records of net tonnage of commerce shipped on the river (see Chapter 10, Transportation). Areas devoted to fleeting and terminal activity were calculated from Ohio River Navigation Charts, and are displayed in **Figure 9-11**.

Pittsburgh District mapping of 'Fleeting Areas' applies to both commercial dockage areas and to more remote locations where barges may be temporarily moored or anchored.

Huntington District mapping makes a distinction between commercial dockage areas (freight terminals) and 'fleeting harbors' for temporary barge moorage. Different map symbols are used for these two classifications. Interpreting both, as 'fleeting activity areas' would be most consistent with Pittsburgh District terminology. For consistency,

FIGURE 9-11
Mapped Fleeting Areas on the Ohio River



Source: U.S. Army Corps of Engineers

commercial docks were counted and assigned a value of 0.1-mile freight terminal activity unless otherwise mapped.

Louisville District mapping appears to apply 'Fleeting Areas' only to remote temporary moorage of barges. Freight terminal areas are illustrated as commercial docks and/or cells. The 'Fleeting Area' category in this district appears most directly comparable with the 'Fleeting Harbors' category in the Huntington District. Commercial docks were shown only as points in the 1987 and earlier charts, but are shown as stretches of mooring cells that could be measured for length in the 2003 charts. However, there is no basis for comparing changes in the areas of freight terminal activities from past to present. Therefore, past to present comparisons were only for fleeting harbors in the Louisville District.

For the total river, areas devoted to fleeting have increased by 233 per cent from 1976 to 2003. As of 2003, 135 miles of shoreline are used for fleeting activities, representing 6.9% of the Ohio River's total shoreline (981 miles x 2). The rate of increase has been steepest on the lower half of the river; fleeting areas have increased by over 600% in the Louisville District. Shoreline mileage utilized for fleeting activities on the Ohio River is summarized below in **Table 9-6**.

TABLE 9-6
Miles of Fleeting Activity on the Ohio River

Year	Pittsburgh District	Huntington District	Louisville District	Total
1976	25.3	25.3	7.3	57.9
1987	29.4	37.4	26.8	93.6
2003	40.7	49.1	45.1	134.9

Source: U.S. Army Corps of Engineers

9.8 INTERACTIONS WITH OTHER VALUED ENVIRONMENTAL COMPONENTS (VECS)

Recreational activities on the Ohio River exhibit very high levels of interaction with water quality and biological resources. Water quality appears to be the primary factor affecting the attractiveness of most recreational activities. Recreation on and around the river declined wherever water pollution reached excessive levels and returned soon after water quality recovered. Water quality also impacted intermediate factors such as fishing quality, which subsequently affected recreational activity.

In addition to fisheries, the entire spectrum of biological resources impacts the variety and quality of recreational opportunities. Riparian corridors, islands, beaches, and embayments provide varied settings for river-based activities. The bluffs and wooded hillsides contribute a scenic backdrop for such activities plus a focus for sightseeing, scenic drives, relaxing outdoors, and other contemplative approaches to recreation. Recreational demand for these resources may contribute to public and private efforts to protect or enhance such resources.

Although both recreation and commercial navigation have grown significantly over the past several decades, these potentially conflicting activities have managed to coexist with a minimum of friction. The navigation industry trains for and maintains a high degree of professionalism among its operators, contributing to very low accident rates between commercial tows and recreational boaters (see Chapter 8, Health & Safety). Likewise, the U.S. Coast Guard, state agencies, and some municipalities have improved boating safety through development of improved safety equipment standards, requirements for boat operator training, and enforcement of operational rules such as reckless operation and consumption of alcohol. In highly congested areas, additional regulations such as no wake zones are employed to improve safety on the water. Both recreation and commercial navigation are expected to continue to grow, with attendant competition for space on the water and for marinas, terminals, and related support facilities on shore.

Important relationships exist between cultural resources and recreational activities along the Ohio River. Potential income from tourism has often helped motivate the identification, renovation, and protection of historic sites, buildings, and districts in riverfront communities. Similarly, recognition and protection of cultural features may be incorporated into the planning and design of parks, trails, scenic byways, greenways, and urban redevelopment projects.

General relationships between Ohio River recreational factors and other VECs are summarized in **Table 9-7**.

TABLE 9-7
Interactions of Recreation Factors with Other VECs

VEC	Factors & Impacts	Past/Present Trends	Future Trends	Comments
Water Quality	Improved water quality is principal factor underlying past and ongoing growth of recreational activity.	Growth of river oriented activity with improved water quality and accessibility.	Continued growth of river oriented activity with improved water quality and accessibility.	Recreational experience, activity contributes to demand for better water quality.
Biological Resources (aquatic, riparian, T&E).	Resource recoveries contribute to quality, variety of recreational experience.	Growth of river oriented activity with improved fisheries, scenic riparian landscape.	Expanding navigation, commercial/residential and recreational uses of river will conflict with habitat needs.	Long term protection/ management of Biological Resources required to maintain recreational quality, variety.
Transpor-tation & Traffic	Mutual coexistence between commercial transportation and aquatic recreation.	Growth of both activities has not yet created major conflicts.	Continued growth of both activities may contribute to future conflicts, congestion.	Most recreationists accept barge navigation as part of scenic river environment.
Socio-economic & Environ-mental Justice	Expanding leisure time and disposable income per capita.	Growth of river oriented activity with expanded time and income.	Expanding variety of river-oriented activity. Potential conflicts from crowding or incompatible uses.	Continued growth of urban riverfront oriented development (housing, shopping, and recreation).
Health and Safety	Expanding river oriented activities contribute to expanding exposure to river related risks.	Water quality improvements, spill prevention & response, improved monitoring has reduced risks.	Continued expansion of river oriented activities require improved water quality & monitoring to maintain low risks.	Control of contaminant sources affecting water contact recreation and fish consumption issues has slowed following early gains.
Cultural Resources	Historic sites, districts, architecture add variety & quality to recreation experience.	Recreation growth, interest supports historic preservation and heritage tourism.	Continued growth of recreational interests in cultural heritage features.	Parks, trails, greenways, urban riverfront projects can all incorporate cultural resources in planning & design.
Air Quality	Particulate emissions and ozone formation can impair visibility.	Viewscapes, recreational quality have benefited from improved air quality.	Appears likely present air quality will be maintained or improved.	Haze from coal burning, other sources persists throughout Ohio River corridor.
Land Use	Residential, commercial developments compete with recreation for space.	About 40% of land in Ohio River corridor developed during past 20 years.	Conversion of open space for development appears likely to continue.	Opportunities exist to incorporate recreation, preservation values in development, redevelopment designs.

9.9 RELEVANT ACTIONS AFFECTING RECREATION

RFFAs were evaluated for recreation oriented issues utilizing the RFFA Matrix (see Exhibit A, Procedure and Methods, for discussion of RFFA matrix). The matrix evaluation process resulted in identification of 17 RFFAs with high or medium high importance for recreation and an additional 38 that were rated as having medium importance. Results of the RFFA evaluation for recreation resources are summarized in **Table 9-8** and discussed in further detail in text following the table.

TABLE 9-8
RFFA Cumulative Effects Matrix for Recreation VEC

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location On River[4]	Impact	Importance[5]
Navigation Investment Actions					
Lock Extensions/New Locks/ Replacement or Rehabilitation	A	H	SL	+	M
L&D Operation & Maintenance, Non-structural Improvements, Dam Replacement/Rehab	A	H	SL	+	M
Other Corps Actions					
Channel dredging/dredged material disposal	A	H	SL	-	M
Flood damage reduction projects					
levees/floodwalls	A	L	SL	-	M
dry dams, other projects off mainstem	A	H		+	M
nonstructural measures (relocation)	A	H	SL	+	M
Modification of Corps structures for env-onmental improvements (Sec. 1135)	A	M	SL	+	M
Environmental restoration of aquatic ecosystems (Sec. 206)	A	M	SL	+	M
Recreation facilities - Construction and O&M	A	H	SL	+	H
ERP Projects - 5 categories	A	M	SL	+	M/H
Port development (Sec. 107) and maintenance dredging	A	H	SL	-	H
Pool maintenance	A	H	E	+	M
"But for" Actions					
Commercial Navigation					
fleeting areas/barge storage	A	H	SL	-	H
terminals	A	H	SL	-	M
multi-modal sites	A	H	SL	-	M
increased traffic	2, 3	H	U	-	H
dispersed barge traffic	A	H	SL	-	M
accidents/spills	A	H	E	-	M
Hydropower on dams	A	H	SL	-	M
Recreation facilities: Construction/O&M	A	H	SL	+	H
Actions by Others					
Public lands acquisition and management	A	H	SL	+	H

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location On River[4]	Impact	Importance[5]
Floodplain development					
residential	A	M	SL	+/-	M
commercial	A	M	SL	-	M
industrial	A	M	SL	-	M
Private recreational sites: campgrounds, docks, seasonal trailer parks, etc.	A	H	R	+	M
Crossings					
bridges	A	H	SL	+/-	M
Marina development & operation	A	H	SL	+	H
Water -based recreation					
boating	A	H	E	+	H
fishing	A	H	E	+	H
PWCs	A	H	E	+	H
hunting	A	H	R	+	H
wildlife watching	A	H	E	+	H
sight-seeing	A	H	E	+	H
Silviculture	A	H	E	+	M
Agriculture	A	H	R	+/-	M
WWTP discharges					
municipal	A	H	SL	+	H
industrial	A	H	SL	+	M
onsite systems	A	H	SL	-	M
Stormwater discharges	A	H	SL	-	H
Brownfields redevelopment	A	H	SL	+	M
Trail/bikeway development	A	H	SL	+	H
Casinos	A	H	SL	+/-	M
Hazardous waste sites	A	M	SL	-	M
Natural Climatic Events					
floods	A	H	E	-	M
droughts	A	H	E	-	M
severe storms	A	H	E	-	M
Regulatory Environment					
More stringent standards for envir-onmental media, pollutant source control, pollution prevention	A	H	E	+	M
Wetland Mitigation Banking	A	H	SL	+	M
Farmland preservation	A	H	R	+	M
Agricultural discharges	A	H	R	+	M
Small navigation projects	A	H	SL	-	M
Boating safety regulations	A	H	E	+	M
ORSANCO monitoring program	A	H	E	+	M
Spill response	A	H	E	+	M
Environmental sustainability practices	A	H	E	+	M

[1] Reasonably Foreseeable Future Actions

[2] Time period in which the RFFA may occur: 1 = within 10 years, 2 = in 10 - 25 years, 3 = in 25 - 60 years, A = applicable to all time periods

[3] Occurrence probability or likelihood RFFA will happen: H = high, M = medium, L = low

[4] Location or setting on river where RFFA is expected to occur: E = along entire length of river, SL = specific location, e.g., locks and dams, U = urban setting, R = rural setting

[5] Importance of RFFA: H = high, M = medium, L = low

9.9.1 Navigation Investment Actions

- Lock Extension, Replacement, or Rehabilitation (Impact, +; Importance, M): Short-term negative impacts are associated with construction activity. Access through the locks during construction would likely be restricted to commercial vehicles. Long-term positive impacts would be realized as new, extended, or replaced locks would provide more efficient and dependable service to recreational boaters.

- L&D Operation & Maintenance, Non-structural Improvements, Dam Replacement/Rehab (Impact, + Importance, M): Maintenance activities generally contribute to long term safety and efficiency of lockage services to recreational users. Short-term suspension of service may occur during some lock repair closures.

9.9.2 Other Corps Actions

- Channel dredging/dredged material disposal (Impact, -; Importance, M) Localized and temporary impacts occur to recreational boaters in the area of dredging activity. Potential habitat benefits could include dredged materials being used to build up bars or islands and to create or enhance shallow water habitats. Other channel maintenance activities such as clearing snags can have negative impacts on sport fisheries and general aquatic habitat values. Snag clearing appears to cause an unnecessary resource impact when it occurs outside navigation channels.

- Flood damage reduction projects: levees/floodwalls (+/-, M): These projects protect people and infrastructure investments and reduce or eliminate potential damage costs in flood prone areas. Traditional construction of such projects restricted access to the riverbank. Urban renovation, riverfront parks/developments typically include re-establishing links to the river.

- Flood damage reduction projects: dry dams and other projects off mainstem (+, M): These actions would positively impact river-based recreation by easing flooding in the river. This would provide benefits by reducing river flood levels and velocities and minimizing debris, pollutants, and sediments washed into the river.

- Flood damage reduction projects: nonstructural measures (e.g., relocation) (+, M): Streamside buffers that reduce non-point source pollution would improve water quality, aquatic habitat important to fisheries, and make river use more enjoyable. The relationship of water quality to recreation was frequently cited in survey responses and focus interviews.

- Modification of Corps projects for environmental improvements (Sec. 1135) (+, M): Improved habitat would enhance recreational use of the river. Positive benefits to fisheries and aquatic and riparian resources enrich numerous recreational activities.

- Environmental restoration of aquatic ecosystems (Sec. 206) (+, M): Positive benefits to recreation would be derived from improved aquatic and riparian

resources. Benefits would include all types of 'resource oriented' recreation, plus economic, health, and aesthetic benefits.

- Recreation facilities - Construction and O&M (+, H): Positive, long-term impacts would be realized from continued development of facilities specifically designed for recreational use and access.

- Ecosystem Restoration Projects (+, M/H): Improved habitat will result in improved fisheries and increased bird use. Shoreline/river fishing, waterfowl hunting, and bird watching would benefit. River-based hiking, picnicking, and sightseeing would also benefit from enhanced aesthetics of more natural landscapes. Surveys and focus interviews frequently cited the correlation of habitat improvement with improved quality of recreation and aesthetics.

- Port development (Sec. 107) and maintenance dredging (-, H): Development of ports and dredging for navigation traffic in response to increased navigation use of the river would result in conflicts with recreational boaters. Port development and dredging will also result in loss of shallow water habitat and a concomitant loss of fisheries. Port development could contribute some impacts to aesthetics and affect boat use in the area.

- Pool maintenance (+, M): Pool stability benefits docks and other shoreline recreational infrastructure. Suggestions for restored hydrologic functions would improve habitats and benefit resource oriented recreation.

9.9.3 But-for Actions

- Commercial Navigation: fleeting areas/barge storage (-, H): Negative, long-term impacts are associated with conflicts between recreation and commercial activity around these facilities and loss of recreational use. The general perception of aesthetic loss would also affect river use in proximity to these areas. Loss of shallow water habitat would affect fishing, while loss of riparian habitat would impact fishing, birding, and duck hunting. Fleeting areas should be located away from shore when possible, using off shore mooring cells to reduce negative impacts to shoreline habitat, aquatic habitat, fisheries, and recreation. Use of "dead-man" mooring devices causes riparian habitat loss and degradation.

- Commercial Navigation: terminals & multi-modal sites (-, M): Commercial activity around these facilities would contribute to negative, long-term impacts to recreation. The general perception of aesthetic loss would also affect river use in proximity to such areas. Loss of shallow water habitat due to dredging, propeller wash, and scour would negatively affect fisheries. Loss of riparian habitat affects birding and duck hunting.

- Commercial Navigation: increased traffic (-, H): Conflicts between commercial vessels and recreational boats could lead to long-term negative impacts for recreation. The severity of crowding impacts is dependent on the carrying capacity of individual river segments. Negative cumulative impacts to sport and

commercial fisheries will likely occur since commercial towboats have been documented to cause adult and larval fish entrainment mortality.

- Commercial Navigation: dispersed barge traffic (-, M): Significant, short-term impacts occur due to the safety and environmental degradation effects of dispersed navigation. Navigation traffic outside shipping lanes presents a danger to small craft using these areas to fish or sightsee. This danger is related to direct contact or large wakes. Navigating outside the channel causes negative impacts to sensitive aquatic habitats, shorelines, and substrates, possibly affecting sport and commercial fisheries. Sport and commercial fisheries will also likely be affected by entrainment mortality.

- Commercial Navigation: accidents/spills (-, M): Short to medium range impacts associated with safety concerns is linked to exposure to spills. Secondary impacts would be loss of fish and other aquatic organisms and fouling of habitat.

- Small navigation projects (-, M): Negative impacts could occur in the immediate area of the small navigation project if there is increased river traffic. Depending on the nature of the project, impacts to recreation could include limited access, increased congestion, and other effects.

- Hydropower on dams (-, M): Negative impacts will occur to aquatic resources and fisheries unless mitigating flows are mandated.

- Recreation facilities: Construction and O&M (+, H): Positive, long-term impacts would occur due to an increase in facilities specifically designed to facilitate recreation.

9.9.4 Actions by Others

- Public lands acquisition and management (+, H): Such acquisitions are critical to the long term protection and restoration of habitats, open space, and recreational opportunities.

- Floodplain development: residential (+/-, M): Growth in residences along the river would generally support a growth in boating, PWCs, touring boats, and fishing as individuals have less distance to travel to participate. There would be growth in private docks and marinas to accommodate the local population. Floodplain development could necessitate dikes and levees with subsequent loss of aquatic/riparian resources and associated recreational opportunities.

- Floodplain development: commercial/industrial (-, M): Growth in commercial/industrial activity along the river would compete with recreation, agriculture, and other potential land uses. Floodplain development could necessitate dikes and levees with subsequent loss of aquatic/riparian resources and associated recreational opportunities.

- Private recreational sites, including campgrounds, docks, and seasonal trailer parks (+, M): Continued growth of these developments is likely to continue in rural

counties in response to demand for recreational facilities. These facilities may have a higher potential for negative habitat and water quality impacts compared to public parks.

- Crossings: bridges (+/-, M): New or expanded bridges can improve accessibility to an area and promote growth of recreational activity, demand for recreational lands, and services. Bridges also may stimulate residential/commercial growth resulting in overcrowding and loss of recreational opportunities.

- Marina development & operation (+, H): Positive, long-term impacts due to an increase in facilities specifically designed to facilitate recreation would occur. However, concentration of marinas in embayments can contribute to losses of wetland/riparian resources.

- Water-based recreation: boating, fishing (+, H): Conflicts exist among fishing, PWCs, navigation, and water-skiing. Most of this conflict is minimized due to typical time of day when use occurs. Fishing occurs more in early morning and evening while other uses tend to occur mid-day. Because of their duration, fishing tournaments can conflict with other river uses. Survey and focus interview respondents report a low level of conflicts; the river provides adequate space for multiple uses.

- Water-based recreation: PWCs (+/-, H): As PWC use increases, there is greater potential for user conflict between them and recreational boaters and fishing. Implementation of training requirements and licensing would help mitigate this impact. Survey and focus interview respondents also suggest enforcement of rules can reduce conflicts.

- Water-based recreation: hunting (+/-, H): No significant conflicts with hunting are expected as long as it continues to occur away from residential and other populated areas. Most hunting occurs at dawn and dusk, thus avoiding most conflict with other users. Long-term availability of hunting areas will continue to decline in response to floodplain development.

- Water-based recreation: wildlife watching, sightseeing (+, H): Survey and focus interview respondents indicate that passive forms of relaxing outdoors are the most popular forms of river oriented recreation. Aesthetic factors, solitude, peace and quiet are important to these user groups. Up to a point, urban development and commercial navigation are accepted as part of the river environment and viewscape.

- Silviculture (+, M): Wooded shorelines and islands would add to the aesthetics of the river and enhance the recreational experience. Trees also enhance aquatic and riparian resources, control erosion, and filter runoff. Harvesting of timber could affect aesthetics and could serve as a source for non-point runoff that would negatively affect recreational use of the river, but most commercial harvest can be managed to minimize such impacts and maintain compatibility with recreation and aesthetic values.

- Agriculture (+/-, M): Agriculture is a source of non-point runoff of sediment, fertilizer, and pesticides that can negatively affect recreational use of the river due to water quality impacts and effects on fish. Implementation of BMPs (wooded riparian corridors, grass swales, filter strips, etc.) reduces sediment and pollutant runoff. Agricultural activity negatively impacts corridor habitat by eliminating tree canopy and native plant communities. Conversely, agriculture would be considered very aesthetic by most river users and would not detract from the recreation experience.

- WWTP discharges: municipal, industrial (+, M/H): In general, WWTP operations and treatment of industrial discharges have made significant contributions to improved water quality and recreational uses of the river. Impacts depend on level of treatment, operational consistency, and water levels in the receiving stream. Toxicity, temperature, odors, and visual effects are potential negative impacts to recreation.

- WWTP discharges: onsite systems (-, M): Onsite systems tend to be less reliable than WWTPs and, depending on their locations and numbers, can negatively impact water quality and recreational use.

- Stormwater discharges (-, H): Stormwater discharges include CSOs, SSOs, and runoff from urban surfaces, which contribute to elevated bacteriological contamination that create health risks and aesthetic impacts for recreational users of the river.

- Brownfields redevelopment (+, M): Many brownfields are being developed into mixed commercial, residential, and industrial uses. Developments are often up-scale and use the river as an asset. Depending on the river amenities added to these developments, the effects on recreation have generally been positive.

- Trail/bikeway development (+, H): Positive, long-term impacts result from an increase in such facilities. Forested or open park landscape, plus trail and infrastructure design contribute to environmental benefits, including viewscape protection. Survey and focus interview respondents also note importance of pedestrian connectivity and riverfront access to success of mixed-use riverfront developments.

- Casinos (+/-, M): Casinos may compete with marinas for space in embayments and contribute to loss of wetland and riparian habitats. Casino gambling generates mixed reactions among survey respondents.

- Hazardous waste sites (-, M): Unmanaged sites can cause a wide range of environmental damage with negative impacts to recreational use and aquatic life. Remediation or stabilized containment and long term monitoring is required to minimize negative impacts. (See also comments under Brownfields.)

9.9.5 Natural Climatic Events

- Floods and severe storms (-, M): Periodic impacts occur to all forms of recreation during and immediately after such events due to safety considerations. Rising water would affect all boats. Floating debris creates safety and aesthetics problems. Medium importance due to infrequency of events.

- Drought (-, M): Severe droughts could have a significant impact on recreation. The lowering of the river level decreases the surface acreage thereby increasing the potential for conflict. Less water also means less dilution of pollutants, thus decreasing water quality. Medium importance due to infrequency of events.

9.9.6 Regulatory Environment

- More stringent quality standards for environmental media, pollutant source control, and pollution prevention (+, M): Long-term positive impacts would be associated with improved environmental conditions. The river becomes a more enjoyable place to play.

- Wetland Mitigation Banking (+, M): This activity would benefit recreation by reducing run-off, improving habitat, and providing recreational opportunities.

- Farmland preservation (+, M): These programs are becoming important components of efforts to preserve open space and wildlife habitat and to control runoff. Preserved farmland creates incentives to implement agricultural BMPs (see agricultural discharges).

- Agricultural discharges (+, M): Implementation of BMPs (wooded riparian corridors, grass swales, filter strips, etc.) contributes to reduced sediment and pollutant runoff. Stronger incentives are needed to expand participation.

- Boating safety regulations (+, M): Some beneficial impacts could result if boater and PWC user behaviors are modified through education and enforcement of common sense rules. Conflicts among users and perceptions of crowding can be reduced through regulation of individual behaviors.

- ORSANCO monitoring program (+, H): Monitoring programs for the Ohio River provide data to states and others for management and enforcement responsibilities and contributes to maintenance of water quality. Though ORSANCO has no statutory authority, it does educate the public, public officials, and industry on water quality status.

- Spill response (+, M): Effectiveness of spill prevention, monitoring, and response programs reduces spills and minimizes damages from spills that do occur.

- Environmental sustainability practices (+, M): Provides a benchmark for evaluating present and desired future uses of the river and its resources.

9.10 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve environmental sustainability (ES). ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of CEs can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An Analysis of Environmental Sustainability (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps:

(1) identification of "common effects" on recreation parameters from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix;
(2) selection of sustainability indicators for recreation, and their grouping, as appropriate; and
(3) consideration of the "connections" between the common effects and the indicator groups

The output of the AES consists of a qualitative (descriptive) discussion of the "connections", with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for recreation, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – the composite conditions for the selected indicators of ES for recreation do not reflect conditions that would facilitate attainment of acceptable standards or would not maintain existing standards in concert with collective impacts of proposed activities.

- Marginally sustainable – the composite conditions for the selected indicators of ES are such that attainment of acceptable quality and variety of recreational opportunities is accomplished for the majority, but not all, of the potentially affected populations. However, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of recreation for the Ohio River).

- Sustainable – the composite conditions for the selected indicators of ES are such that the attainment of acceptable quality and variety of recreational opportunities is accomplished for essentially all of the potentially affected populations in the Ohio River Valley, and such standards are maintained in concert with foreseeable future activity. Further, the conditions of the indicators exceed regulatory thresholds, and

various governmental programs are in place to respond to any potential erosion of recreational values.

Common effects of multiple actions have been previously discussed in the sections entitled "Interactions with Other VECs" and "Relevant Actions Affecting Recreation". Indicators or groups of indicators of ES were identified earlier in the section entitled "Indicators of Sustainability", and relevant information on them have been presented in the sections entitled "Past to Current Baseline Conditions" and "Recreation Surveys for ORMSS." For the purposes of this ES analysis, the sustainability indicators are associated with three tiers:

- first tier – "quantitative measures of recreation resource factors", for example, census information related to recreation opportunity or demand and ramp/marina counts from navigation charts

- second tier – "composite measures of recreation resource factors", for example, ramp/marina and fleeting area trends over time and survey trend questions related to future accessibility, and

- third tier – "composite indicators of recreation sustainability"; this includes measures developed from multiple indicators, for example, data on support for subsidized recreation infrastructure and on the busiest commercial pools.

Tables 9-9 and 9-10 include selected indicators of recreation sustainability. **Table 9-9** addresses the indicators of opportunity and accessibility. These indicators encompass general factors affecting one's ability to participate in the recreational opportunities provided by the Ohio River. The first column of **Table 9-9** lists examples of RFFAs associated with these indicators. General aspects of the maintenance, expansion, and operation of the Ohio River navigation system contribute to opportunity by providing stable pools, sufficient depth, and efficient, dependable service for recreational boaters. Included as principal RFFAs are actions that increase access (e.g., marina development and construction and maintenance of recreation facilities) and actions that can restrict access (e.g., port and terminal development and development or expansion of fleeting areas). From the discussion of RFFAs, it is apparent that many access-related actions have multiple effects. New or expanded highways and bridges, for example, increase river access and may lead to development of marinas and other facilities that support recreation. Marinas, however, may cause aquatic habitat damage/loss, which can reduce the overall quality of the recreation experience. Excessive recreation/commercial development resulting from transportation improvements also can result in localized congestion and competition. Limited resources such as embayments and wetlands, which constitute important habitats, desirable natural settings for recreation activity, and attractive sites for recreation oriented development, are particularly susceptible to such impacts. Thus, as one straightforward action leads to a series of other actions, a complex network of CEs can result that may be more than the "sum of its parts".

Table 9-10 considers actions related to the quality of recreation experiences. Experiences gained from participation in a recreational activity will directly influence future recreational choices. Likewise, public and private actions that contribute to maintenance or enhancement of recreational quality will be motivated by experience and

will contribute to long term sustainability. Environmental restoration of aquatic ecosystems and acquisition of lands for public use potentially enhance recreation aesthetics and use and also may lead to habitat and water quality improvements. Increased barge traffic or heavily concentrated recreational activity may contribute conflicts that detract from river recreation and even present safety hazards. CSOs and other nonpoint sources of pollution also can detract from river recreation and cause public health concerns. Counterbalancing these RFFAs are efforts such as the ORSANCO monitoring program, which assesses the river's water quality and helps warn of conditions that may degrade the environment and recreation experience.

9.11 SUMMARY AND CONCLUSIONS

Currently, the Ohio River is a popular setting for a broad spectrum of recreational activities. People living in counties adjacent to the river tend to view this resource as an important contributor to their quality of life and a significant portion of their recreational activity is oriented to the river. In urban areas, interests in the river have contributed to the provision of a wider range of opportunities, including riverfront parks and landings, large marinas, special events, and riverfront dining, shopping, and related entertainments. Almost every large and small community along the river provides some type of facility and event oriented to the river. Urban, small town, and rural settings along the river also serve as regional recreation and tourism destinations.

Events that draw large crowds and activities with large numbers participating attract a lot of attention, but solitude and quiet relaxation are some of the most important values associated with recreation on the Ohio River. People who look to the river for their recreation speak often of 'enjoying back-to-nature settings,' 'relaxing in quiet, uncrowded areas,' and 'scenic qualities, the beauty of the river.' These values are important to people participating in all types of activities, such as riverfront dining and sightseeing, hiking, biking, fishing, or just relaxing. People living in urban areas especially appear to value the river as a convenient way to escape and relax.

Recreational activities on the Ohio River have grown steadily since the early 1950s. Improved water quality during a time of economic prosperity appears to have been the principal contributor to past and recent growth trends. Water quality, accessibility, maintenance of recreation facilities, and an expanding selection of recreation choices are the primary factors affecting current trends in recreational activity.

There appear to be no significant impediments to continued growth of recreation on the Ohio River. People are generally willing to accept high levels of crowding on the busier urban pools, while more rural pools offer plenty of room for activities in a more natural setting. People using the river tend to be tolerant of others who recreate there and confident that reasonable enforcement of common sense rules can address most problems. People using the river also tend to accept the present level of commercial navigation activity and do not view barge traffic as posing a significant threat to their enjoyment or safety. As reported in the aquatic resources chapters, it appears likely that water quality in the Ohio River will continue to improve.

People who recreate on the river generally plan to continue doing so or to increase their activity in the foreseeable future. Existing parks and access facilities along the urban

pools are heavily used and new facilities are readily discovered and utilized. However, access points and other resources in some rural areas appear to be less crowded. A variety of public agencies and private organizations are actively engaged in development of new riverfront parks, greenways, trailways, boating access, and mixed use urban riverfront projects.

The principles of adaptive management can be applied to minimize potential long-term threats to the sustainability of recreation on the Ohio River. Elements of planning, monitoring, and early action before problems become critical can help avoid undesirable consequences. The greatest efforts in this respect should focus on protecting the natural resources that make the Ohio River so attractive to recreational interests. These include water quality, productive fisheries, healthy riparian habitats, scenic vistas, and opportunities for quiet relaxation in both rural and urban settings. In this context, embayments and wetlands should be monitored most closely, as these constitute limited resources along the Ohio River that are subject to competing pressures for use. In particular, embayments can provide important fishery, avian, water quality, and floodplain functionality benefits and are a popular setting for fishing, boating, swimming, waterfront parks, and other outdoor activities. They are also highly desired as sites for marinas, camping, casino resorts, and other developments that can severely degrade their resource functionality values.

Based upon the above-described actions and effects, the tiers of indicators, and the ES categories, the ES of recreation for the Ohio River mainstem can be characterized and depicted in **Figure 9-12** as follows:

- In the time period prior to 1920, and continuing up to about 1970, recreation on the Ohio River occurred in a degraded environment due to largely untreated and uncontrolled pollution discharges from growing municipalities, mining activity, and various types of industries and land uses along the river. Although the river continued to be used for recreation during this period, the overall ES was "marginally sustainable" and may have been "not sustainable" for the worst years of pollution. However, recreation information from the worst decades of pollution is limited as that time period coincided with the Great Depression, World War II, and the post-war period shortly thereafter, when leisure time and financial resources were limited.

- At the present time, recreation on the Ohio River is currently in a "sustainable" condition due in large measure to water quality improvements related to ORSANCO programs and requirements of the Federal Water Pollution Control Act (and the amended Clean Water Act). Water quality improvements, combined with increased economic prosperity, have increased demand for and stimulated development of marinas, ramps, and other recreation facilities along the river. The recent era of more integrated riverfront planning also has addressed recreation needs and has increased opportunities for an expanded spectrum of recreational choices.

- Regarding the future, it is expected that community planning and development of recreation facilities, further water quality improvements, especially in stormwater and CSO management, and habitat protection and restoration efforts will continue

to enhance recreation experiences. Socioeconomic projections for a stable or slowly growing population and continued improving standard of living would be expected to result in continued growth of demand for recreational opportunity. Consequently, the future ES is classified as "sustainable." Although the perception exists that increased participation could lead to overcrowding and competition for limited resources, it does not currently seem to be an overriding influence affecting people's decisions to participate in river-related activities.

FIGURE 9-12
ES of Recreational Resources

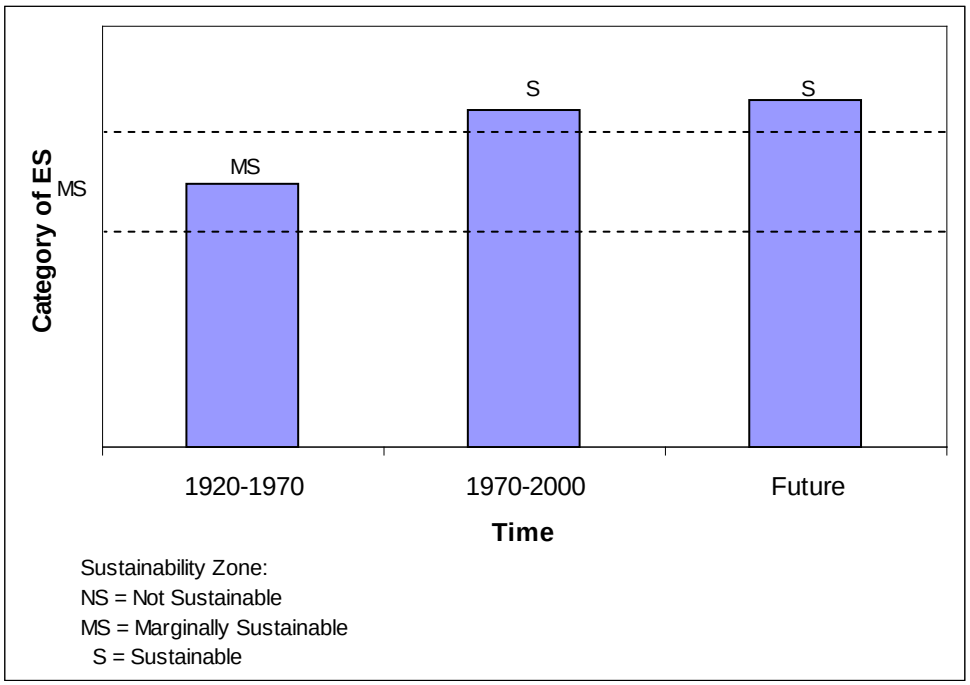


TABLE 9-9 AES Tiers for Actions Causing Recreation Effects Related to Opportunity and Accessibility			
Examples of Actions Impacting Recreation Sustainability	**Quantitative Measures Of Recreation Resource Factors**	**Composite Measures of Recreation Resource Factors**	**Composite Indicators of Recreation Sustainability**
RFFAs include: • New locks, lock extension, replacement or rehabilitation • L/D O & M • Pool maintenance • Development or expansion of fleeting areas • Port and terminal development • Construction and maintenance of recreation facilities • Marina development	• Census counts of income, education, employment, other indicators of recreation opportunity or demand. • Survey of recreation activity, preferences, and demographics. • Ramp/marina and Fleeting area counts from Navcharts • Survey questions addressing accessibility • Focus Interviews • Topics from past-present history of recreational activities.	• Census and BEA calculations of household and per capita incomes, employment levels by SIC code. • Survey trend questions – future recreation demand and future effects of accessibility issues. • Focus interviews re future demand, direction, effects of accessibility issues. • Ramp/marina and fleeting area trends	• Projections based on fertility, mortality, immigration, labor force participation, and growth of national productivity. • "Most congested pools" as case studies for future crowding, space management issues (Markland, EDM, McAlpine). • Busiest commercial pools (lower river, also Markland & McAlpine). • Interpretation of survey & focus group findings (look at answers from urban, PA groups).

TABLE 9-10 AES Tiers for Actions Causing Recreation Effects Related to Quality of Experience			
Examples of Actions Impacting Recreation Sustainability	**Quantitative Measures Of Recreation Resource Factors**	**Composite Measures of Recreation Resource Factors**	**Composite Indicators of Recreation Sustainability**
RFFAs include: • Increased barge traffic • Environmental restoration of aquatic habitats • Public lands acquisition and management • Stormwater discharges • Combined sewer overflows • ORSANCO monitoring programs	• Survey & focus group interviews. • Topics from past-present history of recreational activities.	• Trends – Inferred from survey & focus group interviews, factors influencing future activities.	• Interest/support for publicly subsidized recreation infrastructure: - Parks, trails, boating access, etc. - Riverfront developments-recreation features integrated with other entertainment, dining, shopping, etc. - Protection/enhancement of 'recreation environment' e.g., Ohio River Islands National Wildlife Refuge, other protections of open space, forested bluffs, viewscapes, aquatic/riparian resources, water quality.

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Chapter 10

TRANSPORATION AND TRAFFIC EFFECTS

10.1 TABLE OF CONTENTS

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10.2 DEFINITION OF RIVER-RELATED TRANSPORTATION AND TRAFFIC

Transportation and traffic, as defined for the Ohio River Mainstem System Study (ORMSS), concerns the conveyance of goods and people along the Ohio River mainstem and the associated traffic activities. Transportation and traffic, consequently, considers the Ohio River navigation system, shipping volumes, shipping modes, and commodities shipped, as well as intermodal transportation facilities and connections. Intermodality focuses on how individual transportation modes can be integrated into a seamless, sustainable system.

Numerous business and economic forces influence population growth or loss and related economic changes along the Ohio River mainstem and, in turn, influence

transportation and traffic. Market forces and economic factors also influence the navigation system. Consistency and predictability in operation of the navigation system are keys to efficient, cost-effective transportation on the Ohio River mainstem.

10.3 OBJECTIVES AND SCOPE OF THE TRANSPORTATION AND TRAFFIC STUDY

10.3.1 Objectives

This chapter assesses the system-wide cumulative transportation and traffic effects of all likely major navigation improvements along the mainstem of the Ohio River from 2000 - 2070. Transportation and traffic impacts that are directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFAs) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFAs. These future actions include major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, actions by non-governmental entities, and predictions of general economic expansion and development.

The results of the Cumulative Effects Assessment (CEA) are intended to contribute to two topics of subsequent public debate: (1) whether the impacts of the RFFAs constitute acceptable outcomes for the affected resources and (2) how the proposed navigation improvements contribute to those outcomes.

10.3.2 Geographic Scope

The primary geographic focus for transportation and traffic impacts includes those areas most directly impacted by operation and maintenance of the navigation system, that is, the Ohio River itself and associated ports, terminals, and intermodal sites located in adjacent riparian areas. The more comprehensive intermodal perspective of the study area, however, includes railways and highways radiating out into the larger Ohio River basin.

10.3.3 Time Frame

The established time frame for this project is 1920 to 2070. The earlier date approximates the initiation of modern Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by ORMSS.

10.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through

comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. More detailed discussions of the scoping meetings are presented in Exhibits A and B of this CEA.

The meetings were attended by 185 persons, and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted.

Transportation and traffic was a major focus of the meetings with more than 60 individual comments on it. **Table 10-1** presents comments that directly and indirectly addressed transportation and traffic.

TABLE 10-1
Comments from Public Scoping Meetings

Direct Comments on Transportation and Traffic	Relevance to Transportation & Traffic	Total Comments
Study may overemphasize transportation and river commerce	Other aspects of study may not be considered adequately	1
Application of Ohio River Navigation Investment Model to ORMSS	Integration of model with ORMSS is needed	1
Relationship between ORMSS and completion of Olmsted L/D	Timing and integration of the study and the project	1
Integration with ORMSS with the U.S. DOT Marine Transportation Study	Relationship between the two studies	1
How ORMSS study will affect Greenup L/D upgrade	Clarification of interaction between the study and the project	1
Inclusion of no-action alternative in ORMSS	Need to discuss impacts of no navigation improvements	1
Loss of shoreline trees and river property caused by barge activity	Frequently expressed concern related to barge traffic and "toeing in"	7
Reliability of barge traffic forecasts	Actual need for lock expansions	5
Failure of barges to stay in designated shipping lanes	Environmental impacts and safety issues	2
Changes in shipping demand as low sulfur coal reserves near depletion in next 25 years	Effects on traffic forecasts	1
Why USACE expects only 1% increase in barge traffic, while a 3% increase in gross domestic product is expected	Discrepancy between traffic and economic forecasts	1
Navigation structures presently not keeping pace with traffic demands	Potential inability of navigation system to meet future needs	3
Clarification of scheduling and frequency of lock closures	Assessment of current conditions	1
View of navigation improvements as benefiting only shipping industry	Concern about general need for improvement	1
Why economic forecast model is based on use of auxiliary locks	Clarification of auxiliary locks use	1
Has ORNIM (navigation investment model) been run on the system	Validity of ORNIM	1

Direct Comments on Transportation and Traffic	Relevance to Transportation & Traffic	Total Comments
Support expressed for value and maintenance of OR navigation system	Importance of system to transportation and traffic	3
Importance of maintaining shipping channel	Importance for traffic flow and minimizing environmental impacts	2
Bank undercutting and failure caused by increased barge traffic, queuing and wave action	Frequently voiced environmental impacts of transportation and traffic	7
Enhancement of river transportation capabilities through corresponding development/improvement of intermodal transportation facilities	Relationship between river transportation and other modes of transportation	2
Need for long-range coordination with FHWA, state and local transportation agencies	Coordination of intermodal transportation	1
Need to integrate navigation with other transportation modes	Importance of intermodal transportation	2
Concern about ancillary movement of goods and services in emergencies, e.g., bridge destruction	Preparedness for emergency situations	1
Use of AWO and DINAMO to notify towing industry of public meetings	Concern that relevant parties were notified	1
Interest in including a vision of the river for the year 2070	Projection of transportation and traffic in 2070	1
Accuracy of models for predicting population growth and development	Impacts of such growth on transportation and traffic	1
Relationship between CEA and SIP products schedules	Timing and integration of the two studies	1
Need to consider most operations of commercial navigation system as direct USACE actions	Identification of USACE responsibilities	1
ORMSS schedule possibly lagging behind future navigation needs	Potential inability of navigation system to meet future needs	5
Status of funding for J.T. Myers L/D	Status of this specific navigation improvement	1
Assessment and documentation of Olmsted construction	Status of this specific navigation improvement	1
Current cost estimates on lock extensions at Myers and Green L/Ds	Cost of extensions in today's dollars	1
Effects of Greenup L/D improvements on barge queuing	Impacts of improvements in facilitating traffic movement	1
Overall effects of navigation structures and activities on groundwater levels	Impacts of pool levels on groundwater levels	1
Increase in barge loading/unloading facilities limiting fishing access from shore	Potential conflict between transportation and recreation	1
Need for fish habitat improvements, including fish passages around L/Ds	Interference of navigation system with fish migration	2
Stress and disruption of waterfowl migratory patterns caused by barge traffic	Interference of navigation system with waterfowl migration	1
Estimated number of officers that enforce shipping regulations along OR	Capacity for enforcement affecting existing transportation and traffic	1
Need for USACE to encourage uniformity in navigation charts along length of OR	Addresses safety and communication issues	1

10.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

Indicators of Environmental Sustainability (ES), which vary by Valued Environmental Component (VEC), generally provide benchmarks for measuring CEs on a given resource. Sustainable transportation considers transportation systems, policies, and technologies and is inextricably linked to socioeconomics and the environment. The following definition, adapted from the Centre for Sustainable Transportation in Ontario (http://www/cstctd.org/CSTaboutus.htm), applies to transportation along the Ohio River mainstem:

A sustainable transportation system:

- Allows the basic needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations;
- Is affordable, operates efficiently, connects with other transportation modes, and supports a vibrant economy; and
- Limits emissions and waste within the environment's capacity to handle them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components and minimizes the use of land and the production of noise.

Many transportation indicators are time series, which compare the same data at different times and, consequently, can show movement toward or away from sustainable conditions. Environmental indicators relevant for this study include:

- Barge tonnage passing through each lock over time
- Annual barge tonnage with origin and destination within the Ohio River navigation system
- Annual barge tonnage with origin in the system but moved out of the system
- Annual barge tonnage with origin outside the system but moved into the system
- Percentages of different commodities transported along the river over time
- Numbers of terminals and intermodal transfer facilities over time
- Average queuing times for barge traffic at locks over time
- Capacity and condition of rail and highway links in the study area and
- Amount and types of fuel used by tows over time.

In addition to providing measures of sustainability overall, these indicators can reveal the effects of governmental and business policies and practices. Further, they can help shape new policies and practices.

10.6 LAWS, REGULATIONS, ORDINANCES, AND PROGRAMS

One of the most significant legislative acts related to Corps' regulatory activities and river transportation was enacted more than a century ago in 1899 when the Rivers and Harbors Appropriation Act was passed. Since then, the act has been amended several times, but many key sections of the 1899 act remain relevant to river transportation and

traffic in the 21st century, including the authority of the Corps to issue permits under the act. The Water Resources Development Act, first enacted in 1976 and subsequently reauthorized several times, also has far-ranging implications for Corps' activities and includes general provisions that enlarge the Civil Works program's mission to include environmental protection in planning, designing, constructing, operating, and maintaining Corps' projects. During the 1980s, both the Harbor Maintenance Tax and Inland Waterways Trust Fund began to generate significant funds dedicated to maintaining and expanding the navigation system on the nation's inland waterways.

The latter third of the 20th century also witnessed the passage of several key environmental acts (e.g., NEPA, Clean Water Act, Oil Pollution Act, and others) that directly influence Corps activities. **Table 10-2** presents information on important federal regulations and established programs which influence transportation and traffic on the Ohio River.

TABLE 10-2
Laws, Regulations, Ordinances, And Programs Relevant to Transportation and Traffic

Law/Program	Key Components	Relevance to Transportation and Traffic
Rivers and Harbors Acts (U.S. Army Corps of Engineers)	• Address projects and activities in navigable waters and harbor and river improvements. • Section 7 authorizes promulgation of regulations for use of navigable waterways, including operations that provide channel improvements. • Section 10 of Rivers and Harbors Act (1899) relates to permits for physical obstructions to navigable U.S. waters.	Provides for improvements, maintenance and safety of ports and navigation channels.
Water Resources Development Acts (U.S. Army Corps of Engineers)	• Authorizes the study and/or implementation of various projects and programs to improve river and harbors, including several general environmental provisions. • WRDA of 1986 enacted the Harbor Maintenance Tax, paid by shippers, to cover costs of maintaining navigation channels. • Implements a cost-share formula between local ports and the federal government for improving harbors and channels.	Facilitates safe traffic movement through maintenance of ports and navigation channels.
Inland Waterways Revenue Act	• Created a diesel fuel tax to defray costs of lock and dam construction and major rehabilitation along major inland waterways. • WRDA of 1986 increased fuel tax to 20¢ /gal.	Provides a dedicated source of funding for navigation system expansion and maintenance.
Safe, Accountable, Flexible, Efficient Transportation Act: a	• Builds of the ISTEA and TEA-21 acts which promotes balanced, integrated and efficient approaches to	Emphasizes intermodal facilities and connections (e.g., between barge

Law/Program	Key Components	Relevance to Transportation and Traffic
Legacy for Users (SAFETEA-LU) (U.S. Department of Transportation)	transportation that connect various transportation modes. • PL 109-59, signed into law on August 10, 2005	transportation and highways or railways). Encourages flexibility to attempt new transportation solutions.
Clean Water Act (CWA) (U.S. Environmental Protection Agency)	• Establishes structure for regulating discharges of dredged or fill and pollution materials into U.S. waters and requires establishment of water quality standards. • Section 401 requires applicants proposing activity, which may result in discharge to U.S. waters, to obtain state certification of compliance with state water quality standards.	Applies to removal and disposal of materials dredged to maintain navigation channels or to expand or construct navigation structures.
Emergency Planning and Community Right-to Know Act (a.k.a. as SARA Title III) (USEPA and state and local emergency response agencies)	• Requires emergency planning and preparedness at state and local levels. • Section 304 establishes spill reporting requirements for facilities that release extremely hazardous substances.	Requires commercial shipping companies to prepare emergency response plans and submit records on hazardous chemicals they are transporting.
Hazardous Materials Transportation Act (U.S. Department of Transportation)	• Governs the transportation of hazardous materials, including, but not limited to, solvents, asbestos, PCBs, paints, pesticides, hazardous wastes, etc,	Requires commercial shipping companies to comply with DOT requirements for documentation, labeling, and all other regulations associated with safe transport of hazardous materials.
National Environmental Policy Act (NEPA) (Council on Environ-mental Quality and other agencies)	• Requires preparation of environmental impact statements for new construction projects by private and governmental agencies • Includes federal government's responsibility to prevent environmental degradation.	Applies to all projects receiving federal funding, including construction of navigation structures and port developments.
Pollution Prevention Act (U.S. Environmental Protection Agency)	• Establishes the policy of pollution prevention, reduction and recycling in an environmentally safe manner whenever feasible • Requires facilities filing annual toxic chemical release forms to also file a toxic source reduction and recycling report	Protects public safety by requiring pollution reduction or recycling of hazardous substances, toxic chemicals and toxic and radiological wastes at their sources
Oil Pollution Act (U.S. Environmental Protection Agency and U.S. Coast Guard)	• Strengthens governmental ability to prevent & respond to catastrophic oil spills • Requires oil storage facilities and vessels to submit plans detailing how they will respond to large discharges	Protects drinking water supplies and natural resources from pollution & damage from oil spills.
Spill Response	• Includes emergency response	Minimizes adverse impacts

Law/Program	Key Components	Relevance to Transportation and Traffic
(ORSANCO and U.S. Coast Guard)	activities for river-related spills and accidental discharges and is related to the Oil Pollution Act and Section 301 of the Clean Water Act.	of spills and discharges on mussels and other aquatic life and on water quality
Abandoned Shipwreck Act (National Park Service)	• Provides federal protection for any shipwreck that meets the criteria for eligibility for inclusion on the National Register of Historic Places.	Prohibits disposal of dredged or other material in or near historic shipwrecks.
Executive Order 13274	• Enhances environmental stewardship and streamlines decision-making process for major transportation projects. • Requires DOT to prioritize projects and establishes interagency task force to coordinate decision-making across federal agencies.	Applies to transportation projects on inland waterways.

10.7 PAST TO CURRENT BASELINE CONDITIONS

10.7.1 Transportation Patterns during the 19th and Early 20th Century

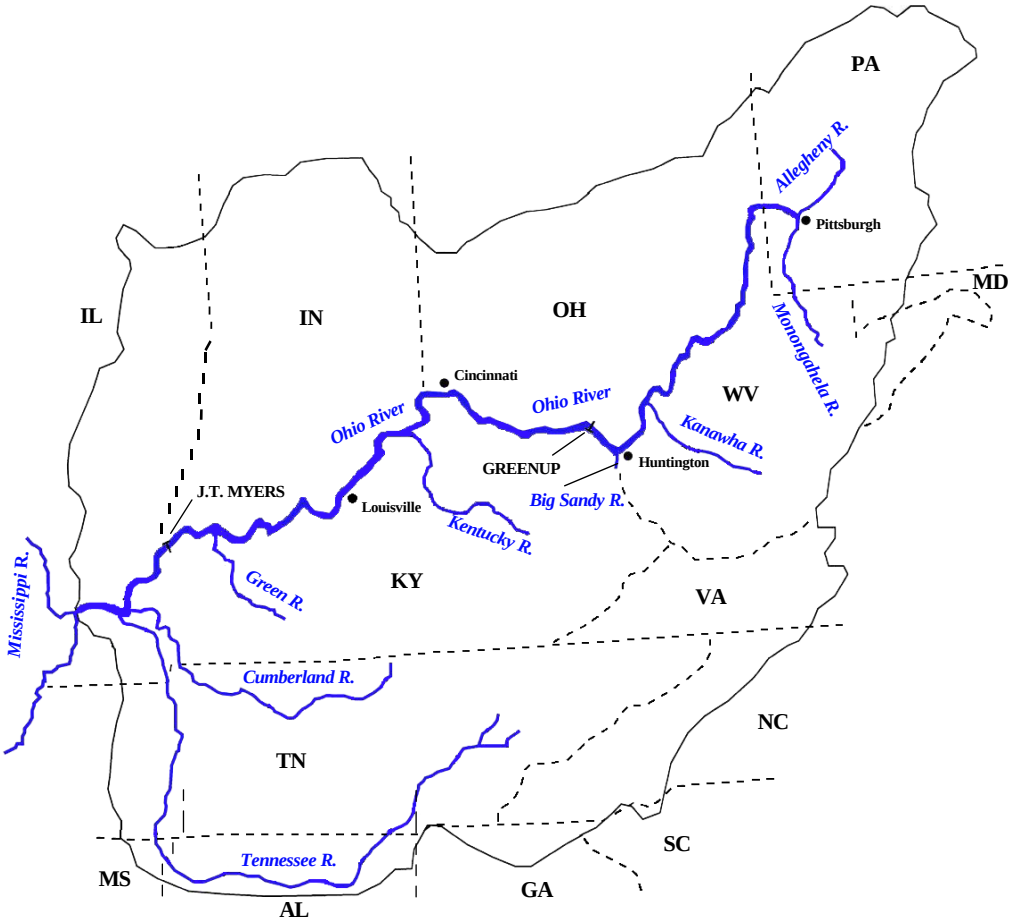
The Ohio River is an important artery of the nation's inland waterway system, providing for commercial navigation in the eastern third of the country. The entire Ohio River navigation system consists of the Ohio mainstem and navigable portions of eight tributaries, the Allegheny, Monongahela, Kanawha, Big Sandy, Kentucky, Green, Cumberland and Tennessee rivers **(Figure 10-1)**. The mainstem serves as a collector of system traffic for distribution points within and outside the Ohio basin. Through interconnections with the Mississippi River and its tributaries, the Ohio River navigation system also has access to Midwestern states and deep-draft ports on the Great Lakes and the Gulf Coast. While this chapter focuses primarily on water transportation, it also considers the intermodal linkages that extend the influence of commerce on the Ohio mainstem far beyond the Ohio basin.

Bigham (1998) refers to the Ohio mainstem as the nation's first interstate highway, bringing goods and people to the first western frontier. During the early decades of settlement, the Ohio River provided the primary corridor of transportation, both for immigration of new settlers and for the shipment of regional products**;** consequently, initial settlements within the region tended to cluster along the Ohio River. Certain port development opportunities related to transportation, such as the Falls of the Ohio at Louisville or location of the national road crossing at Wheeling, directly contributed to the location and expansion of towns along the Ohio. Some early riverfront settlements subsequently prospered as hubs or service centers to interior regions reached overland by horse and wagon. This was an early example of intermodal transportation.

The earliest flatboats and keelboats mostly provided one-way transport downstream, necessitating shipment of produce through New Orleans and coastal shipping to reach eastern markets. The arrival of steamboats around 1815 permitted two-way traffic and greatly reduced travel times (Carlisle & Mulligan 2001). Development of the Ohio River

in the 1800s included the removal of snags, completion of the initial canal and locks around the Falls of the Ohio in 1833, and completion of the first wicket dam at Davis Island, near Pittsburgh in 1885. However, the Ohio River remained largely unimproved prior to the 1920s. The ability to move commodities, consequently, was constrained by the seasonal availability of high water flows sufficient to support navigation.

Figure 10-1
Ohio River Basin



Inland canals provided the first significant alternative or supplement to river transport, beginning in 1825 with completion of the Erie Canal from Buffalo to New York City. Important canals in the Ohio River Valley included the Ohio & Erie from Lake Erie to Portsmouth, OH; the Pennsylvania Mainline from Pittsburgh to Philadelphia; and the Pennsylvania & Ohio from Pittsburgh to the Mahoning River Valley in Ohio (Carlisle & Mulligan 2001). By 1830, approximately 3,000 miles of canals operated in the United States. Canals provided nearly year-round transportation and the ability to ship products more directly to eastern markets instead of overland from Upper Ohio, Allegheny, or Monongahela ports. On balance, canal development probably supplemented river traffic more than it competed with or replaced river traffic. Steamboats hauled goods to canal terminals on the Ohio River, creating another early form of multimodality.

The expansion of railroads provided a far more significant level of competition to river transport and quickly became the primary means of commercial transportation in the

region. Railroads provided true year-round transport capabilities, greatly reduced transport times, and could be quickly built to serve any point-to-point business opportunity. The first railroad in the Middle Ohio River Valley was completed in the 1840s, connecting Lake Erie with the Ohio River. By 1850, 242 miles of track were completed in the Middle Ohio River Valley. By 1855, this number exploded to 1,247 miles and virtually saturated rail transport opportunities in the region. Rail mileage in the region grew only an additional 80 miles by 1860 (Carlisle & Mulligan 2001). Railroads almost immediately rendered canals obsolete. Track sometimes was laid beside or over the abandoned canals.

Commercial river transport also declined at a slow but steady pace in competition with railroads. The year-round operability of rails had a distinct advantage over the seasonal limitation of steamboats. Inland cities with good rail connections grew substantially. To a large degree, the early river communities along the Ohio River either prospered or perished with the railroads, depending on their ability to attract rail service. Subsequently, further prosperity came to most towns able to establish railroad bridges across the Ohio River.

The latter decades of the 19th century and early decades of the 20th century included a period of heavy industrial development along the middle and upper Ohio River. This development centered on the iron and steel industry in Pittsburgh, with its convergence of raw materials, coal, river, and rail and river transportation to move materials and products into and out of the region.

Concisely stated, the Ohio River stimulated a variety of transportation and technological strategies that pushed expansion westward and added to the nation's overall prosperity (Bigham 1998).

10.7.2 Transportation Patterns from the 1920s to the Present

Construction of the system of wicket locks and dams ultimately revitalized the Ohio River as a major transportation corridor, although wartime activities would later contribute to its expansion. Following construction of the first project in 1885 at Davis Island, the next lock and dam project was not finished until 1904. Surprisingly, initial construction of the dams was opposed by some members of the barge industry, who feared that breaking up multiple barge tows for passage through the locks would make river freight impractical (McVarnish 2001). However, completion of the initial projects proved the advantages of this navigation development and sentiment began to change to favor canalization. After the Davis Island Lock was in operation, an unexpected flood in July 1888 particularly gave momentum to downstream canalization. One hundred coal barges sank along the Ohio River, but no barge in the harbor behind Davis Island was lost. Furthermore, industry located along the Davis Island pool benefited from a more reliable water supply. Fears that the pool would be a stagnant breeding ground for disease proved unfounded. Instead, sewage and other obnoxious effluents which had formerly rotted along the shoreline during low water periods were washed away.

Both rivermen and industrialists urged the extension of canalization downriver (Johnson 1977; cited in McVarnish 2001). Six lock and dam projects were completed between 1904 and 1910, 23 were completed between 1911 and 1920, and the entire system of more than 50 lock and wicket dam projects was completed by 1929. The original design

for a navigation depth of six feet was modified in 1910 to provide the nine-foot depth required for coal barges that had begun operating on the river by 1900.

As construction of the navigation system continued, however, river traffic declined, primarily because of rail transportation. In 1917, cargo carried on the river reached a low of about 4.6 million tons, a nadir caused largely by the decline of coal shipments from Pittsburgh to New Orleans, as coal was diverted to steel plants in the Upper Ohio Valley. The turning point came as World War I continued and wartime shipping overburdened the country's land transportation system. By 1920, cargo volume on the Ohio River had risen to almost 9.4 million tons, a total that increased further to 10.8 million tons in 1924), 16 million tons by 1925, and 22.3 million tons by 1930 (Froggett 1926a & b, Robinson 1983, and USACE-ORD 1979; cited in McVarnish 2001). Where traffic once consisted primarily of coal and steel products moving downstream, new products were being added as the century progressed. Freight soon included petroleum and its products, iron and steel, dry and liquid chemicals, grain, cement, and a variety of other items (Gaum 1970, cited in McVarnish 2001).

Commerce on the river grew steadily through the 1930s and 1940s while development of diesel towboats and larger barges created opportunities for larger scale, more efficient movement of commodities. Designed for about 15 million tons of commerce annually, the old locks and dams handled more than 70 million tons in 1954; in addition, traffic moving upstream on the Ohio had nearly equaled that moving downstream. Plans to improve system efficiency and accommodate the larger tugs and barges called for reducing the number of dams by building high-lift projects with larger capacity locks. The final plan, approved in 1954, envisioned a total of 19 high-lift projects with dual lock chambers. It began with the construction of Greenup and New Cumberland L&Ds, although construction of Emsworth, Dashields, Montgomery and Gallipolis L&Ds during the 1930s had already replaced some old locks and wicket dams on the upper river. Implementation of the current phase of lock extensions actually overlaps completion of the mid-century modernization program. Olmsted Locks and Dam, under construction at RM 964.4 will complete the 1954 modernization plan and replace old L&D 52 and 53. Upon Olmsted's completion, there will be 19 lock and dam projects along the Ohio River mainstem, as envisioned almost 50 years ago. **Table 10-3** provides a synopsis of the key dates in the historical development of navigation on the Ohio River.

TABLE 10-3
Chronology of Navigation Development - Ohio River

1811	The NEW ORLEANS is the first steamboat to navigate the Ohio.
1824	First Federal funding for river improvements; removal of snags and clearing sand bars
1830	Completion of Louisville and Portland Canal
1874	Beacons, buoys, and daymarks put into use on the River; Corps given jurisdiction at Falls of Ohio.

1885	Davis Island Lock and Dam completed near Pittsburgh.
1929	Series of 51 locks and wicket dams completed.
1954	Corps begins modernization program replacing movable dams with stationary high-lift dams.
1992	Construction begins on Olmsted Locks and Dam, last project in 1950's modernization program.

SOURCE: http://www.lrl.usace.army.mil/ld98/HISTORY.HTM

During the 20th century era of sustained urban growth, the demands of industrial and commercial development outpaced the availability of land within some of the rapidly growing riverfront urban centers. Within the Huntington and Louisville Districts, for example, a series of levee and floodwall projects were completed during the 1930s and 1940s to secure more land for development as well as to protect existing properties against flooding. Rapidly growing cities also expanded beyond the river floodplain to higher ground, utilizing mass transit (e.g., light rail and bus) and automobiles to connect their expanding fringes with urban riverfront cores.

The availability of reliable, inexpensive electric power contributed significantly to the industrial and commercial growth of the Ohio Valley. Construction of the wicket dams contributed to bulk transport of the region's coal and provided stable pool elevations for construction of coal fired utilities on the Ohio River and its primary tributaries. Over the years, economies of scale have favored development of the very large power plants that are now a part of the river landscape of the Ohio Valley.

10.7.3 Current Conditions and Operation of the Navigation System and Transportation

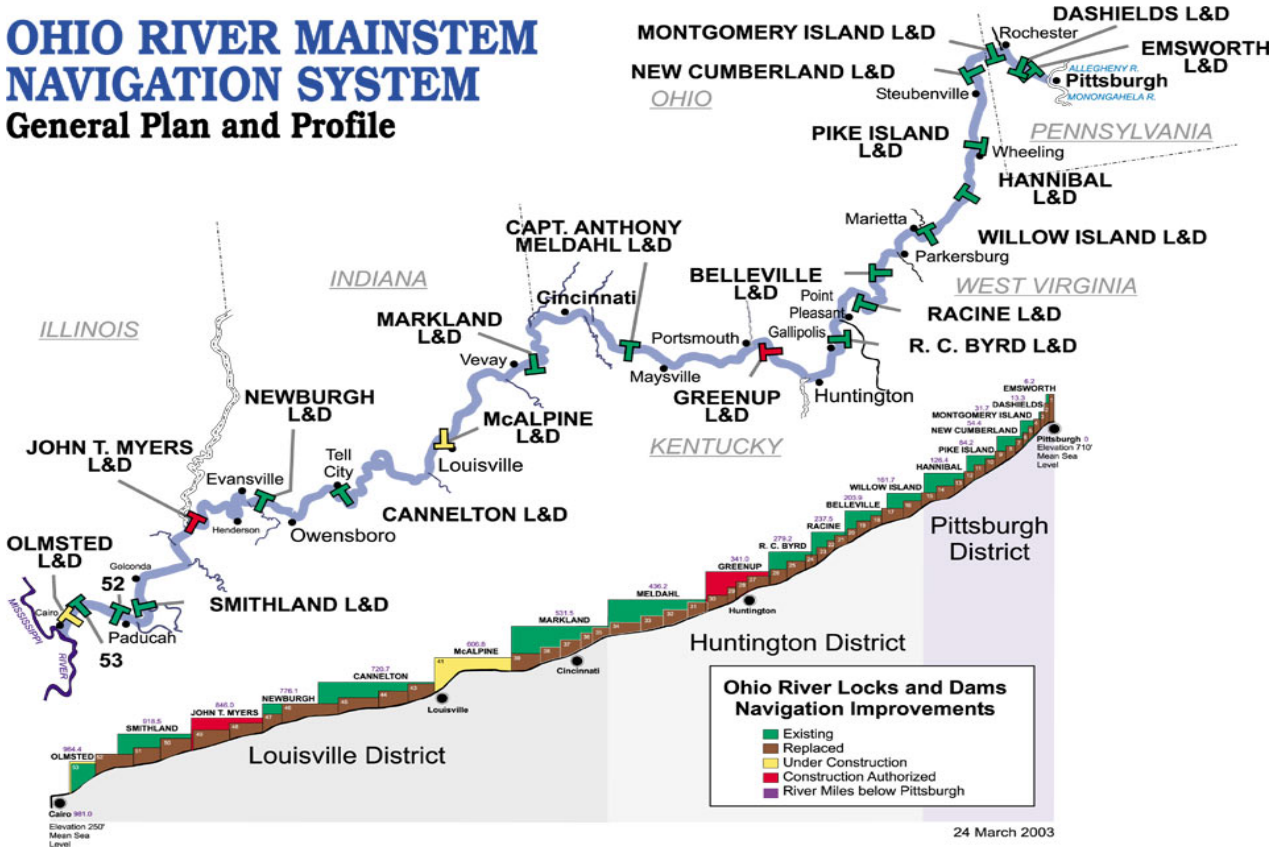
Existing navigation conditions, as described in the J.T. Myers and Greenup Lock Improvements report (USACE 2000) are presented below:

- The current geometry of the river, as improved by the higher pool levels of the modernized dam system, generally provides for safe navigation of commercial tows as long as 1200' long x 108' wide. Over the decades, barges have increased in size. A typical large jumbo-hopper-barge tow consists of fifteen 195' x 35' barges, plus a towboat of varying dimensions, resulting in a tow of about 1170' x 105'. Occasionally, tows on the lowermost reaches of the Ohio, below Smithland L&D, operate in a double-wide configuration of 30 barges (5 long x 6 wide), typical of the larger tows on the lower Mississippi River. During winter months, these six barge-wide tows can navigate over the navigable wickets of Dams 52 and 53 (and the wickets at the new Olmsted Dam when it opens). Such tows cannot navigate these reaches during the drier months, when they must use the locks at L&D 52 and 53. **Figure 10-2** shows the sequence of navigation structures and the river profile.

- The 60+ year-old upper three structures (Emsworth, Dashields, and Montgomery L&Ds) are just downstream of Pittsburgh PA. These three locks each have one larger 600'x110' main chamber and a 360'x 56' auxiliary

chamber. Fifteen-barge tows must be processed in two sections, called "double-cuts," through the main chamber, while tow sizes are limited to five-cuts in the small auxiliary chamber. The age of these structures, combined with the inefficiently-small lock sizes, has raised major concerns. Not only is age important because of its effect on reliability, but also because of the construction methods and design practices used in the 1910s to 1930s when they were constructed. (Frechione & Walker 2003).

FIGURE 10-2



In terms of age and size, the locks and dam facilities may be classified into 3 broad groups:

- The 13 modernized lock and dam structures constructed between 1954 and 1979, plus Byrd L&D, which has new locks completed in 1995. This includes all the sequential locks from New Cumberland downstream to J.T.Myers, a distance of 791.6 miles. Each of the locks has a 1200'x110' main lock chamber and a 600'x 110'auxiliary chamber. The 1200' long main chamber allows 15-barge tows to lock through in a single operation, while smaller tows or other vessels usually use the auxiliary chambers. These newer locks and dams are spaced about 60 miles apart, on average, and replaced about 40 lower-lift dams built at the turn of the 20th century.

- Locks and dams with dual 1200'x110' lock chambers include Smithland (placed in operation in 1980), McAlpine (chamber expansion from 600' to

1200' completed in 2002) and Olmsted (under construction). WRDA 2000 authorized 600' auxiliary lock extensions at J.T. Myers and Greenup L/D that are both currently in design phase.

Specifications for the existing lock and dam projects are summarized in **Table 10-4**.

TABLE 10-4
Current Ohio River Lock Specifications

Lock & Dam	River Mile	Year Operational			Year Rehabilitated			Chamber Sizes	
Project Name	(downstream of Pittsburgh)	**Main**	**Aux.**	**Dam**	**Main**	**Aux.**	**Dam**	**Main**	**Aux.**
Emsworth	6.2	1921	1921	1922	1984	1984	1984	600x110	360x56
Dashields	13.3	1929	1929	1929	1990	1990	1990	600x110	360x56
Montgomery	31.7	1936	1936	1936	1989	1989	1989	600x110	360x56
North Cumberland	54.4	1956	1959	1961				1200x110	600x110
Pike Island	84.2	1963	1963	1965				1200x110	600x110
Hannibal	126.4	1972	1972	1975				1200x110	600x110
Willow Island	162.4	1972	1972	1973				1200x110	600x110
Belleville	203.9	1968	1968	1969				1200x110	600x110
Racine	237.5	1967	1967	1970				1200x110	600x110
R.C. Byrd	279.2	1993	1993	1937			2000+	1200x110	600x110
Greenup	341	1959	1959	1962				1200x110	600x110
Meldahl	436.2	1962	1962	1964				1200x110	600x110
Markland	531.5	1959	1959	1964				1200x110	600x110
McAlpine	606.8	1961	1921	1964		1965		1200x110	1200x110
Cannelton	720.7	1971	1971	1971				1200x110	600x110
Newburgh	776.1	1975	1975	1975				1200x110	600x110
J.T. Myers	846	1975	1975	1975				1200x110	600x110
Smithland	918.5	1979	1979	1979				1200x110	1200x110
L&D No. 52*	938.9	1969	1928	1929	1983	1983	1984	1200x110	600x110
L&D No. 53*	962.6	1980	1929	1929	1983	1982	1984	1200x110	600x110
***Notes:** Olmsted L&D (now under construction near L&D53) will replace both L&D52 and L&D53. Olmsted will have dual 1200' x 110' chambers, with completion projected for 2010.									
Source: J.T. Myers & Greenup Lock Improvements – Economics Appendix (2000).									

The Corps currently operates the Ohio River projects on a first-come/first serve basis during normal periods. The Corps also provides "Lock Status Reports" on the Internet that give real-time information on the status of traffic and lock operations on the navigation system (USACE –Pittsburgh District 2003). The normal procedures for operating the navigation projects follow:

1) tows are processed on a first-come/first-serve basis;

2) the main chamber is used to lock most tows;
3) the auxiliary chamber is primarily used to lock recreational craft and lightboats (towboats without barges);
4) tows are restricted to one-cut lockage operations (no splitting of tows) in the main chamber except for the upper three projects, which allow two-cut lockage operations (splitting tows into two sections) because of the small size of the main chamber;
5) all craft are restricted to one-cut lockage operations through the auxiliary chamber;
6) locks are operational nearly 100 percent of the time during the year (with a low number of weather related closures) (USACE -Pittsburgh District 2003).

During 2000, over eight of every ten tows locked through the main chamber at the projects. The main chamber is often used even when the tow could one-cut through the auxiliary chamber. The main chamber is preferred for several reasons, including better approach conditions and the lock operators' greater familiarity and comfort with operating the main chambers. Traffic and delays by chamber are included in **Table 10-5** which indicates the average delay per tow under normal operation at the main chambers was 0.94 hours (56.4 minutes). The average delay at the auxiliary locks was 0.63 hours per tow (37.8 minutes), but at 14 of 19 projects it was 6.6 minutes or less. Low levels of delays at the auxiliary locks are the norm in the absence of main chamber closures.

Significant delays at Ohio River locks and dams are linked to lock closures rather than to spikes in hourly, daily, or monthly arrivals (USACE - Pittsburgh District 2003). Lock closures are: (1) nearly always scheduled, (2) last from 30 to 60 days, and (3) occur on a five- to ten-year maintenance cycle. Navigation notices, published about six months before lock closures, provide details on operating procedures and expected delays, and give industries time to adapt their operations to reduce closure effects. In general, highest delays occur at the three uppermost projects — Emsworth, Dashields, and Montgomery L/D—due primarily to the extremely small size of the auxiliary locks and at the eight lowermost L/D, due to higher traffic levels (USACE - Pittsburgh District 2003).

Normal operating policies change when lock closures result in significant queues and delays. First, two-cut lockages are allowed at the projects with 600'auxiliary chambers, because this allows the tow size to remain the same over the vessel trip. At the upper three projects, five-cut lockages are allowed because of the much smaller size of the auxiliary locks, although even five-cut lockages are insufficient to lock a 15-barge tow. Second, during closure delays the first-come/first-serve policy is changed to "n up/ n down," a policy which processes multiple barges moving in one direction, followed by an equal number of tows moving in the opposite direction (Frechione & Walker 2003). The n up/n down policy (also called "sequential processing") and other measures to expedite tow movement during lock closures are discussed in the following section.

The towing industry makes adjustments to lock closures, particularly at locks where the longest delays occur. At all times, including closures, shippers attempt to minimize the time spent pushing empty barges by arranging shipments in both directions. The percent of loaded barges is higher at projects along the lower river, where opportunities for backhauls (loaded return trips) are greater than on the upper river, where one-way coal traffic is more dominant (USACE – Pittsburgh District 2003). Towing companies also try

to reduce the number of trips through locks with significant delays. In some cases, they dispatch additional equipment (e.g., "helper" boats) to assist with assembling barges above and below congestion points to expedite returning to normal delivery schedules as soon as a main chamber reopens.

TABLE 10-5
Traffic and Delays by Chamber – 2000

	Tows			Delays - Hrs/tow		
Project	**Main**	**Aux**	**Total**	**Main**	**Aux**	**Total**
Emsworth	3,876	1,123	4,999	0.84	0.08	0.66
Dashields	3,803	935	4,738	0.65	0.07	0.53
Montgomery	3,854	770	4,624	1.09	0.20	0.94
New Cumberland	3,269	1,078	4,347	0.32	0.05	0.25
Pike Island	3,193	1,571	4,764	0.33	2.65	1.10
Hannibal	3,894	586	4,480	0.28	0.03	0.25
Willow Island	3,609	474	4,083	0.47	0.03	0.42
Belleville	3,897	338	4,235	0.38	0.04	0.35
Racine	3,981	495	4,476	0.50	0.03	0.45
Gallipolis	4,461	621	5,082	0.75	0.04	0.66
Greenup	6,202	639	6,841	1.02	0.06	0.93
Meldahl	5,216	255	5,471	1.03	0.11	0.99
Markland	4,694	435	5,129	0.65	0.03	0.60
McAlpine	5,018	18	5,036	1.43	8.94	1.46
Cannelton	4,290	304	4,594	0.71	0.05	0.67
Newburg	5,094	698	5,792	0.52	0.05	0.46
Myers	5,359	599	5,958	0.83	3.48	1.09
Smithland	3,504	3,761	7,265	0.03	0.04	0.03
L/D 52	7,230	2,328	9,558	3.56	1.57	3.07
Total	84,444	17,028	101,472			
Average	4,444	896	5,341	0.94	0.63	0.89
Percent	83.2%	16.8%		88.0%	12.0%	
SOURCE: USACE – Pittsburgh District 2003						

Delays represent transportation inefficiencies that could possibly be reduced by more effective management of the navigation system rather than by costly construction efforts. A framework for formulating and evaluating alternatives to navigation problems, including those related to inland navigation, exists in the Corps' Planning Guidance Notebook (ER 1105-2-100). Regulations in the Notebook are general enough to allow substantial flexibility, but do have basic requirements, including that:

1) evaluations must be made within a system context,
2) project economics must be based on national economic benefits and costs, and
3) nonstructural alternatives must be evaluated along with structural alternatives.

The Corps is using a new tool, the Ohio River Navigation Investment Model (ORNIM) to identify and evaluate the structural and nonstructural alternatives that yield the optimal combination of capacity enhancement and nonstructural investments for the Ohio River system (Frechione & Walker 2003).

10.7.4 NONSTRUCTURAL TRAFFIC MANAGEMENT MEASURES

Nonstructural alternatives are used to facilitate tow passage through the locks and provide transportation efficiencies, particularly during unexpected lock chamber outages and planned lock closures for inspection and repairs, as well as during normal operations when two or more tows arrive simultaneously expecting lockage service. Nonstructural measures can be divided into two groups:

1) technical measures that increase capacity of the system of locks and dams and
2) demand management measures that provide the lowest cost to users who value the system most.

Technical measures seek to improve tow passage through locks during times of congestion when the first-come/first-serve policy is less effective than under normal operating conditions. In contrast, demand management measures seek to alter shipper behavior either by more closely aligning shipper costs with the true economic costs of using the navigation system or by educating users such that external costs are reflected in their prices. Demand management efforts do not directly increase lock throughput; instead they potentially decrease traffic delays by moving traffic away from congested shipping periods and locations.

Table 10-6 describes and compares the three main technical nonstructural measures currently in use on the Ohio River. All projects, except those with dual 1200'chambers, employ both sequential processing and helper boats during lock closures. Although time savings vary by project, the reduction in processing time per tow when these two measures are combined is about 125 minutes. Further, the combination of sequential processing and helper boats is estimated to be one-third more time effective than the use of tow haulage by itself (Frechione & Walker 2003). Additional nonstructural technical measures to further reduce delays are not apparent at present.

TABLE 10-6
Technical Nonstructural Measures that Increase System Capacity

Measure	How Measure Works	Effectiveness	Current Usage
Sequential tow processing (n-up/n-down)	Changes tow processing from first-come/first-serve to sequential processing of tows moving in the same direction. Allows tow to wait at the lock for processing rather than wait at the approach point several hundred feet distant.	Reduces approach time by about 15 minutes per tow and therefore increases efficiency of locks by reducing idle time.	Employed during lock closures at all projects with auxiliary chambers smaller than the main chamber.

Measure	How Measure Works	Effectiveness	Current Usage
Tow haulage systems to extract unpowered barges	When double lockages are required,: 1) Unpowered barges are cabled to a moveable tie-down unit, which moves along railroad tracks to pull barges out of the chamber. 2) The second set of barges, powered by a towboat, enter and lock through the chamber. 3) After the second lockage, the first and second cuts are assembled along the guidewall.	Estimated time savings per tow is one to two hours. The alternative of "double tripping" at smaller locks would require towboats to lock through with the first cut of barges, return through the same lock, then return with the second cut and reassemble all the barges. Assuming 15-barge tows, locks with and without tow haulage systems can process 8.7 and 6 tows per day, respectively.	Permanent tow haulage systems are currently in use during normal operations at Emsworth, Dashields and Montgomery L/D. Remains an option at 16 projects where 600' auxiliary lock is one-half the size of the main chamber.
Helper boats	When double lockages are required: 1) the last towboat to arrive at a congested project in the direction opposite of ongoing lockage operations disconnects from its barges, moves to the lock, and helps the tow locking through by extracting unpowered cuts of barges from the lock chamber. 2) It will then move the barges to a refleeting site away from the project so that tow reassembly does not interfere with lockage operations. 3) Help is provided to each tow until all barges have moved through the lock. Most Ohio River projects allow two cuts. Exceptions are the three uppermost projects, which allow up to five cuts per tow.	Typically reduces time a tow occupies a lock by as much 25 minutes. Time saved at the smaller Montgomery Lock is approximately 50 minutes.	Employed during lock closures at all projects with auxiliary chambers smaller than the main chamber.
SOURCE: USACE – Pittsburgh District 2003, Frechione & Walker 2003.			

Successful demand management measures encourage shippers to internalize congestion and environmental costs and focus on the efficient movement of goods, not just vessels, to reduce delays. The Transportation Research Board's Committee for the Study

of Freight Capacity for the Next Century (TRB 2002) has identified traffic demand management as a means of forestalling expensive capital investments in all modes of freight transportation. On waterways, traffic demand management measures are designed to reduce or redirect tow arrivals away from times when a lock is in heavy use. The goal of traffic demand management during lock closures is the complete avoidance by recreational watercraft of locks experiencing closures and a dramatic slowing in commercial tows arriving at the project. Although most measures are proposed to expedite river traffic during significant delays, some measures may be implemented on a full-time basis to reduce shipping costs or eliminate delays during normal use (Frechione & Walker 2003). Examples of such measures include shippers' self-imposed scheduling and increasing backhauls. The Ohio mainstem currently has the lowest empty barge return rates in the inland waterway. Between 22 to 28% of all barges return empty to their point of origin in contrast to up to 90% of upbound barges on the Mississippi returning empty (Dager, personal communication).

Table 10-7 compares and contrasts the two most frequently mentioned demand management measures.

TABLE10-7
Potential Traffic Demand Management Measures

Measure	How Measure Works	Effectiveness	Current Usage
Congestion fees	Charges tows a fee for processing through congested locks. Fees are aimed at reducing tow arrivals at congested locks to some "optimum" number that would maximize system benefits given lock closure inefficiencies.	Magnitude of delays is related to number of tows continuing to be processed through locks despite fees. Where congestion is directly related to structural condition problems, congestion fees have not performed well.	Implementation of such fees is considered in all Corps inland navigation studies, although pricing policies are not currently within the Corps' purview. Congestion fees will be evaluated in development of the System Investment Plan (SIP) for ORMSS.
Lockage appointment system	Requires shippers to have an appointment "slot" to lock through a project on a specific date at a specific time. With demand for slots likely exceeding lock capacity during closures, slots would be awarded to carrier via lottery or sale.	Use of this option to alleviate costly delays during closures has not been evaluated at Corps projects on the Ohio mainstem. Where congestion is directly related to structural condition problems, this option, like congestion fees, fails to address the major cause of periodic and costly closures. Among concerns related to	Not currently in use in the Ohio River system. A survey conducted by the Corps in 2001 revealed industry opinion that scheduling lockages would not be effective in dealing with delays, primarily because of difficulty in predicting tow arrival times at locks, given varying weather conditions and other factors. Also cited of concern was

Measure	How Measure Works	Effectiveness	Current Usage
		this option are when to require appointments, how to award slots, length of slots, and how to manage purchase/exchange of slots.	unfairness of locking tows except in the order that they arrive. Industry spokesmen favored helper boats as a more effective alternative.
SOURCE: Frechione & Walker 2003, (USACE - Pittsburgh District, 2000).			

Other measures that have been proposed include:

1) Use of vessel tracking systems to allow operational centers to locate and track all equipment moving on the river, enhancing identification of congestion areas and homeland security. Many large tows already are equipped with geopositioning systems (GPS) such that shippers can monitor their vessels and customers can locate their cargo.
2) A controlled schedule of shipments similar to that used on the Panama Canal, requiring passage through locks by appointment for the entire trip, not simply for a single lockage at a congested project. This concept has met with industry opposition due to unpredictability related to weather, potential crew inexperience, and other factors, and
3) Use of auxiliary locks to reduce normal delays. This is not time-effective even with normal delays, because it would take one-third more time to process a two-cut operation through an auxiliary lock than to process a one-cut operation through the main lock. Economically, it is not considered feasible because it would require installation and operation of a tow haulage system at an annual estimated cost of nearly three-quarters of a million dollars (USACE – Pittsburgh District 2003).

As **Table 10-7** indicates, the Corps' most recent analysis of traffic demand management measures (Frechione & Walker 2003), concluded that such measures do not perform well relative to structural solutions (e.g., lock extensions) when addressing episodic delays related to structural condition problems at specific projects. Frechione & Walker's report further states:

> Diminishing lock reliability due to unplanned failures of major lock components and more frequent maintenance and repair of heavily used, aging, structures will lead to degraded system performance at many locks, i.e., more tows sitting in queues incurring lengthy delays, a growing hesitancy on the part of shippers to use the waterway for bulk shipments, and increased reliance on overland modes that leads to greater exposure of the general public to highway congestion, the risk of accidents, and air pollutants. In this instance, structural alternatives more directly address the underlying problems of degraded lock conditions and their associated delays. Delays and the associated accumulation of delay costs that occur during normal operations of the locks are sizable. It is here that the more aggressive, price-related demand management measures may be most appropriate and, therefore, worthy of consideration.

Further, Frechione & Walker suggest that the Corps' Waterway Analysis Model (WAM), which is a lock simulation model, and the Ohio River Navigation Investment Model (ORNIM) can be combined to estimate potential benefits of scheduling under ideal conditions. Ideally, tows are spaced such that no delays occur because of simultaneous arrival of tows at a lock. If the combined models indicate that traffic scheduling under ideal conditions could realize significant benefits, additional work would be needed, including modification of WAM and ORNIM, to reflect varying levels of chaos in lock operations and tow movements.

Calculation of optimal congestion fees is challenging because such fees should incorporate the variables of time, lock, and commodity. Initial work has been completed to modify ORNIM within these constraints. ORNIM will examine a range of possible congestion fees, converge on an optimal fee, and include the cost of implementing and running a fee program within the overall analysis (Frechione & Walker 2003).

Nonstructural technical measures that increase system capacity, as well as potential traffic demand management measures, have some common environmental benefits. For example, all of these measures are focused on decreasing queuing prior to lock passage, and on moving barge traffic through the locks in a shorter time period and with a minimum of barge "cut operations." The environmental benefits include improvements in local water quality in or near potential queuing areas, areas used to accomplish "cut operations," and areas where "tow reassembly" typically occur. Reductions in damage and disruptions to shallow mussel beds would also be anticipated in areas in or near potential areas for queuing, areas for "cut operations," and areas for "tow reassembly."

10.7.5 TRANSPORTATION EFFICIENCIES, COMMODITIES TRANSPORTED, AND TRAFFIC DEMAND FORECASTING

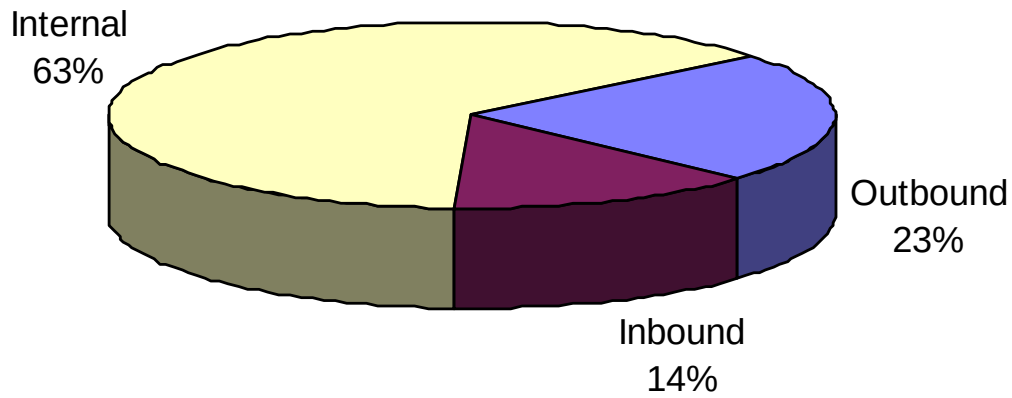
Inland waterways carry 11 percent of domestic intercity ton-miles nationwide, but account for only 1 percent of freight expenditures, making inland shipping the cheapest freight mode in terms of average transportation cost per ton-mile (Wilson 2001, cited in Transportation Research Board 2002). Barge transportation also is the most energy efficient mode for carrying large quantities of bulk commodities. A typical jumbo barge (195' x 35') can transport as much coal or grain as 15 rail cars for one-fourth the energy per ton-mile (USACE – Huntington District 2003). A typical Ohio River tow consisting of 15 barges and carrying a total of 22,500 tons is equivalent to 225 railcars or 870 semi-trucks.

As **Figure 10-3** indicates, 63 percent of traffic on the Ohio River system is internal (i.e., confined to the Ohio mainstem and navigable tributaries). In 2001, 87 % of traffic within the Ohio River system moved on the mainstem (see **Table 10-8**).

Growth on the Ohio mainstem has proceeded at a faster pace than the Ohio River system as a whole, reflecting the relatively recent navigation development of the mainstem, compared with some of the tributary streams like the Monongahela and Kanawha Rivers. Since 1990, growth on the Ohio mainstem has slowed somewhat from its rapid 1940-1990 pace, when it averaged 4.2 percent annually. The annual growth rate for the mainstem from 1990 to 2001 was 0.7 percent (USACE – Huntington District 2003). Since 1996, and through 2003, total mainstem traffic has stabilized around 240 million tons per year.

The average haul length on the Ohio River is about 400 miles, which is the lowest average haul length in the inland waterway system (Dager, personal communication). Haul length is directly related to the nature of commodities shipped, their origins, and destinations. Commodities transported on the Ohio River system are the products of coal mines, petroleum refiners, stone quarries, cement plants and farms, along with raw materials for construction companies, steel mills, electric utilities, paper plants, aluminum manufacturers, and chemical companies – the foundation of the region's economy. Commodity traffic flow at a given lock and dam is largely determined by its geographic location. The commodity mix consequently influences barge type and flow configuration (USACE 2000).

FIGURE 10-3
Ohio River System Traffic



Inbound freight originates from points outside the Ohio Basin to destinations within the Basin. Outbound is freight from within the Basin to points outside. Internal freight moves entirely from one port to another within the system.

SOURCE: SIP Economics Appendix, USACE – Huntington District (2003).

TABLE 10-8

Historic Ohio River System and Mainstem Ohio Traffic (million tons)

Year	Mainstem	Ohio River System	Mainstem %
1940	29.5	51.2	58%
1950	48.6	66.1	74%
1960	79.5	105.3	75%
1970	129.6	163.9	79%
1980	174.9	200.5	87%
1990	225.7	257.8	88%
2000	236.3	271.7	87%
2001	242.5	279.9	87%
Avg. Annual:			
1940-01	**3.5%**	**2.8%**	
1990-01	**0.7%**	**0.8%**	

Source: Waterborne Commerce Statistics Center data cited in SIP Economics Appendix, USACE – Huntington District (2003)

Like the Ohio River system, Ohio River mainstem traffic is dominated by transport of coal. Since the 1970s, over 50 percent of the tonnage of commodities shipped on the Ohio River mainstem each year has been coal (**Table 10-9**). Coal transport historically has been more prevalent on the upper portion of the Ohio River than on the lower portion. The primary markets for coal shipments are domestic electric utility plants. Coal traffic also moves to coal blending facilities, industrial facilities, and coking facilities. These three coal destinations, however, collectively accounted for less than 20 percent of the total coal traffic in 2000 (USACE-Huntington District 2003). Although **Table 10-9** shows a 2.5 percent annual increase in coal traffic from 1965 through 2003, coal traffic declined (-0.9% annually) for the interval from 1993 through 2003 To some extent, changes in the coal export market account for this decline. The export market for Ohio River coal has been relatively flat in recent years due to increasing competition from other exporting countries and the movement of many importers away from coal for environmental reasons. Additional information on intermodal transport is included in the following section.

The dominance of electric utility coal transport on the Ohio River and attention focused on coal by the government and the public are reflected in the Corps' most recent traffic demand forecasts, which place special emphasis on utility coal and the sorbent materials (lime and limestone) used for coal desulfurization. While other commodities and barge-served markets face uncertainty, none equals the dominance of coal or level of uncertainty regarding future use. Deregulation is affecting the electric utility industry, but experts acknowledge that environmental regulations will be the dominant factor affecting future coal utilization and sourcing by the electric utility industry. In light of this, the Corps has developed five alternative traffic forecast scenarios presented in detail in (USACE-Huntington District 2003). These scenarios are being used in the economic analyses being conducted as part of the SIP.

TABLE 10-9
Historic Ohio River Mainstem Traffic by Commodity
(Million tons)

Year	Coal	Petrol	Aggs	Grain	Chem	Ores	Iron	Other	Total
1965	46.6	20.5	14.2	2.6	6.0	7.6	3.4	2.3	103.2
1970	59.0	25.3	17.2	3.6	10.6	3.9	4.4	5.5	129.5
1975	73.3	19.6	16.5	4.1	9.1	3.5	3.9	10.1	140.1
1980	86.1	18.3	21.2	6.7	11.5	3.2	4.1	9.6	160.7
1985	98.2	12.5	20.9	11.7	12.7	3.5	5.0	13.4	177.9
1990	135.1	14.4	30.4	13.2	9.3	5.5	6.5	11.2	225.6
1991	131.6	13.9	27.0	10.2	9.0	5.7	6.2	14.8	218.4
1992	134.7	13.3	28.1	11.3	9.6	5.5	5.8	18.1	226.4
1993	130.3	14.2	29.5	14.0	10.5	5.9	7.5	17.6	229.5
1994	134.8	14.2	32.2	12.0	10.2	6.8	9.6	17.0	236.8
1995	130.0	13.6	33.3	12.0	10.2	6.7	10.1	18.2	234.1
1996	134.8	13.2	37.3	10.7	9.4	7.5	9.7	15.1	237.7
1997	135.1	12.8	39.9	10.9	9.6	6.8	9.5	15.4	240.0
1998	132.7	20.2	42.9	13.9	9.8	5.9	10.2	6.3	241.9
1999	124.8	20.6	43.2	15.2	10.0	6.6	12.1	8.4	240.9
2000	118.9	20.2	40.9	15.6	10.2	6.9	14.3	9.5	236.5
2001	128.0	20.3	40.8	18.0	9.7	6.8	10.9	7.9	242.4
2002	131.0	19.7	39.1	16.9	9.7	6.4	12.4	7.6	242.8
2003	118.5	16.3	41.7	13.8	10.3	7.4	13.9	6.8	228.8
Avg. Ann. Growth Rate									
(1965 - 2003)	**2.5%**	**-0.6%**	**2.9%**	**4.5%**	**1.4%**	**-0.1%**	**3.8%**	**2.9%**	**2.1%**
(1993 - 2003)	**-0.9%**	**1.4%**	**3.5%**	**-0.1%**	**-0.2%**	**2.3%**	**6.4%**	**-9.1%**	**0.0%**

Source: Waterborne Commerce Statistics Center data cited in SIP Section 4

Recent trends in the other important commodities reflect growth rates exceeding 4.0 percent annually in aggregates, grain, and iron. Aggregates consist primarily of crushed limestone, sand and gravel, and building stone and accounted for just under 17 percent of traffic at all mainstem locks in 2003. These construction materials typically are extracted as close as possible to their market areas; therefore, aggregate traffic on the Ohio River is frequently short-haul and may be entirely within one pool. These intra pool movements are included in the ORNIM shipment list and reported as part of system statistics; however, they do not contribute to lock delays.

Grain traffic, consisting primarily of corn, wheat, and soybeans, composed 7.4 percent of Ohio mainstem traffic in 2001. The three Ohio River basin states of Ohio, Indiana, and Illinois produce about one-quarter of the nation's corn and soybeans. In 2000, approximately 71 percent of the grain traffic on the Ohio River system was outbound, primarily for export markets; 20 percent was inbound, primarily for grain processors on the Tennessee River, and about 9 percent was destined for internal processors along the Ohio mainstem.

Transport of iron on the system has changed with the massive changes undergone by the iron and steel industry in recent decades. Within the Ohio River system, only four integrated steel mills remain in operation, out of about a dozen that were operating as recently as 1980. Scrap iron is important to mini mills, integrated mills are a critical source of scrap iron, and this has contributed somewhat to the present distribution of mini mills within the Ohio River system. Mini mill location is also influenced by electricity cost, scrap availability, transportation, and access to final customer.

The availability and quality of scrap potentially limits the quantity and, more importantly, quality of steel a mini mill can produce. Mini mills with processes capable of using Direct Reduced Iron (DRI) have the ability to produce the high quality steel required by appliance and auto manufacturers by adding high quality DRI to scrap. Hot Briquetted Iron (HBI) is a type of DRI produced from high quality iron ore. HBI used in Ohio River Basin mini mills originates in South America and some of it moves on barges from New Orleans up the Ohio. In addition, integrated steel mills have recently begun moving South American iron ore to New Orleans and then barging the ore to plants in the Ohio Valley.

Detailed traffic demand forecasts for each of the commodities discussed in these paragraphs are included in Attachment 3 to the ORMSS SIP/PEIS Economics Appendix (USACE-Huntington District 2003).

The Corps has developed detailed lock-level traffic demand forecasts (included in Table 11 of Attachment 3 of the SIP?PEIS Economics Appendix). These forecasts reflect the effects of coal source switching by electric utilities to comply with existing or proposed environmental regulations. The most recent forecast growth rates are highest for some upper Ohio projects (e.g., Willow Island and Belleville L/Ds) and for projects on the lower river. These rates reflect anticipated increases in use of Northern Appalachian coal and Illinois Basin coal by electric utilities, as well as increases of western coals coming into the Ohio River system. The lower costs of Northern Appalachian and Illinois Basin coals coupled with improving scrubber technology to desulfurize coal make use of these coal sources more attractive to utilities than in the past. Conversely, reduced availability and increased production costs of Central Appalachian coal are anticipated to be reflected in lower traffic growth rates at locks in the middle river. Projected lower growth rates at the uppermost Ohio River locks suggest increased usage of local coal on the Monongahela and upper Ohio.

10.8 Ohio River Mainstem Traffic and Intermodal Connections

State profiles from the U.S. Department of Transportation's Freight Analysis Framework (FAF) were reviewed to obtain a comprehensive perspective on current and future freight movement in the six states bordering the Ohio River. Benchmark dates used in the framework were 1998, 2010, and 2020. **Figure 10-5** shows that the proportions of truck, rail, and water transportation are expected to remain relatively consistent in each state from 1998 through 2020, although tonnages by mode are expected to increase.

In all states except West Virginia, highway transportation (i.e., by truck) is by far the leading freight mode, comprising as much as 72% of the freight traffic in Indiana in 1998. Truck transportation is expected to gradually increase in tonnage and percent of total freight in all states throughout the forecast period. The maximum prediction is for 2020 in Ohio, where trucks are predicted to transport 76% of the total freight. Value of goods is an important variable in truck transportation. In general, higher value commodities are trucked longer distances than lower value commodities.

Only in West Virginia was rail the dominant mode, carrying about 51% of freight in 1998. Rail is expected to be the dominant freight mode in West Virginia through 2020. **Figure 10-4** shows rail carrying 45% of the West Virginia tonnage in 2020 as compared to

37% by truck. However, the overall tonnage of commodities transported by rail is expected to remain flat or slightly decline in all six Ohio River states. Similarly, water transportation is expected to remain flat or slightly decline in all states except Illinois, which will experience a slight increase in water transportation. The freight analyses are statewide and do not specifically break out the proportion of water traffic on the Ohio mainstem from tributaries, Great Lakes traffic, or Upper Mississippi-Illinois Waterway traffic.

The FAF also looks at the principal commodities by weight. In 1998, coal and nonmetallic minerals ranked as the top two commodities in all states except Illinois. Coal and nonmetallic minerals were first and second, respectively, in commodity flows from West Virginia and Kentucky, while the opposite order occurred in commodity flows from Pennsylvania, Ohio, and Indiana. Coal and nonmetallic minerals will continue to be important throughout the forecast period. During 1998, farm products were the top commodities from Illinois, closely followed by nonmetallic minerals and coal.

The Transportation Rate Study (TRS) (2001) performed by the Tennessee Valley Authority for the Corps' Navigation Center in Huntington, WV, provides more specific information on the Ohio River system than the more generalized commodity movement picture provided by the FAF. The TRS reviewed approximately 1,600 commodity movements, which included 83% of tonnage on the Ohio River system during the study period. The TRS revealed that intermodal connections with Ohio River system traffic vary not only by commodity but also by a commodity's origin. The dominant commodity, coal, illustrates this point.

Coal, mined in the upper Ohio Valley, historically has been moved a relatively short distance (<100 miles) to barge loading facilities. Currently, overland coal transportation in the upper Ohio is about 40% by truck, about 10% by rail, and the remaining 50% by conveyor belt (up to 10 miles long) or direct loading at a mine mouth. Since 1992, lower sulfur Western coal, primarily from Wyoming, has been transported 1,500 to 1,800 miles by rail to lower Ohio River transfer facilities, such as the Cook Coal Terminal at RM 947.5 at Metropolis, IL, that is owned by American Electric Power. After loading on the lower river, Western coal travels 200 to 800 miles upriver to coal blending facilities and power plants. A secondary effect of the influx of Western coal on the system has been a reduction in the amount of sand and gravel backhauled, because barge operators receive a higher price for hauling coal than for hauling sand and gravel. As scrubbers and other clean air technologies are introduced at electric generating plants, however, the demand for Western coal is expected to decrease and the present trend may be reversed. This reversal, in turn, may benefit the sand and gravel industry.

Grain transportation also is related to point of origin. Most grain barges are downbound on the river for export. The TRS showed that currently about 95% of grain arrives at river terminals by truck while only about 5% arrives by rail. The primary rail connections are at Evansville and Mt. Vernon, IN, and Mound City, IL. Grain arrives at river terminals in the larger cities of Cincinnati and Louisville exclusively by truck. The TRS found that about 50% of river terminals have rail access, but only 5 to 10% use it, primarily because connections are with the wrong rail companies. For example, the Norfolk Southern and CSX railroads have numerous connections at barge terminals, but these railroads are not key players in grain transport. Also, in some cases, railroads at

barge terminals lack the necessary connections with other lines for cost effective transport of goods.

The transport of steel and related materials on the Ohio River system also has been affected by different points of origin and material inputs dating from more than 20 years ago, when larger integrated steel mills dominated. Today's steel minimills depend in part on iron intermediates from Brazil and Venezuela that travel upriver from New Orleans, effectively reversing traffic patterns that prevailed earlier. This upbound trend is expected to continue into the foreseeable future. In addition to affecting Ohio River traffic, the minimill trend has reduced iron ore traffic on the Great Lakes (Dager, personal communication).

Future transportation demands relative to Ohio River system capacity by mode are more difficult to assess. The TRS did not review traffic movements with regard to capacity, but assumed that system capacity would be built as needed. The Transportation Research Board's (TRB) special report on Freight Capacity for the 21st Century (2002) was reviewed to gain an understanding of capacity problems the freight industry is experiencing today nationwide. The TRB's report, however, does not forecast future capacity or traffic volumes, presumably because numerous factors can complicate such predictions and compromise their reliability. For water transportation, the report noted that capacity constraints on the inland waterway include aging infrastructure and peak-period congestion at certain locks. Rail capacity constraints are also localized in time and space, but most trends are consistent with tightening capacity, including long-term contraction of the rail network. In general, the report concluded that if the nation's addition of

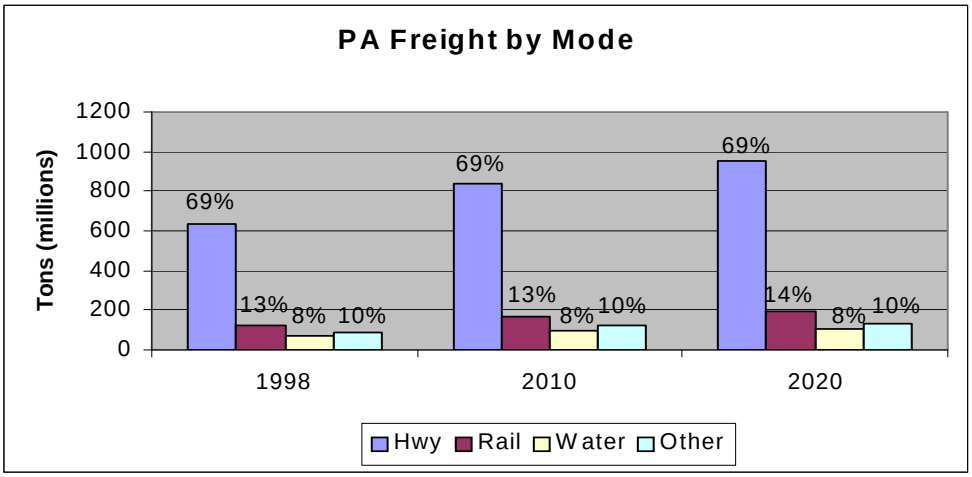
transportation capacity does lag traffic growth and congestion worsens, as seems likely, long-run consequences will not be a "massive breakdown."

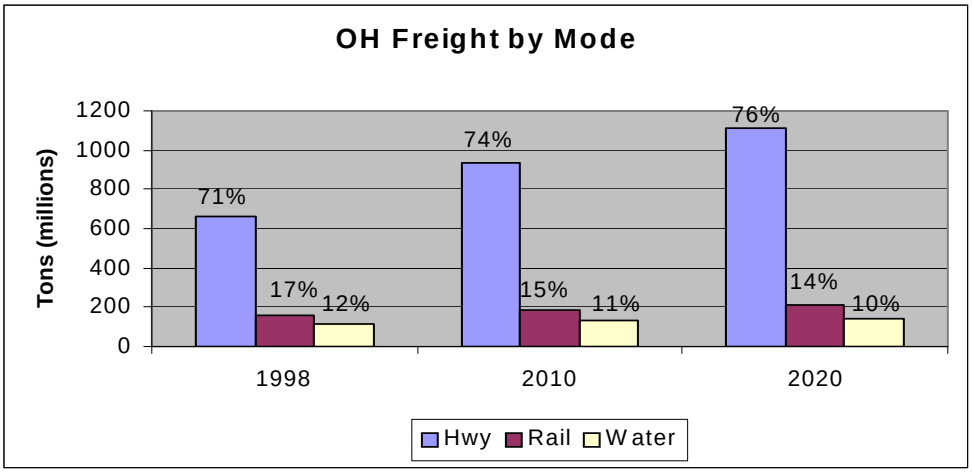
Several factors the TRB identified as affecting transportation efficiencies and capacity include:

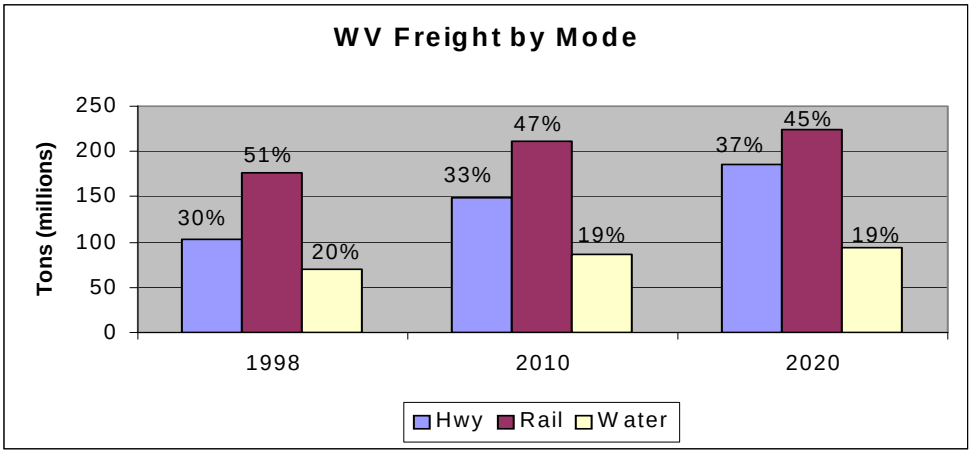
1) continued changes in character of freight demand (e.g., the changing Ohio River coal scenario)
2) potential changes in government regulations of vehicles (e.g., truck size and weight regulations that affect highway capacity)
3) international trade policies
4) improvements in infrastructure that can facilitate traffic movement
5) management, operational, and financial changes that can markedly improve efficiency (e.g., information technology that improves coordination and scheduling of water or overland shipments)
6) changing population densities and demographics (e.g., shifts in percentage of working age populations)
7) overall urbanization and competing land uses and
8) air and water pollution control requirements.

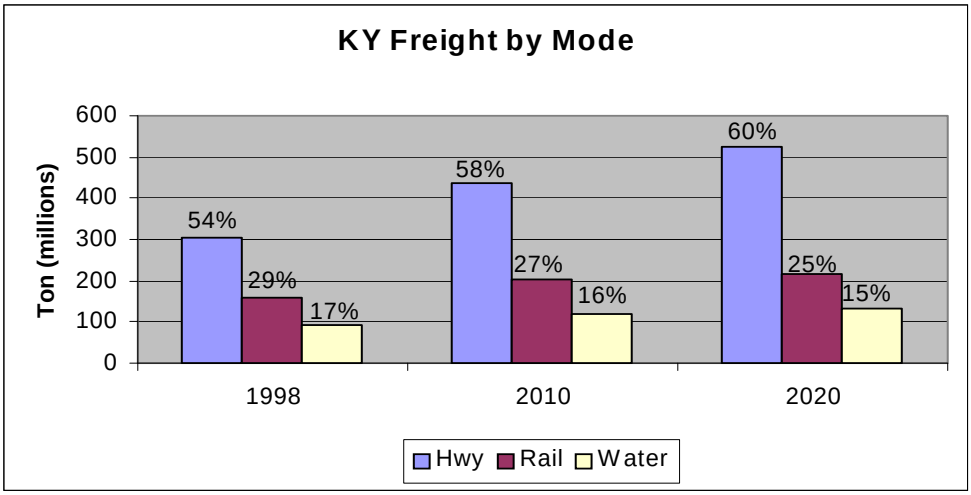
FIGURE 10-5

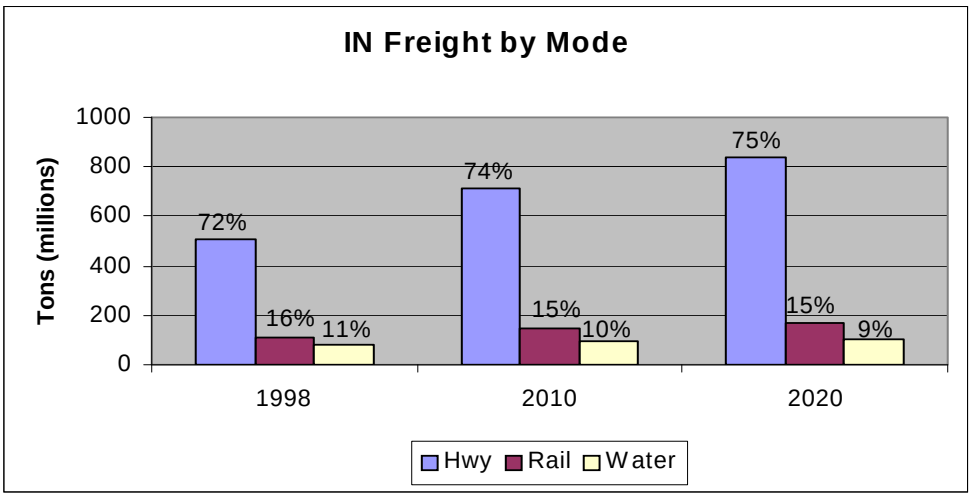
Comparison of Total Annual Freight by State and Mode

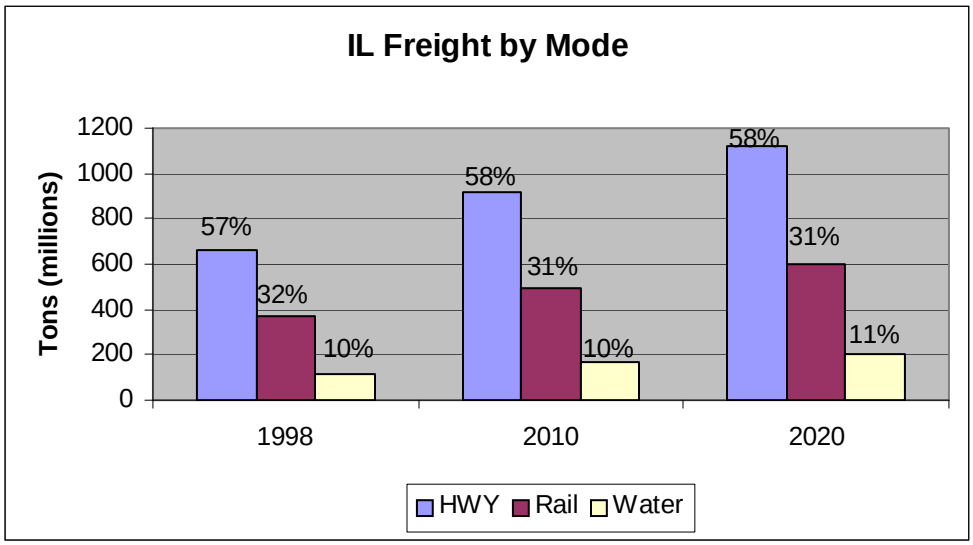












Source: U.S. Department of Transportation's Freight Analysis Framework

10.9 INTERACTIONS WITH OTHER VECS

The four-fold increase in shipping traffic demands on the Ohio River since 1950 has been accompanied by increasing interactions with several other Valued Environmental Components (VECs). Land use and socioeconomics along the Ohio River are closely linked with river transportation and traffic, as well as with surface and air transportation. The growth of recreation on the river, in turn, is related to land use and socioeconomic factors.

Concerning mussels and fish, operation and maintenance of the navigation system have resulted in habitat changes that have shifted the fauna away from riverine species to those more suited to lake-like conditions. The chapters on mussels and fish provide additional details on ways the navigation system and traffic movement influence distribution and reproductive success of species in these groups. Good water quality, essential for healthy aquatic life, is influenced by potential spills and handling of commodities transported and transferred on or near the river.

River traffic does not interact highly with cultural resources, but the infrastructure that supports traffic, including terminals, has affected cultural resources through burial and loss as terminals and related infrastructure are developed. Pool maintenance, which enables navigation, continues to inundate some cultural resources in the floodplain. The reduction in natural fluctuations of water levels due to pool maintenance also has caused changes in riparian resources and floodplain hydrology.

Traffic and transportation are linked directly to air quality, although emissions from tows represent less than 3 percent of mobile source emissions along the Ohio River corridor (see Chapter 7, Air Quality). Aesthetics also are affected by traffic, although such impacts are difficult to measure because of their subjective nature.

10.10 RELEVANT ACTIONS AFFECTING TRANSPORTATION AND TRAFFIC

In considering the relevant actions discussed in this section, it is important to reiterate that "transportation and traffic," as defined for ORMSS, concern the conveyance of goods and people along the Ohio River mainstem and related traffic activities and efficiencies. Consequently, transportation and traffic focus primarily on human activities and communities within the CEA planning context. In this regard, beneficial effects are considered as those that will improve the conveyance of goods and people along the Ohio River mainstem. Detrimental effects are considered as those that reduce the efficiency of conveyance of goods and people. The numerous interactions that occur among transportation and traffic and environmental resources and ecosystems are explored in more detail elsewhere in this document, especially in the chapters on water quality, mussels, fish, and riparian resources.

The RFFA matrix for Transportation and Traffic (**Table 10-10**) shows that 45 of the RFFAs listed were not ranked either because they are not applicable or links to

Transportation and Traffic are weak. Many RFFAs were ranked low because individually they have little influence on transportation or traffic.

The 21 RFFAs ranked high (H) or medium (M) in importance are discussed below in the context of:

- Actions directly affecting traffic
- Actions related to commerce on the river and
- Actions conflicting with barge traffic.

TABLE 10-10
RFFA Cumulative Effects Matrix for Transportation and Traffic

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Transportation	Importance[5]
Navigation Investment Actions					
Lock Extensions/New Locks/Replacement or Rehabilitation	A	H	SL	(+)	H
L&D operation and maintenance	A	H	SL	(+)	M
Non-structural navigation improvements	A	H	SL	(+)	M
Dam replacement and rehabilitation	A	H	SL	(+)	H/M
Other Corps Actions					
Flood damage reduction projects					
dry dams, other projects off mainstem	A	L	SL	(+)	M
Recreation facilities - Construction and O&M	A	H	SL	(-)	M
Port development (Sec. 107) and maintenance dredging	A	H	SL	(+)	M
"But for" Actions					
Commercial Navigation					
barge queuing	A	H	SL	(-)	M
terminals	A	H	SL	(+)	M
multi-modal sites	A	H	SL	(+)	M
increased traffic	A	H	E	(+)	M
Coal utilities	A	H	SL	(+)	H
Other coal industries	A	M/L?	SL	(+)	M
Industrial users, excluding coal-related	A	H	SL	(+)	H
Recreation facilities - Construction and O&M	A	H	SL	(-)	M
Actions by Others					
Marina development & operation	A	H	SL	(-)	M
Water -based recreation					
boating	A	H	E	(-)	M
fishing	A	H	E	(-)	M
PWCs	A	H	E	(-)	M
Natural Climatic Events					
floods	A	H	E	(-)	L/M
droughts	A	H	E	(-)	L/M

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Transportation	Importance[5]
Regulatory Environment					
COE permitting programs	A	H	E	(-)	M
ORSANCO monitoring program	A	H	E	(+)	M

[1] Reasonably Foreseeable Future Actions

[2] Time period in which the RFFA may occur:

1 = within 10 years, 2 = in 10 - 25 years, 3 = in 25 - 60 years, A = applicable for all time periods

[3] Occurrence probability or likelihood RFFA will happen

H = high, M = medium, L = low

[4] Location or setting on river where RFFA is expected to occur:

U = upper (Pittsburgh - Huntington), M = middle (below Huntington - Louisville),
L = lower ((below Lousiville - mouth), E = along entire length of river,
SL = specific location, e.g., locks and dams, U = urban setting, R = rural setting

[5] Importance of RFFA: H = high, M = medium, L = low

10.10.1 Actions Directly Affecting Traffic

This category includes actions that facilitate or impede traffic flow on the river; it is primarily related to locks and dams and to other projects or facilities that support commercial navigation.

The RFFA listed as lock extensions/replacements (H) involves expanding lock chambers from 600’ to 1200’ at up to seven navigation projects between R.C. Byrd and Smithland L/D. Replacements involve replacing small 360’ auxiliary lock chambers at Emsworth, Dashields, and Montgomery L/D in the upper river, with 600’ or 1200’ main chambers. This action is considered beneficial because it would reduce traffic delays and provide more capacity. Lock maintenance, repair, and rehabilitation (M), if proactive, would be beneficial by keeping the navigation system efficient, but would not be expected to increase system capacity. In general, additional capacity is not needed if locks are reliable and efficient. Negative impacts on transportation and traffic as these activities are implemented are temporary. Nonstructural navigation measures (M), by definition, do not involve construction or temporary closures, but facilitate traffic movements in congested areas through several means. In contrast, barge queuing (M), associated with all three previously mentioned RFFAs, has a negative effect on the navigation system because it impedes traffic flow and occurs frequently.

Dry dams and other projects off the Ohio mainstem (M) do not affect overall system traffic capacity, but are considered important and beneficial because they aid in decreasing or supplementing flows during floods or droughts. Although floods and droughts (both ranked M/L) are not frequent occurrences, the problems they cause can have major, short-term adverse effects on navigation.

In general, the development of terminals (M) and multimodal sites (M) would facilitate movement of commodities in the navigation system and enhance links with other modes of transportation. The benefits of developing an individual facility and negative

aspects of construction, however, are to some extent dependent on a facility's location along the river and the type of commodity handled. These projects and other activities subject to Corps permitting programs (M) which may involve dredging, discharges and conversion of wetlands during development can cause conflicts and disruptions in relation to navigation traffic and are considered negative in the short term.

10.10.2 Activities Related to Commerce on the River

Both coal utilities and industrial users (other than coal) are RFFAs ranked as having high (H), positive importance to the Transportation and Traffic VEC because they represent a high proportion of commerce on the Ohio mainstem. Previous sections of this chapter have emphasized the commercial importance of these activities by tonnage, as well as the profound effects changing needs of industry can have on transportation demand. Also grouped in this category and ranked beneficial is the RFFA called increased traffic (M), which refers to additional barge traffic on the Ohio mainstem with or without future improvements to the lock and dam system.

10.10.3 Actions that Conflict with Barge Traffic

This category includes several RFFAs, all ranked medium (M), that either directly conflict with barge traffic or that support recreational activities that conflict with barge traffic. Boating, fishing and the relatively recent use of personal water craft (PWC) have the potential to conflict with barge traffic and raise safety concerns, including noise in some cases. Marina development and operation and construction and operation of river-related recreation facilities both by the Corps and other entities ensure the continuance and growth of recreation activities that promote conflicting river uses.

10.11 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve environmental sustainability (ES). ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of CEs can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An AES has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps: (1) delineation of "common effects" on 9 identified metrics from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix; (2) selection of indicators for ES for transportation and traffic, and their grouping, as appropriate; and (3) consideration of the "connections" between the common effects and the indicator groups. Output of AES consists of a qualitative (descriptive) discussion of the "connections," with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions -- what is the current ES for

transportation and traffic, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable -- composite conditions and selected contributing indicators of ES for transportation and traffic do not reflect conditions that would facilitate meeting societal needs over time by an appropriate blending of economic and environmental concerns; these conditions periodically occur at a large number of the locks along the river.

- Marginally sustainable -- composite conditions and selected contributing indicators of ES for transportation and traffic are problematic at several locations along the Ohio River; these problematic conditions are somewhat tenuous both in location and likelihood of occurrences, thus periodic short-term declines in the cost-effectiveness and efficiency of the movement of goods, and associated increases in externalities, would be expected to occur.

- Sustainable -- composite conditions and selected contributing indicators of ES for transportation and traffic are such that sustained conditions of cost-effectiveness and efficiency, along with the minimization of externalities, are achieved along the majority of the river.

ES of the waterway transportation system on the Ohio River mainstem includes three features:

(1) It is "cost-effective and efficient" in that it is affordable, operates efficiently, connects with other transportation modes, and supports a vibrant economy.

(2) It "minimizes externalities" in that it limits emissions and waste within the environment's capacity to handle them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes use of land and production of noise.

(3) It "meets societal needs over time by an appropriate blending of economic and environmental concerns;" this can occur as a result of allowing the basic needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations.

Accordingly, these three features (or indicators of ES) can be considered in the following manner -- number (3) reflects the "composite indicator" of ES for transportation and traffic, while numbers (1) and (2) represent contributing indicators to (3).

Nine environmental indicators were identified earlier, and relevant data and information on them have been presented in the sections entitled "Past to Current Baseline Conditions," and "Ohio River Mainstem Traffic and Intermodal Connections." The environmental indicators can be considered as metrics that are related to either the "cost-effective and efficient" ES feature, or the "minimize externalities" ES feature as follows:

- Cost-effective and efficient

  -- Barge tonnage passing through each lock over time
  -- Annual barge tonnage with origin and destination within the Ohio River navigation system
  -- Annual barge tonnage with origin in the system but moved out of the system
  -- Annual barge tonnage with origin outside the system but moved into the system
  -- Percentages of different commodities transported along the river over time and
  -- Numbers of terminals and intermodal transfer facilities over time

- Minimize externalities (note that the following three metrics could also be listed for "cost-effective and efficient")

  -- Average queuing times for barge traffic at locks over time
  -- Capacity and condition of rail and highway links in the study area and
  -- Amount and types of fuel used by tows over time (will be less than fuel usage per ton-mile by trains and trucks)

As noted above, the 21 RFFAs ranked as high (H) or medium (M) can be grouped into actions directly affecting barge traffic (either by enhancing or potentially decreasing traffic movement), actions that increase commerce, and actions that conflict with barge traffic. These four groups of actions, along with nine environmental indicators and three features related to ES for transportation and traffic, are displayed in **Tables 10-11 through 10-14**. **Table 10-11** includes nine RFFAs that are anticipated to enhance barge traffic on the Ohio River mainstem. The connections between the RFFAs and the six measures related to cost-effectiveness and efficiency, and the three measures related to minimizing externalities are summarized in the table. Finally, the right-most column summarizes resulting effects on the three composite indicators of transportation and traffic sustainability. In general, it can be seen that these actions would move the waterway navigation system toward a more sustainable condition.

Table 10-12 relates to the two RFFAs that are anticipated to decrease navigation traffic movement. The structure of **Table 10-12** is similar to that for **Table 10-11**. In general, it can be seen that the two RFFAs in **Table 10-12** are anticipated to cause periodic and temporary movement of the waterway navigation system away from a sustainable condition.

Table 10-13 addresses four RFFAs that are expected to increase commerce along the Ohio River mainstem. The structure of this table is similar to **Tables 10-11 and 10-12**. The underlying assumption for **Table 10-13** is that the "commercial" increases would occur without navigation investment actions. If so, these RFFAs would move the waterway navigation system away from a more sustainable condition.

Finally, **Table 10-14** highlights the CEs of six RFFAs that are anticipated to cause conflicts with barge traffic movement. Again, the structure of **Table 10-14** is similar to that for **Tables 10-11 through 10-13**. As shown in **Table 10-14**, the six RFFAs would move the waterway navigation system away from a sustainable condition.

To summarize the relationships between the CEs of the 21 high and medium importance RFFAs and transportation and traffic sustainability, the following key points are noted:

- Groups of actions that are anticipated to improve the ES of transportation and traffic include those that enhance navigation traffic movement, and those that increase commerce (if it is assumed that navigation investment actions occur).

- Groups of actions that are anticipated to move the waterway navigation system away from a more sustainable condition include those that decrease traffic movement, those that increase commerce (if it is assumed that navigation investment actions will not occur), and those that cause conflicts with traffic movement (these are primarily water-based recreational RFFAs)

TABLE 10-11
AES Tiers for Actions That Enhance Navigation Traffic Movement

RFFAs That Enhance Navigation Traffic Movement	Measures (Metrics) Related to Cost-Effectiveness and Efficiency (See Notes)	Measures (Metrics) Related to Minimizing Externalities (See Notes)	Composite Indicators of transportation and Traffic Sustainability
• Lock extensions, new locks, replacement or rehabilitation (H) • L & D operation and maintenance (M) • Non-structural navigation improvements (M) • Dam replacement and rehabilitation (H/M) • Dry dams (M) • Port development and maintenance dredging (M) • Terminals (M) • Multi-modal sites (M) • ORSANCO monitoring program (M)	Increases are expected for (1), (2), (3), (4), (5), and (6) over time; such increases should lead to increased cost effectiveness and efficiency for the movement of goods.	Decreases are expected for (7). For (8), it may be necessary to repair and improve existing rail and highway links in the study area in order to meet multi-modal demands. For (9), increases in the total externalities are expected; however, they would be less than condition if all goods moved via rail or highway links.	• Cost-effectiveness and efficiency -- increases are expected • Minimizes externalities -- decreases in emissions are expected, relative to rail and highway modes for the sole movement of goods • Meets societal needs over time by an appropriate blending of economic and environmental concerns -- would move the waterway navigation system towards a more sustainable condition.

Notes: The measures (metrics) in numbered order are as follows:

(1) Barge tonnage passing through each lock over time
(2) Annual barge tonnage with origin and destination within the Ohio River navigation system
(3) Annual barge tonnage with origin in the system but moved out of the system
(4) Annual barge tonnage with origin outside the system but moved into the system
(5) Percentages of different commodities transported along the river over time
(6) Numbers of terminals and intermodal transfer facilities over time
(7) Average queuing times for barge traffic at locks over time
(8) Capacity and condition of rail and highway links in the study area and
(9) Amount and types of fuel used by tows over time.

TABLE 10-12
AES Tiers for Actions That Decrease Navigation Traffic Movement

RFFAs That Decrease Navigation Traffic Movement	Measures (Metrics) Related to Cost-Effectiveness and Efficiency (See Notes)	Measures (Metrics) Related to Minimizing Externalities (See Notes)	Composite Indicators of Transportation and Traffic Sustainability
• Barge queuing (M) • COE permitting programs (M)	Barge queuing at specific locks, along with water-side construction and operational activities associated with permitting, would be expected to cause decreases for (1), (2), (3), (4), (5), and (6) over time; such decreases should lead to decreased cost effectiveness and efficiency for the movement of goods.	Barge queuing at specific locks, along with water-side construction and operational activities associated with permitting, would be expected to increase (7) and lead to increased air pollution and water quality disturbances. Increased requirements would occur relative to increasing the capacity of rail and highway links.	• Cost-effectiveness and efficiency -- periodic and temporary decreases are expected • Minimizes externalities -- periodic and temporary increases in emissions are expected, and greater usage of rail and highway modes for the sole movement of goods are expected • Meets societal needs over time by an appropriate blending of economic and environmental concerns -- would cause periodic and temporary movement of the waterway navigation system away from a more sustainable condition.

Notes: The measures (metrics) in numbered order are as follows:

(1) Barge tonnage passing through each lock over time
(2) Annual barge tonnage with origin and destination within the Ohio River navigation system
(3) Annual barge tonnage with origin in the system but moved out of the system
(4) Annual barge tonnage with origin outside the system but moved into the system
(5) Percentages of different commodities transported along the river over time
(6) Numbers of terminals and intermodal transfer facilities over time
(7) Average queuing times for barge traffic at locks over time
(8) Capacity and condition of rail and highway links in the study area and
(9) Amount and types of fuel used by tows over time.

TABLE 10-13
AES Tiers for Actions That Increase Commerce

RFFAs That Increase Commerce	Measures (Metrics) Related to Cost-Effectiveness and Efficiency (See Notes)	Measures (Metrics) Related to Minimizing Externalities (See Notes)	Composite Indicators of Transportation and Traffic Sustainability
• Increased navigation traffic (M) • Coal utilities (H) • Other coal industries (M) • Industrial users, excluding coal-related (H)	Increases in "commercial" actions, without the associated navigation investment actions, would be expected to cause increased system demands; however the result would be expected decreases for (1), (2), (3), (4), (5), and (6) over time; such decreases should lead to decreased cost effectiveness and efficiency for the movement of goods. If such increases in commercial actions occur in conjunction with navigation investment actions, there would be expected increases in the cost-effectiveness and efficiency for the movement of goods.	Increased system demands, without the associated navigation investment actions, would be expected to increase externalities such as fuel usage (9), and water quality disruptions from barge queuing (7). Greater demands would also be placed on the capacity of existing rail and highway links (8). If such increases in commercial actions occur in conjunction with navigation investment actions, there would be expected increases in the composite indicators of transportation and traffic sustainability.	• Cost-effectiveness and efficiency -- decreases are expected without navigation investment actions. • Minimizes externalities -- increases in emissions are expected, relative to rail and highway modes for the sole movement of goods • Meets societal needs over time by an appropriate blending of economic and environmental concerns -- would move the waterway navigation system away from a more sustainable condition.

Notes: The measures (metrics) in numbered order are as follows:

(1) Barge tonnage passing through each lock over time
(2) Annual barge tonnage with origin and destination within the Ohio River navigation system
(3) Annual barge tonnage with origin in the system but moved out of the system
(4) Annual barge tonnage with origin outside the system but moved into the system
(5) Percentages of different commodities transported along the river over time
(6) Numbers of terminals and intermodal transfer facilities over time
(7) Average queuing times for barge traffic at locks over time
(8) Capacity and condition of rail and highway links in the study area and
(9) Amount and types of fuel used by tows over time.

TABLE 10-14
AES Tiers for Actions That Causes Conflicts With Barge Traffic Movement

RFFAs That Cause Conflicts With Barge Traffic Movement	Measures (Metrics) Related to Cost-Effectiveness and Efficiency (See Notes)	Measures (Metrics) Related to Minimizing Externalities (See Notes)	Composite Indicators of Transportation and Traffic Sustainability
• Recreation facilities - construction and O & M (Corps) (M) • Recreation facilities - construction and O & M ("but for" actions by others) (M) • Marina development and operation (M) • Water-based recreation-boating (M) • Water-based recreation -fishing (M) • Water-based recreation-PWCs (M)	Increased water-based recreational usage, if at a sufficient level, would be expected to cause decreases in (1), (2), (3), (4), (5), and (6) over time; such decreases should lead to decreased cost effectiveness and efficiency for the movement of goods.	Increases are expected in average queuing time (7) and fuel usage by tows (9); further, greater demands will be placed on moving goods via rail and highway links (8), thus increasing the externalities.	• Cost-effectiveness and efficiency -- decreases are expected • Minimizes externalities -- increases in emissions are expected, particularly due to greater dependency on rail and highway modes for the sole movement of goods • Meets societal needs over time by an appropriate blending of economic and environmental concerns -- would move the waterway navigation system away from a more sustainable condition.

Notes: The measures (metrics) in numbered order are as follows:

(1) Barge tonnage passing through each lock over time
(2) Annual barge tonnage with origin and destination within the Ohio River navigation system
(3) Annual barge tonnage with origin in the system but moved out of the system
(4) Annual barge tonnage with origin outside the system but moved into the system
(5) Percentages of different commodities transported along the river over time
(6) Numbers of terminals and intermodal transfer facilities over time
(7) Average queuing times for barge traffic at locks over time
(8) Capacity and condition of rail and highway links in the study area and
(9) Amount and types of fuel used by tows over time.

10.12 CONCLUSIONS

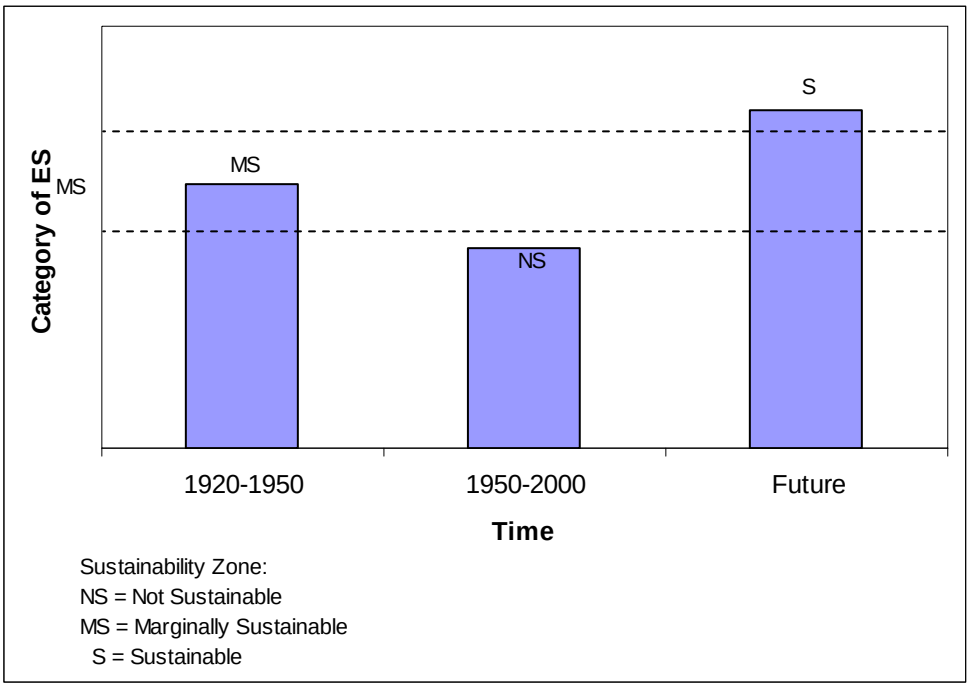
Based upon the above-described historical information, the actions and effects, the three features (or indicators) of ES of transportation and traffic, transportation and traffic sustainability can be characterized and depicted in **Figure 10-6** as follows:

- In the time period prior to 1920, and continuing up to about 1950, the waterway transportation and traffic system can be classified as "marginally sustainable." This classification is a result of system capacities that tended to exceed demands; however, the system was not particularly cost-effective or efficient, nor was it focused on minimizing externalities.

- In the time period from 1950 to 2000, "non-sustainable" conditions were often experienced as a result of construction of new infrastructure, demands that exceeded system capacities at numerous locations, and necessary use of auxiliary locks during repair and maintenance periods.

- Due to the aging infrastructure, it can be anticipated that "non-sustainable" conditions will continue into the future, and even further decline, in the absence of the system investment plan and its implementation. However, it is anticipated that sustainability of the transportation and traffic system will improve as a result of navigation investment actions.

FIGURE 10-6
ES of Transportation and Traffic System



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Chapter 11

SOCIOECONOMIC EFFECTS

11.1 TABLE OF CONTENTS

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11.2 DEFINITION OF RIVER-RELATED SOCIOECONOMIC IMPACTS

Socioeconomic Resources (SR) are related to human communities in the Cumulative Effects Assessment (CEA) planning context. The National Environmental Policy Act (NEPA) provides the basic national charter to assess and mitigate impacts to human communities, neighborhoods, cultural groups, and others. These "social impacts" have been defined in federal guidance issued by the U.S. Department of Commerce, NOAA, as "the consequences to human populations of any public or private actions – that alter the ways in which people live, work, play, relate to one another, organize to meet their needs and generally cope as members of society. The term also includes cultural impacts involving changes to the norms, values, and beliefs that guide and rationalize their cognition of themselves and their society" (Interorganizational, 1994).

The above guidance goes on to define social impact assessment "in terms of efforts to assess or estimate, in *advance*, the social consequences that are likely to follow from

specific policy actions (including programs, and the adoption of new policies), and specific government actions (including buildings, large projects and leasing large tracts of land for resource extraction), particularly in the context of NEPA." (Interorganizational, 1994)

Environmental Justice (EJ) addresses the issue of disproportionate impacts on minority and economically disadvantaged populations. Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," provides that "each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations (EO 12898)."

11.3 OBJECTIVES AND SCOPE OF THE SOCIOECONOMICS STUDY

11.3.1 Objectives

This chapter assesses the system-wide cumulative SR and EJ impacts of all likely major navigation improvements along the mainstem of the Ohio River from 2000 - 2070. SR and EJ impacts that are directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFA) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFAs. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, actions by non-governmental entities, and predictions of general economic expansion and development.

The results of the CEA are intended to contribute to two topics of subsequent public debate: (1) whether the impacts of the RFFAs constitute acceptable outcomes for the affected resources and (2) how the proposed navigation improvements contribute to those outcomes.

11.3.2 Geographic Scope

The geographic focus for SR impacts includes those areas most directly impacted by operation and maintenance of the navigation system. In order to reflect influences of the navigation system in the context of broader business and economic forces, as well as to maintain consistency with the scope of other chapters (Land Use, Health and Safety), counties adjacent to the Ohio River mainstem are defined as the geographic focus for SR impacts. Where such counties are part of a Census-defined Metropolitan Statistical Area (MSA), all counties in the MSA are included in the geographic focus for SR impacts.

11.3.3 Time Frame

The established time frame for this project is 1920 to 2070. The earlier date approximates the initiation of modern Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the Ohio River Main Stem Study (ORMSS).

11.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. More detailed discussions of the scoping meetings are presented in Exhibits A & B.

185 people attended the meetings and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Comments that directly or indirectly addressed SR or EJ issues are presented in **Table 11-1**. Some of the comments listed below incorporate issues that are more completely addressed in the 'Health and Safety' or 'Transportation and Traffic' chapters.

TABLE 11-1
Comments from Public Scoping Meetings

Direct Comments on Socioeconomic Impacts or Environmental Justice Issues	Total Comments	Impact[1]
Loss of shoreline trees and river property caused by barge activity	7	-
Bank undercutting & failure caused by increased barge traffic & queuing and wave action	7	-
Potential adverse effects of higher pool elevations on bridges, other infrastructure and property	6	-
Trash increasingly becoming a problem for property owners and river users	6	-
Reliability of barge traffic forecasts	5	Q
ORMSS schedule possibly lagging behind future navigation needs	5	-
Mouths of tributaries silted in, impairing fish habitat, limiting access and damaging property	5	-
Loss of green space & wildlife habitat with development of marina facilities	5	-
Need more public access ramps in each pool to reduce recreational crafts' usage of locks	5	R-M
Possibility of developing hydroelectric power at dams	5	+/-
Development of floodplains & wetlands resulting in increased runoff and habitat loss	4	-
Loss of significant farmland to urban development along river corridor	3	-
Need to develop comprehensive plans for development along river	3	R-M
Navigation structures presently not keeping pace with traffic demands	3	-
Bank erosion caused by USACE-controlled pool fluctuation	3	-

Direct Comments on Socioeconomic Impacts or Environmental Justice Issues	Total Comments	Impact[1]
Health and safety concerns related to increased traffic and development	3	-
Role of USACE related to litter and debris in river, especially at locks and dams	3	Q
Procurement and control of land by the federal government	3	+/-
Restrictions placed on property owners participating in federal programs	2	+/-
Interest by Ohio to promote Ohio River as a vacation destination	2	+
Degradation of recreational value of river caused by increased industrialization	2	-
Increased development of scenic byways and bikeways	2	+
Accuracy of models for predicting population growth & development	2	Q
Importance of including commercial dredging & associated permitting process in CEA	2	R-S
Challenge to water quality presented by CSOs and SSOs	2	-
Impaired water quality & bioaccumulation in fish tissue of harmful substances stirred up by dredging.	2	-
Importance of maintaining shipping channel	2	+
Pools maintained at higher level than agreed on in flowage easement contracts with property owners	2	-
Concern that landowners must sell at USACE's price for OR Islands National Wildlife Refuge	2	-
Enhancement of river transportation capabilities through corresponding development/improvement of intermodal transportation facilities	2	+
Need to integrate navigation with other transportation modes	2	R-M
Need for long-range coordination with FHWA , state & local transportation agencies	1	R-M
Study may overemphasize transportation and river commerce	1	-
Reliability of barge traffic forecasts	1	Q
Why USACE expects only 1% increase in barge traffic, while a 3% increase in gross domestic product is expected	1	Q
OH Division of Watercraft receives many complaints about barges damaging shoreline near Greenup L/D	1	-
Overall effects of navigation structures and activities on groundwater levels	1	-
Need to protect public groundwater supplies.	1	R-M
Need for long-term plan to address silt removal and prevent future sedimentation	1	R-M
Potential partnering with private enterprise to remove marketable aggregates when dredging	1	+
Habitat damage caused by Corps permitted commercial sand and gravel dredging	1	-
Shoreline instability threatening costly restoration projects in wildlife management areas	1	-
Severe erosion occurring at Slough Wildlife Mgmt. Area (downstream from Henderson, KY)	1	-
Need for elevation management to prevent water levels from exceeding flood stage	1	R-M
Effects on recreation and quality of life of raising Montgomery pool level	1	-
Economic impacts if pool elevations change	1	-
Increase in barge loading/unloading facilities limiting fishing access from shore	1	-
Danger to recreational users of submerged trees toppled by bank erosion	1	-
Suggestion of greater use of levees for passive recreation	1	R-M
Effects on recreation and heritage sites in Illinois, including Tower Rock Recreation Area	1	-
Include recreational facilities as design components of L/D revitalization	1	R-M

Direct Comments on Socioeconomic Impacts or Environmental Justice Issues	Total Comments	Impact[1]
& construction projects		
Need for long-term plan for replacement & maintenance of existing recreational launch ramps	1	R-M
Need more access ramps in each pool for emergency response and boating safety officials	1	R-M
Potential application of eminent domain in the Ecosystem Restoration Program	1	Q
Need for eminent domain in restoration of Ingram Island	1	R-M
Cumulative effect of discharges to river may offset water quality improvements.	4	-
Damage/destruction of mussel beds and fish spawning areas	4	-
Changes in shipping demand as low sulfur coal reserves near depletion in next 25 years	2	+/-
Possible trash hauling by barges in the future	2	+/-
Possible use of dredge spoils to improve riparian or island habitat or for upland filling	2	+/-
Need for fish habitat improvements, including fish passages around locks and dams	2	R-M
Loss of wildlife corridors as shoreline develops	2	-
Loss of unique, sensitive species due to water quality problems and habitat modifications	2	-
Potential instability of OR islands & futility of creating islands wildlife refuge	2	-
How ORMSS study will affect Greenup L/D upgrade	1	Q
Need for ORMSS to address livability issues of 2-for-3 (EMD) plan	1	R-S
View of navigation improvements as benefiting only shipping industry	1	-
High levels of mercury, arsenic, fecal coliform bacteria and agri-chemicals in surface water	1	-
Importance of coordination between USACE and OR public water suppliers	1	R-M
Importance of continued water quality improvements as a high priority	1	R-M
Stress and disruption of waterfowl migratory patterns caused by barge traffic	1	-
Riverfront development constraints related to endangered species	1	-
Need to prevent distribution of exotic /invasive plants and animals through USACE actions	1	R-M
Impairment of scenic value of river corridor for millions of people living in the Ohio Valley	1	-
Consideration by USACE of set-aside amount and other enhancements separate from mitigation	1	R-M
Effects on 4 Wild & Scenic Rivers proposed for Illinois	1	-
Need for adequate financial resources to complete the mitigation requirements within the 401 certification program	1	R-M

[1]Impact codes:
"+, -, +/-" Comments that suggest positive, negative or mixed impacts to the socioeconomic environment.
"R-M, R-S" Comments recommending an action for management of river resources (M) or as a topic in the CEA study (S).
"Q" General questions.

11.5 INDICATORS OF SUSTAINABILITY

Socioeconomic Effects (SE) can occur as a result of job creation and/or population relocations to new areas. Further, secondary consequences result from new jobs created to meet infrastructure and service needs of new populations. On the negative side, closure of

old industrial plants causes job losses and declines in economic indicators in local areas. Unique SR effects can occur during major construction projects involving construction workers moving into local areas.

Numerous business and economic forces influence population growth or loss and related economic changes along the Ohio River mainstem. The navigation system and its associated economic influences is only one such force in the overall socioeconomic characteristics of the area. The navigation system has been in existence for many decades, and the types and levels of product movement within the system are fairly stable. Other than small annual percentage changes, no major changes are anticipated.

There are numerous indicators of SR; for purposes of this study, the following are used: (1) total population, (2) minority population, (3) economically disadvantaged population, (4) Indian tribes and their populations, (5) economic indicators such as per capita incomes, households in poverty, etc., and (6) employment levels by SIC code and unemployment rates (or levels).

Information on the above indicators is available through the U.S. Bureau of the Census, Bureau of Economic Analysis (BEA) and commercial sources. Data on some factors go back to 1900 or earlier and this information is generally available at the county-level.

The primary indicator of SR sustainability used in this chapter is the baseline county-level projection of populations for Ohio River states prepared by the economic consulting firm NPA Data Services (NPA, 1999). NPA's key forecasting assumptions involve several demographic and economic variables. The demographic variables are fertility, mortality, and immigration rates. The economic variables are labor force participation and growth of national productivity, or product Gross Domestic Productivity (GDP) per worker. Fertility and mortality rates are taken from Census Bureau forecasts published in 1996 (Report P25-1130). In the baseline scenario, the Census Bureau's middle series fertility and mortality rates are used.

11.6 LAWS, REGULATIONS, ORDINANCES, AND PROGRAMS

11.6.1 Legal Mandates

The Dept of Commerce "Guidelines and Principles for Social Impact Assessment" includes the following discussion of legal mandates. Although NEPA created requirements for the assessment of impacts to the human environment, initial direction was somewhat vague. Subsequent regulations from CEQ stated that the "human environment is to be interpreted comprehensively to include the natural and physical environment and the relationship of people with that environment" (CEQ, 1986 (40 CFR 1508.14)). Agencies need to assess not only so-called "direct" effects, but also "aesthetic, historic, cultural, economic, social, or health" effects, "whether direct, indirect, or cumulative" (40 CFR 1508.8).

The CEQ Regulations also note that "economic or social effects are not intended by themselves to require preparation of an environmental impact statement" (40 CFR 1508.14). However, when an EIS is prepared "and economic or social and natural or

physical environmental effects are interrelated, then the EIS will discuss all of these effects on the human environment" (40 CFR 1508.14). The EIS is thus intended to provide a kind of full-disclosure procedure for federal decision-makers, who are then expected to consider the negative as well as the positive implications of potential courses of action, and the unintended as well as the intended consequences, before they proceed.

NEPA also provides citizens with the opportunity to challenge agency decisions; again in this case, however, NEPA's provisions are often misunderstood. The greatest level of legal vulnerability for the agency is *not* created by taking actions that will create negative impacts. It comes from failing to consider or fully analyze those impacts in advance (Interorganizational, 1994).

11.6.2 Agency Guidelines

Numerous federal agencies have published guidelines addressing SR issues, EJ, or both topics. Guidance from the General Services Administration (Fact Sheet, GSA) notes that "NEPA provides a major planning context in which EJ issues can be addressed, though such issues should be considered under other environmental review authorities as well (e.g., the National Historic Preservation Act and the Endangered Species Act). The Presidential Memorandum (EO 12898) identifies four important ways to consider EJ under NEPA, which are summarized in the CEQ's EJ guidance (CEQ 1997) as follows:

- "Each Federal agency should analyze the environmental effects, including human health, economic, and social effects of Federal actions, including effects on minority populations, low-income populations, and Indian tribes, when such analysis is required by NEPA.

- Mitigation measures identified as part of an environmental assessment (EA), a finding of no significant impact (FONSI), an environmental impact statement (EIS), or a record of decision (ROD), should, whenever feasible, address significant and adverse environmental effects of proposed Federal actions on minority populations, low-income populations, and Indian tribes.

- Each Federal agency must provide opportunities for effective community participation in the NEPA process, including identifying potential effects and mitigation measures in consultation with affected communities and improving the accessibility of public meetings, crucial documents, and notices.

- Review of NEPA compliance (such as EPA's review under Section 309 of the Clean Air Act) must ensure that the lead agency preparing NEPA analyses and documentation has appropriately analyzed environmental effects on minority populations, low-income populations, or Indian tribes, including human health, social, and economic effects."

CEQ's guidance outlines six principles that should be addressed in the course of NEPA review to ensure consideration of EJ, which can be paraphrased (from Fact Sheet, GSA) as follows:

- Consider the human composition of the affected area - that is, its population and how it is used by human communities, and determine whether any such communities are characterized by low-income levels or high-minority composition. If so, determine whether there may be disproportionately high and adverse effects on such populations.

- Consider not only direct impacts on the health and environmental quality of EJ communities, but indirect, multiple, and Cumulative Effects (CE) as well, including effects that are not within the control of or subject to discretionary actions of the reviewing agency.

- Recognize that the cultural, social, occupational, historical, and economic characteristics of an EJ community may amplify the environmental effects of an action. Such a population may be more sensitive to such effects and less resilient in adapting to them, than another community.

- Implement effective public participation strategies that seek to overcome linguistic, cultural, institutional, geographic and other barriers to meaningful participation, and that include active outreach.

11.6.3 Laws, Regulations, Ordinances, and Programs

Virtually every law, regulation or program addressing the development or management of public resources can be interpreted as having a social impact component. **Table 11-2** lists regulatory actions of significance to Corps activities that include specific reference to public (or state/local) participation in agency decision making or that mandate attention to differential impacts of program activities. Other regulatory actions with specified social impact objectives are listed in the Health and Safety, Recreation, and Transportation and Traffic chapters.

TABLE 11-2
Laws, Regulations, Ordinances, And Programs Relevant to Social Impacts and Environmental Justice

Law/Program	Key Components	Relevance to Socioeconomic Issues or Environmental Justice
National Environmental Policy Act (NEPA), 1970	• Requires preparation of environmental impact assessments for new construction projects by private and governmental agencies • Includes federal government's responsibility to assess the social impact of proposed actions.	Provides basic national charter to assess and mitigate impacts to human communities, neighborhoods, cultural groups and others.
U.S. Council on Environmental Quality (CEQ), 1976 (40 CFR 1500-1508). Also, 1986 re-issue of regulations.	• Regulations for implementing NEPA procedural provisions. • "Human environment" shall be interpreted comprehensively to include the natural and physical environment and the relationship of people with that environment.	Regulations addressing implementation of NEPA. 1986 re-issue clarified treatment of incomplete or unavailable information.

Law/Program	Key Components	Relevance to Socioeconomic Issues or Environmental Justice
Emergency Planning and Community Right-To-Know Act of 1986 and Pollution Prevention Act of 1990	• Provides citizens, local governments, and response authorities with information regarding potential hazards in their community. • Requires emergency planning, mandates reporting, designates local authorities as recipients of information.	Designated to promote emergency planning and preparedness at both the state and local level.
Corps' Permitting Statutes (U.S. Army Corps of Engineers)	• Section 10 of Rivers and Harbors Act (1899) prohibits the unauthorized obstruction or alteration of any navigable water of the United States. • Section 404 of CWA authorizes the Corps to issue permits for the discharge of dredged and fill materials into waters of the U.S..	Permits require assessment of impacts on water quality, aquatic ecological resources, socioeconomics; and mandate mitigation of adverse impacts
Farmland Protection Policy Act	• Minimize federal actions contributing to unnecessary and irreversible conversion of farmland to nonagricultural uses. • Assure federal compliance with state and local farmland protection initiatives.	Protects economy and culture of rural communities.
Federal Water Project Recreation Act	• Establishes policy to consider opportunities for outdoor recreation and fish and wildlife enhancement planning of any Federal navigation, flood control, reclamation, hydroelectric or multi-purpose water resource project. • May include recreation & wildlife benefits in project cost/benefit analysis.	Requires non-federal partners to cost-share, operate and maintain recreation, wildlife enhancement facilities.
Fish and Wildlife Conservation Act	• Act declares that fish and wildlife are of ecological, educational, esthetic, cultural, recreational, economic and scientific value to the Nation.	May provide financial and technical assistance to States to conduct inventories and conservation plans for non-game wildlife.
Fish and Wildlife Coordination Act	• Act recognizes contribution of wildlife resources to Nation, increasing public interest and significance due to expansion of national economy and other factors. • Provides that wildlife conservation receive equal consideration and be coordinated with other features of water-resources development programs.	Corps shall consult with U.S. Fish and Wildlife Service (FWS), National Marine Fisheries Service (NMFS) as appropriate, and state wildlife resource agencies.
Flood Control Act of 1944	• Authorizes the Corps, to construct, maintain and operate public park and recreational facilities at water resources development projects (includes non-reservoir projects). • Local interests also permitted to construct, operate and maintain such facilities	Water areas of all such projects shall be open to public use for general recreational purposes, includes public access.

Law/Program	Key Components	Relevance to Socioeconomic Issues or Environmental Justice
Executive Order 12898 Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations	• Directs Federal agencies to address disproportionately high and adverse human health or environmental effects of agency programs, policies, and activities on minority populations and low-income populations.	Includes provisions for assisting disadvantaged group's participation in agency decision making.
Title VI of the Civil Rights Act of 1964	• Requires agencies to ensure effects of actions are nondiscriminatory.	Similar to EJ, but generally required action by affected groups to address impacts.

11.7 PAST TO CURRENT BASELINE CONDITIONS

Discussions of past to current conditions that may also be pertinent to SR concerns are presented in other VEC chapters. Exhibit D, Land Use, included a summary of historic studies recently funded by the Corps, reviews of current land use patterns and trends in the Ohio River Valley, and population trends and projections for counties adjacent to the Ohio River. Chapter 8, Health and Safety, addressed spills of fuel, oil, and other contaminants on or along the Ohio River, boating accidents, bacteriological contamination of water quality, and fish consumption advisories. See also the Cultural Resources, Transportation and Traffic, and Recreation chapters for additional discussion of baseline conditions relevant to SR concerns.

11.7.1 Economic Benefits of the Ohio River Navigation System

Historic settlement and development patterns were summarized in **Exhibit D**, Land Use. That discussion noted the rapid construction of railroads in the Ohio Valley between 1850 – 1860 and the subsequent decline of canals, river transportation, and some cities. While canals were relatively quickly and completely displaced by the railroads, impacts to river transportation were more gradual and never resulted in complete displacement of commercial traffic on the Ohio River. Steamboat construction in Cincinnati, for example, declined only slightly during the 1850s, and the cheaper cost of water transportation combined with the opening of other markets farther west where the railroad had yet to penetrate meant that the long-term effects of the railroads on river commerce took a while to be fully realized (Muller 1972: 346).

However, the railroad's ability to operate year round was a significant advantage over the seasonal and sometimes unpredictable fluctuations of river borne commerce. The railroads also improved their competitiveness by offering steeply discounted freight rates during the 1850s. As a result of these and other factors, rail lines increasingly came to dominate the transportation of Upper and Middle Ohio Valley agricultural produce to national markets and the movement in merchandise and manufactured goods moving the other way (Muller 1972: 343).

The lack of much additional rail expansion in Ohio by 1860 also meant that cities were largely "stuck" with the network that had evolved quickly during the 1850s. This benefited some Ohio River cities, but towns without rail service were largely dependent for commerce on whatever could be brought in or shipped out in the slowly diminishing river trade. Overall, the effect of the railroads on Ohio River towns was beneficial if the town was selected as a railroad throughway or terminal. Even so, the railroads gave increased economic importance to newer inland towns located well away from the river and re-directed the movement of trade. River towns were no longer the only "players" on the urban scene (Muller 1972: 341-342).

While the role of the Ohio River in shaping early settlement and development patterns is broadly recognized, the emergence of railroads in the mid-nineteenth century has tended to overshadow the economic contributions of the Ohio River navigation system during the twentieth century. Construction of the initial navigation system between 1904 and 1929 occurred at a time when commercial river traffic in general was falling off due to the combined impact of the railroads and the subsequent emergence of the nation's highway system. The appearance and growth of these forms of transportation—both of which have had major effects on urban life in the river valley—also have acted to blur recognition of the continuing but "lower amplitude" contribution of river commerce to contemporary urban life, especially in the cost-effective transport of bulk commodities such as coal and steel products, petroleum, and chemicals. The contributions of the river and its navigation system thus have been largely overlooked.

Completion of the navigation system resulted in the availability of dependable year-round transportation in a nine-foot channel from Pittsburgh to Cairo. The demands of World War I contributed to a rediscovery of the capabilities of the improved system and cargo shipments began to increase from 1917 and continued increasing through the 1920s. Commercial towing companies and related construction, maintenance, and repair facilities became an important part of the valley economy and have remained such (Blagg, p. 14).

After the Second World War, the Ohio Valley enjoyed an economic boom that was based on the low cost of moving bulk goods on the river and the region's low electric power costs, which were due in large part to the same factor. Between 1946 and 1953 some 2500 new industrial plants were built in the Ohio Valley on or near navigable streams, an investment of approximately $5.5 billion (Bigham 1991:165). Steam electric plants in the region grew because of the advantages of cheap transportation of coal by water from both the Appalachian and lower Ohio fields. The ability to move large quantities of petroleum, coal, sulfur, and other raw materials led to the expansion of the chemical industry at Calvert City, Kentucky, near Paducah. In 1951 General Electric chose Louisville for the site of its huge Appliance Park plant. One of Louisville's advantages was its ability to receive steel from Pittsburgh by water year round. Alcoa chose Evansville for a major smelter in 1957 due to water transportation and cheap electricity. A number of metal, especially aluminum, fabricating firms have located manufacturing facilities along the Ohio in Hancock County, Kentucky for the same reason. While river transportation has not been a major source of direct employment for some time, its indirect impact on employment, and thus economic and population growth, became more important after World War II.

One of the few specific studies of the economic benefits of the Ohio River Navigation System was conducted by Joseph R. Hartley (Hartley 1959). Hartley found that river shipping had experienced a dramatic decline in the late nineteenth and early twentieth centuries due to the national growth of railroads and, beginning in the 1920s and 1930s, to the development of long-haul trucking. However, inland river shipping had made a significant comeback, growing from 20 billion ton-miles in 1939 to 120 billion ton-miles in 1957. Barge tonnage carried on the Ohio River in 1957 actually was larger than that on the Mississippi River if coastal traffic on the Lower Mississippi River was excluded (81.6 million tons vs. 74.6 million tons on the Mississippi). Hartley also was encouraged by the 9.5 percent annual growth rate in the number of ton-miles carried on the Ohio and its tributaries, rising from 1.5 billion ton-miles in 1929 to 17.2 billion ton-miles in 1957. Most of this consisted of coal and coke (32.9 percent of ton-miles and 54.7 percent of tonnage in 1957) followed by petroleum (34 percent), iron and steel (19.9 percent), chemicals (7.6 percent), and other commodities (5.6 percent). Actual tonnage had increased from just 22 million tons to 81.6 million tons over the same period.

The reasons for this dramatic traffic growth on the Ohio River system included:

- Technological developments in barge design, construction and method of towing
  - Steel barges supplanted wooden barges
  - Integrated tows permitted joining up to 30 barges in a single tow
  - Tow boats installed radar and adopted diesel engines
- Construction of the system of locks and dams by the U.S. Army Corps of Engineers
- Water transportation rates compared favorably to railroad rates
- In 1957, water-borne commerce averaged 0.4 cents/ton-mile, versus 1.4 for rail
- Transportation cost savings were passed on to shippers and consumers.

Hartley also concluded that transporting coal on the Ohio River to industrial consumers, many of them electrical generating plants built on the river flood plain, had kept the cost of both coal and electrical power down for millions of ultimate consumers. Ohio River electrical plants, Hartley discovered, were producing about 12 percent of the nation's electrical supply in 1957, up from 6 percent in 1939. River transportation of coal to these plants allowed them to save nearly one-third the cost of production when compared with the national average. Since these electrical generating plants also were developing transmission lines to towns and cities within 100-150 miles of the river, the benefits of cheaper electricity was being shared with urban centers far removed from the Ohio River itself (Hartley 1959: III).

In sum, by the mid-1950s, development of the Ohio River Navigation System had helped to sustain lower costs for delivered coal, had provided cheap but reliable water supplies, and had lower prices for steel and other industrial transportation. These economies, in turn had helped to keep down energy prices and the cost of steel-using durable goods (such as automobiles, stoves, and refrigerators) for individual consumers. River transportation also had boosted the prospects of the aluminum smelting industry and the chemical industries in the river valley. Prices for refined oil and petroleum products used in the rapidly growing number of automobiles now being driven on the nation's expanding interstate highway system were held down by lower cost barge transportation.

Although the cost benefits of river transportation radiated outward to the nation as a whole, Hartley found that the Ohio River Valley had benefited directly from increased industrial investment, job growth, greater per capita income, higher retail sales, and urban growth. The last three categories were higher in the Ohio River Valley than for the nation as a whole even though, Hartley concluded, the overall prosperity of the Ohio River Valley still lagged behind the rest of the country. In general, Hartley (1959: IV) concluded, "Improvement of the River has helped provide an economic base for healthy, sustained, and rational economic growth."

Many of the patterns of economic activity observed by Hartley 44 years ago remain today. Coal utilities in the Ohio River Valley still account for about 12 percent of national energy production, and the majority of that coal is moved by barge on the Ohio River system. Coal for industrial power production, petroleum products, chemical feedstock, and iron and steel commodities each account for about 5 percent of annual tonnage moved on the Ohio River.

11.7.2 Population History and Projections

Population history and projections for each county along the Ohio River were obtained from the 1999 National Economic Projection Series (NPA Data Services, 1999). This study provides three alternative growth projections of U.S. population and the economy at the national and regional levels over the period 1997-2050. The alternatives include a baseline or mid-range scenario and high and low growth scenarios intended to produce projections near the limits of plausibility. Population projections for the baseline scenario are presented in this report. These can be compared to population trends and projections based on Census Bureau data (including the 2000 Census) presented in Exhibit D, Land Use.

The baseline scenario follows middle series fertility and mortality assumptions of Census Bureau projections published in 1996 (Report P25-1130) and based on actual data for the years through 1994. These Census assumptions were modified by NPA Data Services, Inc., to conform to actual birth and death experience of the U.S. through 1997. The baseline scenario assumes the number of foreign immigrants per 1,000 population will continue to increase at the rate of 1.4 percent per year through the year 2025. This conforms to the actual rate of increase from the mid 1960s through the mid 1990s. After 2025, the number of immigrants is projected to rise only with population. U.S. labor force participation for civilians 16 and older in the baseline increases from a rate of about 0.67 in 1997 to about 0.71 by 2016, and thereafter diminishes to 0.59 by 2050. Productivity or Gross Domestic Productivity (GDP) per worker increases at an annual rate of 1.16 percent between 1997 and 2025, and thereafter grows at a rate of 1.12 percent between 2025 and 2050.

As a result of these assumptions, the total population of the U.S. is projected to grow at the annual rate of 0.87% from 1997 to 2025 and at 0.65% from 2025 to 2050, averaging 0.8 percent per year over the entire projection period. For the six-state region, annual population growth averages 0.32% through 2025 and 0.38% through 2050. For the 82 counties in the Ohio River region, population is projected to grow at an average annual rate of 0.31% through 2025 and 0.39% through 2050. The estimated population of 7,341,000 for the Ohio River region in year 2000 is projected to reach 7,911,000 by 2025 and

8,696,000 by 2050. These projections for the Ohio River region and sub-areas including the Metropolitan Statistical Area (MSA) are presented in **Table 11-3.**

TABLE 11-3
Population Projections for Ohio River Region and Sub-areas

(population = table entry x 1,000)									
	1970	**1980**	**1990**	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Pittsburgh MSA	2,792	2,683	2,504	2,467	2,428	2,447	2,499	2,541	2,588
Steubenville-Weirton MSA	167	163	142	137	129	126	125	125	126
Wheeling MSA	183	185	159	155	147	143	143	143	144
Parkersburg to Wheeling	53	59	52	52	51	51	52	52	53
Parkersburg-Marietta MSA	144	158	149	152	154	159	165	170	175
Huntington to Parkersburg	146	163	165	176	185	195	207	217	227
Huntington-Ashland MSA	308	337	312	317	320	328	339	350	360
Cincinnati to Huntington	133	149	143	150	157	167	178	188	197
Cincinnati CMSA	1,669	1,729	1,822	1,975	2,094	2,236	2,392	2,531	2,662
Louisville to Cincinnati	47	53	53	58	61	64	68	72	75
Louisville MSA	890	922	914	959	983	1,024	1,079	1,129	1,174
Evansville to Louisville	163	185	186	200	211	224	237	250	263
Evansville- Henderson-Owensboro MSA	334	363	367	385	395	410	429	447	465
Below Evansville	150	160	155	158	160	166	173	181	187
Totals	**7,179**	**7,309**	**7,123**	**7,341**	**7,475**	**7,739**	**8,087**	**8,396**	**8,696**
Source: NPA Data Services, 1999									

For sub-areas within the Ohio River region, the majority of projected population growth is concentrated within the established, major urban areas and is heavily influenced by population trends from 1967 to 1997. The Cincinnati Consolidated Metropolitan Statistical Area (CMSA), which showed strong growth during the previous 30 years, is projected to grow by almost 35% through 2050, reaching a population of 2,662,000. By contrast, the Pittsburgh MSA, which lost population during the previous 30 years, is projected to continue losing population through 2010. It is then projected to gradually gain population, reaching a total of 2,588,000 by 2050. However, the net growth of 121,000 for the Pittsburgh area (for 2000 to 2050) still accounts for about 9% of total growth in the region. Significant growth also is projected to occur in the Louisville and Evansville-Henderson-Owensboro MSAs, while the Huntington-Ashland MSA grows at a rate slower than the regional average. These 5 MSAs, representing 38 of the 82 counties and 83% of the year 2000 population, are projected to account for about 84.6% of total population growth in the region. Population projections for these MSAs are presented in **Figure 11-1**.

Population growth, or lack of growth, in other sub-areas also reflects past trends. The 12 county region on the upper Ohio River from Steubenville to Parkersburg is expected to experience almost no net growth through 2050. Modest growth in the Parkersburg MSA will be offset by continued population declines in the remainder of the

area. By contrast, non-MSA counties between Huntington and Parkersburg, Cincinnati and Huntington, Evansville and Louisville, and below Evansville are expected to grow by about 30% through 2050. These trends are illustrated in **Figures 11-2 and 11-3**.

FIGURE 11-1
Population Projections for Major MSAs

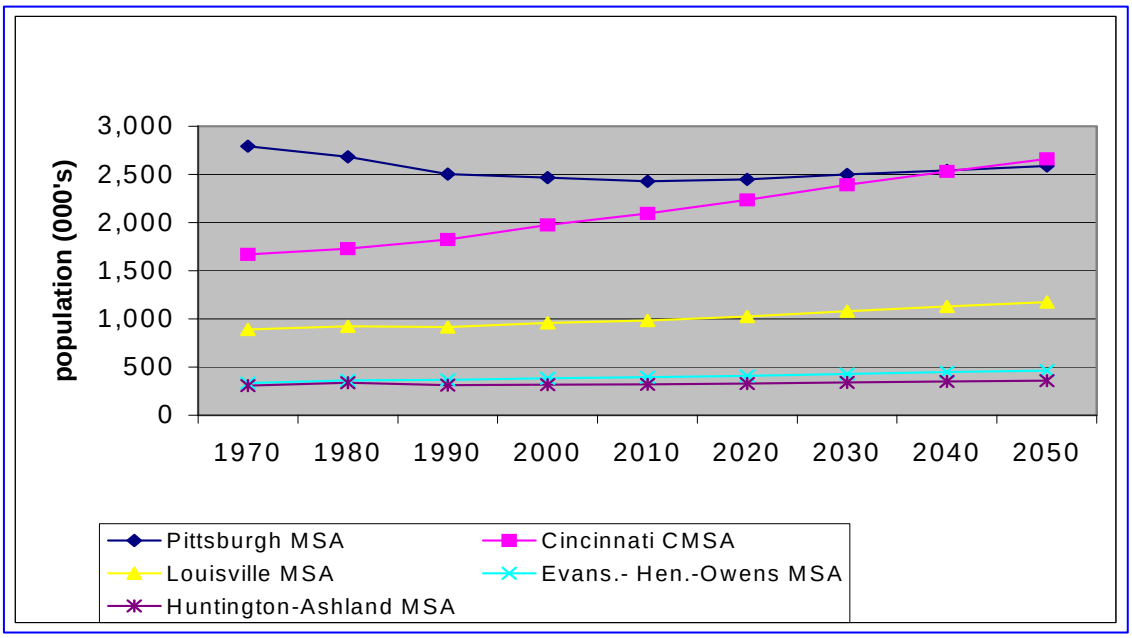


FIGURE 11-2
Population Projections for Upper River Sub-areas

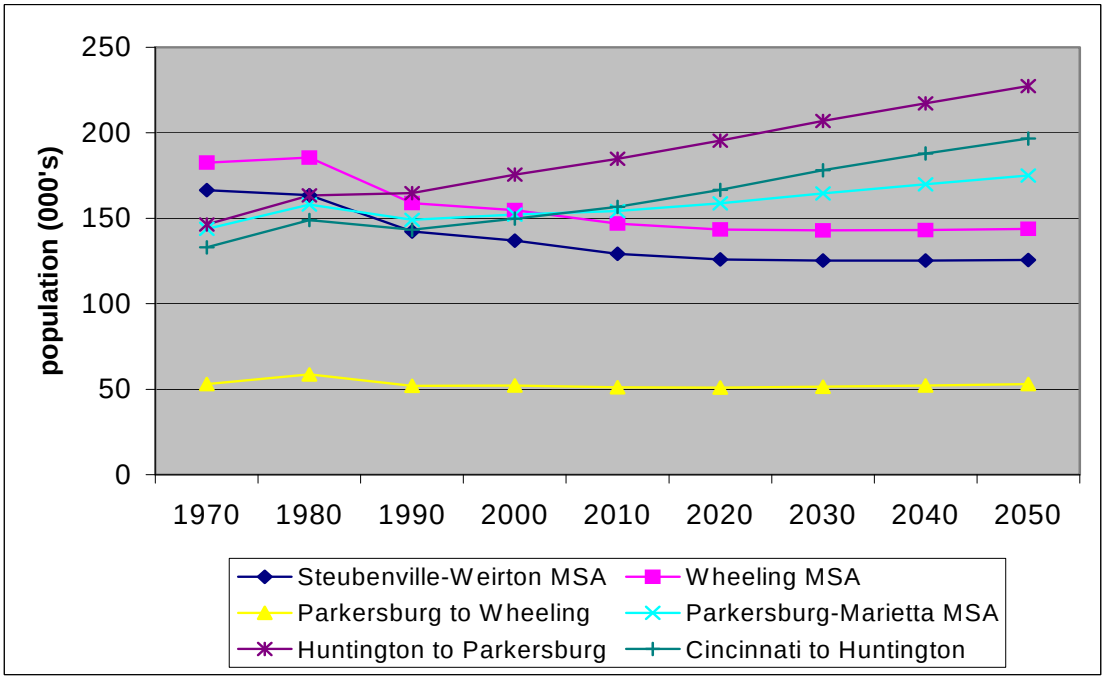
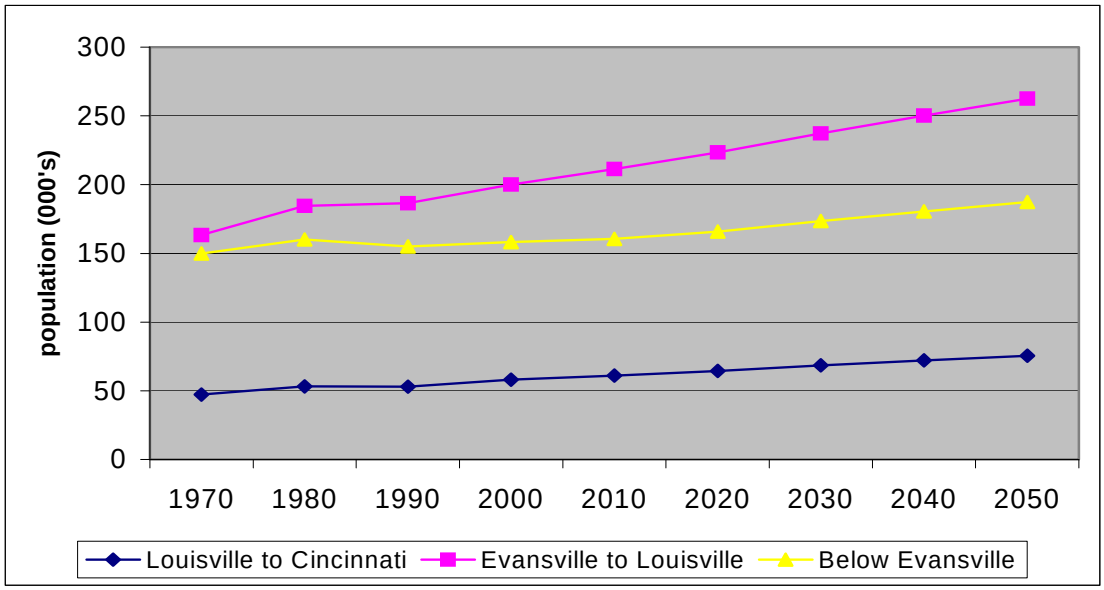


FIGURE 11-3
Populations Projections for Lower River Sub-areas



Source for Figures 11-1 through 11-3: NPA Data Services, 1999

11.7.3 Minority Populations

The Ohio River region has very few counties that exceed state averages for minority populations. In many counties, the percent minority population is only 20 or 30 percent of the state average. Counties that do exceed the state average are generally metropolitan centers such as Cincinnati in Hamilton County, Ohio. Rural counties with above average minority populations include Pulaski County, Illinois; and Hardin, Mason, Meade, and Union Counties, Kentucky. **Table 11-4** lists state averages and all counties that equal or exceed the state average.

TABLE 11-4
Non-White Populations

	Percent Estimates				
County and State	**1960**	**1970**	**1980**	**1990**	**2000**
Indiana	5.9	7.2	8.8	9.4	14.2
- no Indiana counties exceed the state average					
Illinois	10.6	13.6	19.1	21.7	32.2
- Pulaski	36.2	34.4	33.5	33.1	34.1
Pennsylvania	7.6	9.0	10.2	11.4	15.9
- Allegheny	8.3	9.3	11.2	12.5	16.2
Ohio	8.2	9.4	11.1	12.2	16.0
- Hamilton	14.4	16.1	19.9	22.3	27.6
West Virginia	4.9	4.1	3.8	3.8	5.4
- Cabell	4.5	4.4	4.9	4.9	7.1
- Ohio	3.1	3.4	4.1	4.1	5.9

Percent Estimates					
County and State	**1960**	**1970**	**1980**	**1990**	**2000**
Kentucky	7.2	7.4	7.7	8.0	10.7
- Hardin	7.4	9.0	14.7	14.9	19.5
- Henderson	10.2	8.4	7.7	7.6	9.3
- Jefferson	12.9	14.0	16.8	18.1	23.6
- McCracken	10.9	10.4	10.5	10.6	13.8
- Mason	9.9	9.3	7.8	7.9	9.5
- Meade	5.0	6.4	9.0	12.5	8.7
- Union	9.1	18.0	18.9	16.0	15.6
Source: US Census Bureau.					
Definition: White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa. It includes people who indicate their race as "White" or report entries such as Irish, German, Italian, Lebanese, Near Easterner, Arab, or Polish.					

Census records were also searched for Native American populations. Through 1980, state and county records identified very few individuals who identified themselves as Native American. The 1990 and 2000 Census appear to be identifying slightly larger populations, which may be the result of more sensitive measuring procedures. **Table 11-5** lists state averages and all counties that exceed the state average.

TABLE 11-5
Native American Populations

Percent Estimates					
County and State	**1960**	**1970**	**1980**	**1990**	**2000**
Indiana	0.1	0.1	0.1	0.2	0.3
- Clark	0.1	0.1	0.1	0.2	0.3
- Crawford	0.1	0.1	0.4	0.3	0.4
Illinois	0.1	0.1	0.1	0.2	0.2
- Gallatin	0.0	0.1	0.1	0.1	0.7
- Pope	0.1	0.1	0.2	0.4	0.8
Pennsylvania	0.1	0.1	0.1	0.1	0.1
Ohio	0.1	0.1	0.1	0.2	0.2
- Adams	0.0	0.1	0.1	0.3	0.7
- Athens	0.1	0.1	0.1	0.3	0.3
- Gallia			0.1	0.1	0.4
- Meigs	0.1	0.1	0.1	0.2	0.3
- Scioto	0.1	0.1	0.1	0.5	0.6
West Virginia	0.1	0.1	0.1	0.1	0.2
- Pleasants	0.0	0.1	0.1	0.1	0.5
Kentucky	0.1	0.1	0.1	0.2	0.2
- Bracken	0.1	0.1	0.1	0.1	0.3
- Bullitt	0.0	0.1	0.1	0.2	0.3
- Hancock	0.0	0.1	0.1	0.2	0.3
- Hardin	0.1	0.2	0.3	0.4	0.4
- Lawrence	0.0	0.1	0.1	0.1	0.3
- Livingston	0.0	0.1	0.1	0.2	0.4
- Meade	0.1	0.1	0.2	0.4	0.6
- Trimble	0.0	0.1	0.1	0.3	0.4
Source: US Census Bureau.					
Definition: American Indian and Alaska Native. A person having origins in any of the original peoples of North and South America (including Central America) and who maintain tribal affiliation or community attachment.					

Census records for 1970, 1980, 1990 and 1995 were reviewed for people of all ages in poverty, based on Census definitions for the periods studied. **Table 11-6** lists counties in the Ohio River region with higher than average poverty rates, and **Figure 11-4** illustrates their locations. Counties were identified for occurrence of high poverty rates if the percent in poverty exceeded 1.5 times the state average or 1.5 times the regional average (average poverty rate for the six state region) for any two of the four periods measured. Counties that exceed twice the state or regional average are also noted. Note that statewide poverty rates for Kentucky and West Virginia in 1970 exceeded 1.5 times the regional average.

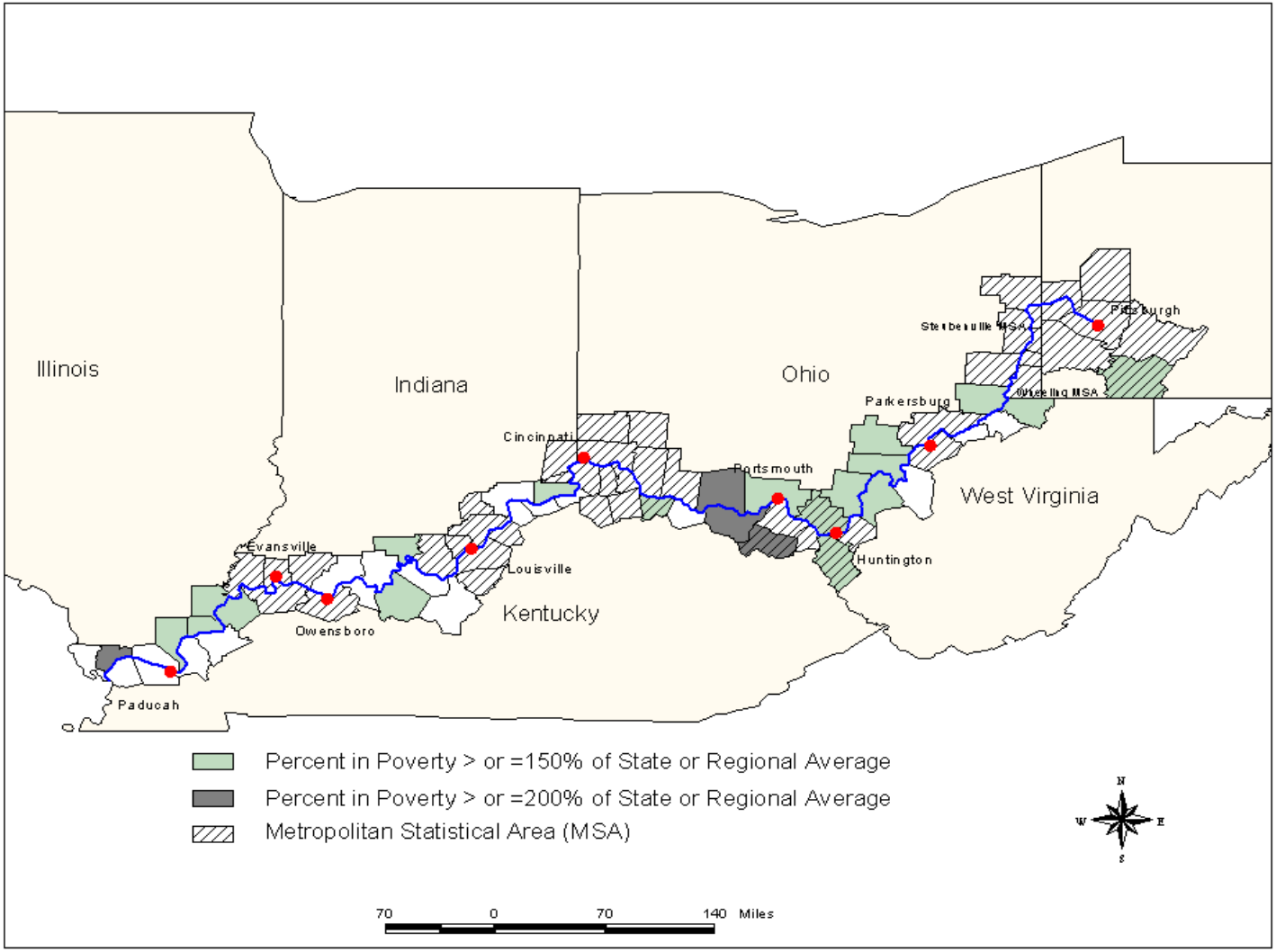
Table 11-6
People of All Ages in Poverty

	Percent Estimates			
State and County	**1970**	**1980**	**1990**	**1995**
Indiana	9.7	13.6	10.7	9.8
- Crawford	**21.5**	**25.4**	**18.5**	14.1
- Switzerland	**16.5**	**22.2**	15.2	13.4
Illinois	10.2	14.4	11.9	11.3
- Gallatin	**20.8**	**23.8**	**21.4**	**19.0**
- Hardin	**30.0**	**27.8**	**26.7**	**19.7**
- Pope	**39.9**	**27.6**	**25.2**	16.6
- Pulaski	**45.5**	**37.3**	**30.2**	**24.9**
Pennsylvania	10.6	14.6	11.1	11.4
- Fayette	**20.8**	21.0	**20.9**	
Ohio	10.0	14.0	12.5	11.3
- Adams	**31.6**	**24.7**	**28.5**	**20.3**
- Athens	**20.0**	**21.6**	**28.7**	**20.1**
- Gallia	**22.8**	14.9	**22.5**	**18.9**
- Lawrence	**20.2**	15.2	**23.5**	**19.9**
- Meigs	**23.9**	16.7	**26**	**21.4**
- Monroe	**18.1**	13.5	**21.5**	**17.4**
- Scioto	**20.5**	17.9	**25.8**	**21.4**
West Virginia	**22.2**	20.6	19.7	19.9
- Mason	**26.1**	18.7	**22.1**	20.2
- Wayne	**26.5**	**25.3**	**21.8**	**22.1**
- Wetzel	**21.4**	18.1	20.5	**20.7**
Kentucky	**22.9**	23.5	19.0	17.9
- Bracken	**28.9**	23.9	**21.4**	17.4
- Breckinridge	**24.8**	**29.7**	**23.2**	**20.7**
- Carter	**33.5**	**34.9**	**26.8**	**27.1**
- Lawrence	**45.0**	**37.9**	**36.0**	**30.9**
- Lewis	**31.1**	**39.7**	**30.7**	**28.1**
- Union	**27.8**	**27.1**	**22.1**	16.0
# counties > 1.5 state/regional avg.	**23**	**13**	**21**	**16**

Bold – exceeds 1.5 x state or regional average; **bold** – exceeds 2 x state or regional average.

Source: US Census Bureau, 1970, 1980, and 1990.
US Census 1995, http://www.census.gov/hhes/www/saipe/stcy.htm
Definition: Poverty http://www.census.gov/hhes/poverty/povdef.html

FIGURE 11-4 Ohio River Counties with High Poverty Rates



Per capita incomes provide an alternative to Census poverty rates for comparison of states, counties, and other subregions. Per capita incomes are calculated annually by the Bureau of Economic Analysis (BEA). For the six state region, the population weighted per capita income in 2002 represented 0.981 percent of the national per capita income. All states in the region show fairly stable maintenance of their income status relative to the national average, with four states gaining, Ohio essentially unchanged, and West Virginia showing slight decline. These rankings and trends are illustrated in **Table 11-7.**

TABLE 11-7
State Per Capita Income as % U.S. Average

State	2002 (rank/51)	Highest (year)	Lowest (year)	22 Year Trend
Illinois	1.080 (9)	1.100 (1997)	1.050 (1985)	+3.3%
Pennsylvania	1.025 (16)	1.025 (2002)	0.977 (1984)	+2.9%
Ohio	0.950 (26)	0.980 (1994)	0.944 (2001)	-0.15%
Indiana	0.913 (33)	0.940 (1994)	0.892 (1983)	+2.4%
Kentucky	0.827 (40)	0.827 (2002)	0.779 (1986)	+4.0%
West Virginia	0.766 (49)	0.793 (1982)	0.729 (1989)	-0.88%
Source: US Dept. of Commerce, Bureau of Economic Analysis http://www.bea.doc.gov/				

Individually, Illinois and Pennsylvania consistently rank among states with the highest per capita incomes, Ohio steadily represents the midpoint among states, and Indiana represents the point at which 2/3 of the states have higher per capita incomes. Despite significant gains for the past two decades, Kentucky remains in the bottom tier of states while West Virginia's declining incomes keep it very near the bottom for all states.

Per capita incomes for Ohio River counties and their geographic groupings are in **Figure 11-5** and in **Table 11-8**. For the 82 counties in the Ohio River region (counties adjacent to the river plus adjoining MSA counties), per capita incomes can be used to compare subareas of individual states or to illustrate the general income status of multi state groups of counties along the river. Counties can be grouped as upriver or downriver, with Cincinnati CMSA counties occupying the middle area between these groups.

Within the Ohio River region, 47 of the 82 counties (57.3%) have per capita incomes less than or equal to 75% of the national average. A total of 25 counties (30.5%) have incomes less than or equal to 67% of the national average. In general, upriver areas and non-MSA areas have a higher proportion of counties with below average per capita incomes. The Pittsburgh MSA area has only 2 of 7 counties below the 75% threshold, while in Cincinnati 5 of 13 counties have per capita incomes below 75% and 4 are below 67% of average. Between Pittsburgh and Cincinnati, all of the 13 non-MSA counties fall below 75% of average, with 9 falling below 67%. Among MSA counties between Pittsburgh and Cincinnati, 8 of 14 fall below 75%, with 3 of 14 below 67%.

Along the lower river, only one of the 12 MSA counties within Louisville, Evansville, Owensboro, or Henderson falls below 75% of the national average per capita income. Among the 22 non-MSA counties, 17 of 22 fall below 75% and 8 fall below 67%.

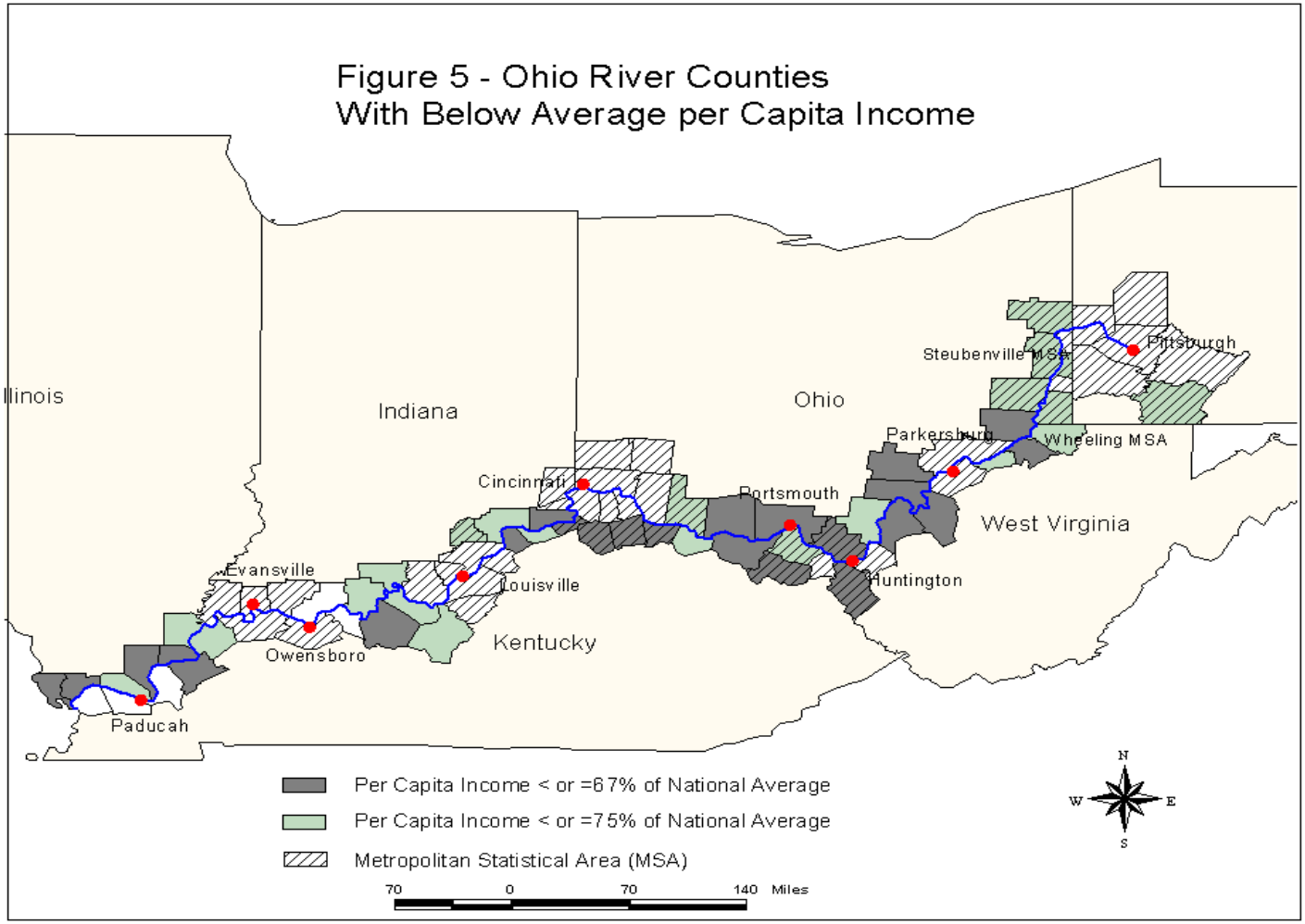
Counties with higher than average per capita incomes along the Ohio River are almost exclusively associated with major urban centers. Of the 5 counties with per capita incomes above the national average, 3 are the core counties for the cities of Pittsburgh, Cincinnati, and Louisville while 2 are adjacent counties within the MSAs of Cincinnati and Louisville.

TABLE 11-8
MSAs and Non-MSA Counties Adjacent to Ohio River

Pittsburgh, PA MSA	**Per Capita Income***		**Non-MSA Counties**	
Allegheny, PA	121			
Beaver, PA	88		All 7 PA counties are in	
Butler, PA	93		Pittsburgh MSA.	
Fayette, PA	75			
Washington, PA	99			
Westmoreland, PA	92			
Columbiana, OH	71			
Stuebenville-Weirton, OH-WV MSA	**Per Capita Income***			
Brooke, WV	75			
Hancock, WV	83			
Jefferson, OH	72			
Wheeling, WV-OH MSA	**Per Capita Income***		**Parkersburg to Wheeling**	**Per Capita Income***
Marshall, WV	68		Monroe, OH	63
Ohio, WV	93		Pleasants, WV	72
Belmont, OH	73		Tyler, WV	59
			Wetzel, WV	69
Parkersburg-Marietta, OH-WV MSA	**Per Capita Income***		**Huntington/Ashland to Parkersburg**	**Per Capita Income***
Washington, OH	76		Athens, OH	65
Wood, WV	81		Gallia, OH	75
			Meigs, OH	61
			Jackson, WV	67
			Mason, WV	62
Huntington-Ashland, WV-KY-OH MSA	**Per Capita Income***		**Cincinnati to Huntington/Ashland**	**Per Capita Income***
Cabell, WV	82		Adams, OH	62
Wayne, WV	54		Scioto, OH	67
Boyd, KY	85		Bracken, KY	60
Carter, KY	63		Lewis, KY	44
Greenup, KY	70		Mason, KY	73
Lawrence, OH	63			
Cincinnati, OH-KY-IN CMSA	**Per Capita Income***		**Louisville to Cincinnati**	**Per Capita Income***
Dearborn, IN	92		Jefferson, IN	74
Ohio, IN	77		Switzerland, IN	58
Boone, KY	99		Carroll, KY	73
Campbell, KY	87		Trimble, KY	54

Gallatin, KY	58			
Grant, KY	65			
Kenton, KY	95			
Pendleton, KY	63			
Brown, OH	73			
Butler, OH	94			
Clermont, OH	98			
Hamilton, OH	117			
Warren, OH	101			
Louisville, KY-IN MSA	**Per Capita Income***		**Evansville to Louisville**	**Per Capita Income***
Clark, IN	87		Crawford, IN	69
Floyd, IN	96		Perry, IN	75
Harrison, IN	81		Spencer, IN	83
Scott, IN	71		Breckinridge, KY	58
Bullitt, KY	78		Hancock, KY	85
Jefferson, KY	110		Hardin, KY	75
Oldham, KY	106		Meade, KY	74
Evansville- Henderson-Owensboro, IN-KY	**Per Capita Income***		Below Evansville	**Per Capita Income***
Daviess, KY	83		Alexander, IL	60
Henderson, KY	87		Gallatin, IL	71
Posey, IN	96		Hardin, IL	63
Vanderburgh, IN	98		Massac, IL	71
Warrick, IN	96		Pope, IL	59
			Pulaski, IL	60
			Ballard, KY	90
			Crittenden, KY	59
			Livingston, KY	78
			McCracken, KY	99
			Union, KY	71
Source: US Dept. of Commerce, Bureau of Economic Analysis ***Year 2001, as per cent of U.S. Average**				

FIGURE 11-5 Ohio River Counties with Below Average per Capita Income



11.8 INTERACTIONS WITH OTHER VALUED ENVIRONMENTAL COMPONENTS (VECS)

SR and EJ factors exhibit a high level of interaction with Land Use. Both subjects address past to present patterns, projections of population, settlement patterns, and economic indicators. SR also interacts strongly with Health and Safety, Recreation, Transportation and Traffic, and Cultural Resource VECs. These VECs address various community values that are reflected in the socioeconomic character of the region. Connectivity is less obvious between SR factors and the environmental resource VECs, although there is growing recognition of the contributions of natural systems functionality to the well being of human communities. VEC interactions are illustrated in **Table 11-9.**

TABLE 11-9
Interactions of Socioeconomic and EJ Factors with Other VECs

VEC	SR & EJ Factors & Impacts	Past/Present Trends	Future Trends	Comments
Land Use	Home ownership opportunities and expectations.	Traditional city/rural patterns replaced by suburban patterns.	Development consumes more acreage per capita.	EJ – limited alternatives if cannot afford 'conventional' housing.
Transport -ation & Traffic	Vehicle ownership opportunities and expectations.	Expanding highway network to accommodate traffic growth.	Continued growth of miles driven per capita.	EJ – limited alternatives if cannot afford personal vehicle.
Recreatio n	Expanding leisure time and disposable income per capita.	Growth of river oriented activity with improved water quality and accessibility.	Expanding variety of river-oriented activity. Potential conflicts from crowding or incompatible uses.	Potential continued growth of urban river-front oriented development (housing-shopping-recreation).
Health and Safety	Expanding river oriented activities contribute to expanding exposure to river related risks.	Water quality improvements, spill prevention & response, improved monitoring has reduced river related risks.	Continued expansion of river oriented activities require improved water quality and monitoring to maintain low risk factors.	Control of contaminant sources affecting water contact recreation and fish consumption issues has slowed following early gains.
Cultural Resource s	Development threatens architectural and archaeological resources.	Regulatory oversight contributes to protection, impact avoidance, and mitigative actions.	Interpretations at landscape scale expand complexity of cultural resource protection.	Cultural resource protection most effective when part of planning & design vs. reactive assessment.
Water Quality	Improved public health, recreational opportunity, aesthetic values with improved water quality.	See recreation, health and safety comments.	Appears likely present water quality will be maintained or improved.	Broad and expanding public recognition of water quality benefits and value.
Air Quality	Improved public health and	See recreation, health and safety	Appears likely present air quality	Broad and expanding public recognition of

VEC	SR & EJ Factors & Impacts	Past/Present Trends	Future Trends	Comments
	aesthetic values with improved air quality.	comments.	will be maintained or improved.	air quality benefits and value.
Biological Resources (aquatic, riparian, T&E).	Resource recoveries contribute to improved recreational opportunity, aesthetic values.	See recreation, health and safety comments.	Expanding navigation, commercial/residential and recreational uses of river will conflict with habitat needs.	Long term protection/ management of significant habitat areas required to maintain Bio Resources

11.9 RELEVANT ACTIONS AFFECTING SOCIOECONOMIC RESOURCES AND ENVIRONMENTAL JUSTICE

RFFAs were evaluated for SR and EJ issues utilizing the RFFA Matrix (see Exhibit A). The matrix evaluation process resulted in identification of 15 RFFAs with high or medium high importance for SR issues and an additional 24 that were rated as having medium importance. Results of the RFFA evaluation for SR are summarized in Table 10 and discussed in further detail in text following the table. Results of the evaluation for EJ issues are summarized in Table 11-10.

TABLE 11-10
RFFA Cumulative Effects Matrix for Socioeconomic Resources VEC

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Impact	Importance
Navigation Investment Actions					
Lock Extensions/New Locks/Replacement or Rehabilitation	A	H	SL	+	M/H
L&D operation and maintenance	A	H	SL	+	L/M
Non-structural navigation improvements	A	H	E	+	L/M
Other Corps Actions					
Channel dredging/dredged material disposal	A	H	E	+	L/M
Navigation aids - Construction and O&M	A	H	E	+	L/M
Flood damage reduction projects					
levees/floodwalls	A	L	SL	+/-	M
channel modifications	A	H	SL	+	L/M
nonstructural measures (relocation)	A	H	SL	+	L/M
Emergency streambank stabilization (Sec. 14)	A	H	SL	+	L/M
Modification of Corps structures for env. improvements (Sec. 1135)	A	M	SL	+	L/M
Environmental restoration of aquatic ecosystems (Sec. 206)	A	M	SL	+	L/M
Recreation facilities – Cons. and O&M	A	H	SL	+	M

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Impact	Importance
ERP Projects - 5 categories	A	M?	SL	+	M/H
Port development (Sec. 107) and maintenance dredging	A	H	SL	+/-	M/H
Pool Maintenance	A	H	SL	-	M
"But for" Actions					
Commercial Navigation					
barge queueing	A	H	SL	-	M
fleeting areas/barge storage	A	H	SL	-	M/H
terminals	A	H	SL	+/-	M/H
multi-modal sites	A	H	SL	+/-	M/H
increased traffic	A	H	E	-	L/M
dispersed barge traffic	A	H	E	-	M/H
accidents/spills	A	H	E	-	M
USCG Navigation Aids	A	H	E	+	L/M
Instream sand and gravel mining	A	H	SL	+/-	M
Floodplain sand and gravel mining	A	H	SL	+/-	M
Limestone aggregates mining	A	H	SL	+/-	M
Coal utilities	A	H	SL	+/-	H
Other coal industries	A	M/L?	SL	+/-	M
Industrial users, excluding coal-related	A	H	SL	+/-	M
Recreation facilities – Cons. and O&M	A	H	SL	+	M
Actions by Others					
Park development and operations	A	H	SL	+	L/M
Floodplain development					
commercial	A	M	SL	+/-	M
industrial	A	H	SL	+/-	M/H
Crossings					
bridges	A	H	SL	+/-	M/H
Marina development & operation	A	H	SL	+/-	M/H
Water -based recreation					
boating	A	H	E	+	H
fishing	A	H	E	+	H
personal watercraft	A	H	E	+/-	M
wildlife watching	A	H	E	+	M
sight-seeing	A	H	E	+	M
Agriculture	A	H	R	+	M

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Impact	Importance
Waste Water Treatment Plant discharges					
municipal	A	H	U	+/-	M
industrial	A	H	U	+/-	M
Stormwater discharges	A	H	U	-	M
Brownfields redevelopment	A	H	U	+	L/M
Hazardous waste sites	A	H	SL,U	-	L/M
Natural Climatic Events					
floods	A	H	E	-	H
droughts	A	H	E	-	M
severe storms	A	H	E	-	M
Regulatory Environment					
Phase I & 2 NPDES program	A	H	SL, U	+	M
Site remediation	A	H	SL	+	L/M
More stringent quality standards for environmental media	A	H	E	+	L/M
Wetland Mitigation Banking	A	H	SL	+	L/M
Farmland preservation	A	H	SL, R	+	L/M
Emissions trading	A	H	SL	+	L/M
COE permitting programs	A	H	E	+	M/H
ORSANCO monitoring program	A	H	E	+	M
Spill response	A	H	E	+	M
Environmental sustainability practices	2,3	M	E	+	L/M

[1] Reasonably Foreseeable Future Actions
[2] Time period in which the RFFA may occur
1 = within 10 years, 2 = 10 - 25 years, 3 = 25 - 60 years, A = all time periods
[3] Occurrence probability or likelihood RFFA will happen
H = high M = medium L= low
[4] Location or setting on river where RFFA is expected to occur
U = upper (Pittsburgh - Huntington), M = middle (below Huntington - Louisville)
L = lower (below Louisville - mouth), E = along entire length of river
SL = specific location, e.g., locks and dams, U = urban setting, R = rural setting

11.9.1 Navigation Investment Actions

Lock extension, replacement or rehabilitation (Impact, +; Importance, M/H): Lock extension, replacement, or rehabilitation would result in creation of temporary employment for construction workers, but not creation of permanent jobs. Temporary employment of local unemployed or underemployed construction workers would be a benefit. Short-term local income and revenues would increase as a result of project related employment. No long-term changes to population, property values, local taxes, or existing land use patterns are predicted. Need for additional housing, utilities, or social services also are not

anticipated. On-site or near-by recreational uses may be closed or curtailed during construction.

Long-term positive impacts to efficiency of the navigation industry and reduced shipping costs are the principal justification for navigation improvements. However, future growth of navigation traffic is expected under all scenarios primarily due to continued economic growth.

11.9.2 Other Corps Actions

Port development and maintenance dredging (+/-, M/H): Potentially significant SR impacts include temporary employment increases during construction with associated increased local revenues. The possible development of new terminals and associated facilities would contribute to creation of new permanent employment and changes in property values and tax base. Recreational use would be restricted during construction, and could potentially be permanently altered with a consequent loss of associated revenues.

Ecosystem restoration projects (+, M/H): Short-term local income and revenues would increase as a result of project related employment and other expenditures. Completed projects would potentially enhance fishing and other recreational opportunities, with associated increased revenues. Long term protection of aquatic/terrestrial habitats is critical to protecting the economic viability of recreation oriented businesses.

Levees/floodwalls (+/-, M): These projects protect people and infrastructure investments and reduce or eliminate potential damage costs in flood prone areas. They also remove riparian land from floodplain functionality. These actions are rated 'medium importance' because little additional expansion of levees or floodwalls is expected for the Ohio River mainstem. However, the presence of levee/floodwall protection may contribute to redevelopment initiatives in depressed or underutilized portions of riverfront communities.

Recreation facilities, construction (by Corps or others), and O&M (+, M): These actions would expand the local economy by providing additional services, concessions, and limited new employment. Public access and opportunities to benefit from the resource would be enhanced. The value of nearby communities or shopping/commercial developments may also be enhanced.

Pool Maintenance (-, M): Landowner perceptions of riverbank property damages are attributed to pool elevation maintenance, other Corps actions, and perceived failure to regulate barge activity. State agency perceptions of damages to parks and wildlife management areas are also attributed to pool maintenance. Note the frequency of public comments (**see Table 11-1**) addressing this topic.

11.9.3 But for Actions

Coal Utilities (+/-, H): Coal fired power plants provide employment opportunities and potential development or expansion of related shipping facilities. Potential negative impacts are related to traffic and spills during transfer of materials. New utilities and

expansion of existing facilities will compete with other uses in limited floodplain areas and would result in losses of agricultural lands or riparian habitats. Coal utilities account for 60+ % of commercial traffic on the river and are expected to account for the majority of projected traffic growth.

Fleeting areas, barge storage (-, M/H): Fleeting activities can deter recreational use with loss of associated revenues to the local economy. Potential accidents and spills from fleeting activity adds increased costs. Locating fleeting areas away from shore helps reduce negative impacts but can be problematic during low flows with narrowed river widths. Fleeting activities are an unavoidable 'externality' of barge navigation that has resulted in conflicts with boaters, shoreline residents, and others. Controls and conflict resolution are likely to become more necessary as traffic growth results in continued expansion of areas used for fleeting.

Dispersed barge traffic (-, M/H): Negative economic impacts are associated with the increase in potential accidents and spills when barges fail to stay in designated shipping lanes. These impacts may discourage boaters, reducing associated recreation revenues. Bank tie-offs, groundings, and related shoreline encroachments result in bank erosion, property damage, and conflicts with shoreline residents. Note the frequency of public comments from scoping meetings (**see Table 10-1**) addressing these topics.

Terminals/multi-modal facilities (+/-, M/H): These facilities provide employment opportunities and potential development/expansion of related shipping facilities. Potential negative costs are related to traffic and spills during transfer of materials. New terminals and expansion of existing facilities will compete with other uses in floodplains and would contribute to losses of agricultural lands or riparian habitats.

Barge queuing (-, M): Idling of tows increases operation and shipping costs and potentially increases user conflicts (e.g., accidents) and associated costs. Shoreline stabilization costs may be incurred.

Accidents/spills (-, M): Short to long-term economic impacts vary with the extent of each spill. Resulting shoreline damages may incur costs for clean-up and possible litigation. Provisions for monitoring, spill detection/notification, and response systems help avert damage and associated economic impacts.

Mining activities – instream, floodplain (+/-, M): Mining in close proximity to the river benefits from availability of the navigation system. Impacts include local economic benefits, losses of instream and riparian habitats/functions, and the potential for restoration of riparian sites for recreation and/or habitat functions after completion of mining activity.

Other coal industries, other industrial activities (+/-, M): The navigation system and/or availability of water encourage the location of activities near the river. Impacts include local economic benefits and the loss of instream and riparian habitats/functions.

11.9.4 Actions by Others

Floodplain industrial development (+/-, M/H), floodplain commercial development (+/-, M): Further industrial or commercial development would generally create

employment opportunities, add to local revenues, and potentially change property values and the tax base. Concomitantly, public services would need to be extended with associated costs. Such facilities may or may not generate new business for the shipping industry. Development would take land from agricultural or riparian habitat uses.

New bridge construction (+/-, M/H): Short-term local income and revenues would increase as a result of project related employment and related expenditures. Significant changes to population, property values, local taxes, and existing land use patterns would likely occur (e.g., at a new interstate bridge). Long-term positive impacts to the efficiency of highway transportation and reduced trucking costs are the principal justification for new bridge construction or expansion.

Marina development and operation (+/-, M/H): Development of new marinas would result in temporary employment increases during construction with associated increased local revenues. Marina operations would result in some permanent employment and changes in property values and tax base. Increased recreational activity would generate new revenues for the local economy. Development would result in loss of agricultural lands or riparian habitats, particularly embayment wetlands. There is potential for future growth in this sector if recreational interests continue to grow.

Recreational Boating and Fishing (+, H): Boating generates significant trip-related and boat-related revenues (Husak, 1999). Fishing generates significant trip-, boat-, and equipment-related revenues. Commercial navigation, floodplain industrial or commercial growth, and other competing uses may limit capacity for continued growth of recreational activity on the Ohio River.

Water based recreation – Personal Watercraft (PWCs), wildlife watching, sight-seeing (+, M): These activities generate trip-related revenues, including income for excursion cruises from some larger ports. They also generate equipment purchase revenues. Potential social conflicts could occur if development activities threaten wildlife resources. Potential conflicts exist between incompatible activities such as PWC operation and wildlife watching. There is potential future growth of these activities if recreational interests continue to grow.

Agriculture (+/-, M): Agriculture provides jobs and income, along with food and fiber, and impacts vary with the size or type of operation. Implementation of proper BMPs can limit erosion, pollution, and other costly negative environmental impacts. Agriculture provides the foundation for rural community networks. Most future developments in floodplains would occur on agricultural lands.

Waste Water Treatment Plant (WWTP) discharges – municipal, industrial (+/- M): Clean industries and communities associated with properly functioning treatment systems can encourage economic growth. Pollution and aesthetic problems associated with malfunctioning systems can deter further development. Applies to collection systems (CSOs, SSOs, and infiltration) as well as to plants and discharges.

Stormwater discharges (-, M): Storm runoff from CSOs, SSOs and nonpoint urban surfaces contributes to bacteriological contamination and associated health risks. Significant investments are required to reduce or eliminate CSO and SSO discharges.

Implementation of proper BMPs can limit erosion, pollution, and other negative environmental impacts from storm runoff.

11.9.5 Natural Climatic Events

Flood Events (-, H): Flooding increases the potential for river-related accidents, including vessel casualties, barge breakaways, and pollution incidents along with associated adverse economic impacts. Enormous economic costs can occur when homes, businesses, and industries in flood-prone areas are damaged.

Extreme weather – droughts, storms (-, M): Low water conditions can increase potential for river-related accidents, including vessel groundings, barge breakaways, exposed river hazards, and pollution incidents, along with associated adverse economic impacts. Lower water levels decrease dilution of pollutants entering the river and increase retention time, potentially lowering water quality.

Severe storms can cause high economic losses related to damage from hail, high winds, heavy debris, lightning, and ice formation. Although these occurrences cannot be prevented, better forecasting and enhanced boater education can increase preparation and alleviate or avoid some adverse socioeconomic impacts.

11.9.6 Regulatory Environment

Corps permitting programs (+, M/H): To the extent that these programs address components of the Clean Water Act, they reduce pollutant discharges to local waterways with associated economic benefits. These programs also have implications for several VECs, including aquatic resources, land use, and health and safety. Corps permitting plays a potentially significant role where social conflicts arise over competing uses of resources.

Phase I & II NPDES (+, M): These programs should decrease the amount of stormwater and pollutants entering the river and their associated economic impacts. Because these programs are somewhat complex and costly to implement, many municipalities are establishing stormwater utilities to help fund them.

Ohio River Valley Sanitation Commission (ORSANCO) Monitoring (+, M): ORSANCO's various ongoing monitoring programs provide environmental and human health information with associated SR benefits (e.g., see spill response below).

Spill Response (+, M): Emergency response measures currently in place by ORSANCO, Coast Guard, USACE, EPA and various state agencies help to reduce accidental spills and associated clean-up costs. Spill detection and notification systems along the river have become increasingly sophisticated in the last 20 years. Rapid response and effective containment/recovery also minimizes the severity of spills.

11.9.7 Relevant Actions Affecting Environmental Justice

From the systemwide perspective of a CE study, EJ issues may tend to be overlooked. For example, the collective benefits of affordable electricity stemming in part from development and maintenance of the Ohio River navigation system would accrue to

EJ populations as well as to the general population of the region. Similarly, air pollution impacts stemming from coal combustion effect everyone, EJ populations do not appear to be disproportionately impacted. However, the appearance of no disproportionate impact systemwide may mask important differences on a local or site specific basis. Residents of urban areas exposed to seasonal concentrations of ozone contamination could be more seriously affected than commuters who spend part of each day in less polluted areas outside of the city.

The review of RFFAs resulted in very few indications of disproportionate impacts to EJ populations. **Table 11-11** and the subsequent discussion of individual RFFAs are intended to illustrate some of the more obvious possibilities, as well as to underscore the need to perform adequate EJ scoping at the individual project level.

TABLE 11-11
RFFA Cumulative Effects Matrix for Environmental Justice Considerations

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Impact	Importance
Navigation Investment Actions					
Lock Extensions/New Locks/Replacement or Rehabilitation	A	H	SL	+/-	L
Other Corps Actions					
Flood damage reduction projects					
levees/floodwalls	A	L	SL	+/-	L
nonstructural measures (relocation)	A	M	SL	+/-	L/M
Recreation facilities – Cons. and O&M	A	H	SL	+	M

11.9.7.1 Navigation Investment Actions

Lock extension, replacement, or rehabilitation (Impact, +/-; Importance, L): Except for a few lock and dam projects located in urban settings (i.e., EDM) it is unlikely that construction related impacts would differentially effect EJ populations. Overall socioeconomic impacts of lock extension, replacement, or rehabilitation projects would be about the same for EJ populations as they would be for the general population. Temporary employment of local unemployed or underemployed construction workers would be a potential benefit of more direct importance to EJ populations.

As with any proposed major project, it is important to evaluate site specific characteristics of the project area to identify any populations that may require special communication, planning and involvement efforts, or that may be differentially impacted by the project.

11.9.7.2 Other Corps Actions

Flood damage reduction projects - levees and floodwalls (+/-, L): The benefits of flood protection accrue to all that live or work in areas protected by levees or floodwalls.

Federal laws and policies require that flood damages avoided (benefits) must exceed project costs. Areas with concentrations of low property values often do not receive flood damage reductions as projects in these locations do not have a positive benefit/cost ratio. Therefore, some localized neighborhoods with low income populations are likely to be disproportionately affected.

Flood damage reduction projects – nonstructural measures (+/-, M): Relocation of populations out of a floodplain can sometimes fit better with community needs than building flood control structures. This option can also be less environmentally damaging and offers opportunities for recreational and open space amenities in the floodplain (Johnson Creek, 2003). EJ communities face similar problems with project justification as for structural flood damage reduction measures discussed above. In cases where EJ populations or communities live in a project area, special steps may be necessary to avoid negative impacts to relocated individuals. If residences in the area were mostly rented, compensation may go primarily to property owners, while those who are actually displaced could receive inadequate compensation. Special efforts, including collaborative planning efforts with the impacted communities, would be required to assure that relocated families and communities are not harmed by the project (FHWA East-West EIS, FHWA SC Rt. 72 EA).

Recreation facilities – construction and O&M (+, M): Research conducted by the Corps indicates that some recreation facilities may be disproportionately popular with EJ populations (Gramann, 1996; Dunn, 1999). Factors such as accessibility, available activities, facility design, affordability, and safety can strongly influence the choices of minority groups. This research also suggests that studying the distributions and needs of EJ populations along the Ohio River could facilitate design of new parks or redesign of existing recreation facilities so as to provide enhanced recreational opportunities for these populations. See Chapter 9, Recreation, for more discussion of planning and design of recreational facilities on the Ohio River.

11.10 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve Environmental Sustainability (ES). ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an “ultimate test” whereby the significance of CE can be evaluated. This test is applicable for programmatic impact studies wherein a broad, “high altitude” perspective is utilized. An Analysis of Environmental Sustainability (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps:

(1) identification of “common effects” on SR parameters from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix;
(2) selection of sustainability indicators for SR, and their grouping, as appropriate; and

(3) consideration of the "connections" between the common effects and the indicator groups

The output of the AES consists of a qualitative (descriptive) discussion of the "connections", with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for SR, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – composite conditions for the selected indicators of ES for SR do not reflect conditions that would facilitate attainment of acceptable standards or would not maintain existing standards in concert with collective impacts of proposed activities.

- Marginally sustainable – composite conditions for selected indicators of ES are such that attainment of acceptable living conditions and quality of life is accomplished for the majority, but not all, of the potentially affected populations. However, the conditions of indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of SR for the Ohio River).

- Sustainable – composite conditions for selected indicators of ES are such that attainment of acceptable living conditions and quality of life is accomplished for essentially all of the potentially affected populations in the Ohio River Valley, and such standards are maintained in concert with foreseeable future activity. Further, conditions of the indicators exceed regulatory thresholds, and various governmental programs are in place to respond to any potential erosion of SR values.

Common effects of multiple actions have been previously discussed in the sections entitled "Interactions with Other VECs" and "Relevant Actions Affecting SR".

Indicators or groups of indicators of ES were identified earlier in the section entitled "Indicators of Sustainability", and relevant information on them have been presented in the section entitled "Past to Current Baseline Conditions". For purposes of this analysis, the above indicators are grouped into three tiers for the AES. The three tiers are as follows:

- first tier – "scientific measures of socioeconomic resource factors"
  - (1) Census counts of population, including minority and economically disadvantaged populations.

  - (2) Census counts of income, educational attainment, health status, household composition, and other indicators of socioeconomic status.

- second tier – "composite measures of socioeconomic resource factors"

(1) Census and Bureau of Economic Analysis calculations of households in poverty, per capita income, employment levels by SIC code, and unemployment rates.

- third tier – "composite indicators of SR sustainability;" this includes measures developed from multiple indicators

  (1) Projections based on fertility, mortality, immigration, labor force participation, and growth of national productivity.

Finally, the indicators and tiers are displayed in **Table 11-12**. The first column in **Table 11-12** divides the RFFAs into three broad groups. The first group includes actions that sustain the broad spectrum of socioeconomic viability throughout the Ohio Valley region. The Ohio River navigation system is included as one of the important infrastructure components of the region. The combined effects of these 'major factors' are most directly linked to the socioeconomic measures and indicators summarized in the latter columns. The second group in column one includes actions that are necessary to the long-term maintenance of the navigation system, such as infrastructure maintenance and dredging of the navigation channel. Potential modifications of present day lock systems are included in this group. Finally, the third group looks at the negative SR effects of those actions that are necessary to maintenance of the navigation system.

When comparing actions that may impact sustainability of SR, the most appropriate composite measures and indicators are those that reflect the general health and well being of people affected by such actions. The primary indicator of SR sustainability used in this chapter is the baseline county-level projection of populations for Ohio River states prepared by the economic consulting firm NPA Data Services (NPA, 1999). NPA's key forecasting assumptions involve several demographic and economic variables. The demographic variables are fertility, mortality, and immigration rates. The economic variables are labor force participation and the growth of national productivity, or product (GDP) per worker. Projections of stable to slowly expanding populations are interpreted within the context of these measurements as the most desirable outcomes. Declining populations are interpreted as an indicator of undesirable SR conditions and rapidly expanding populations are interpreted as an indicator of significant changes in the community that may produce a mix of desirable and undesirable outcomes.

On a more localized basis such as a project specific assessment, socioeconomic analysis as outlined above should be supplemented with more specific indicators of general health and well being. This can be largely accomplished by following the guidelines for assessing EJ issues presented earlier in this chapter (see 11.6.1 Legal Mandates and 11.6.2 Agency Guidelines). Potential indicators at the community level could include income related to local cost of living, infant mortality rates, average life expectancy, home ownership rates, and crime rates. Selection of appropriate indicators and SR study design at the community level needs to be based on characteristics of the local community and the nature of the proposed action.

11.11 Conclusions

The general socioeconomic projection for the Ohio River Valley is 'sustainable' for the present and into the foreseeable future. The region offers a reasonably healthy mix of agriculture, varied industries, and commercial, financial, education, and health care services and is supported by a fully developed economic infrastructure. This economic infrastructure includes rail, highway, river, and air transportation, modern communication capabilities, and affordable and reliable utilities, including coal fired electricity generation that depends directly on the river navigation system. The social system is equally well established, with a generally healthy, educated and technically skilled population supported by an established network of urban, suburban and rural communities.

The projected slow population growth and attendant slow growth of the economy allows for a gradual expansion from the existing infrastructure and an opportunity for relative economic stability in contrast to the 'boom and bust' patterns of the past century. Instead of the past pattern of rapid conversion of resources and landscape to meet the industry and infrastructure demands of a rapidly expanding population, there is an opportunity to proceed with a gradual and better planned process of development and redevelopment serving the needs and interests of a stable and established population. This steady pattern for development should score higher for sustainability than the more volatile pattern of explosive growth and recession cycles.

Ongoing investments in social and economic infrastructure should have a generally positive impact on SR values. For the Ohio River Valley, most primary infrastructure investments have already been accomplished. This includes a complete system of interstate and other primary highway networks, railroads, river bridges, airports, locks and dams, levees, and floodwalls. Expansion plans for much of this system continue on the basis of projected demand or existing capacity expansion needs, but a relatively stable population for the foreseeable future should contribute to reduced demand for additional primary infrastructure. Future improvements to this system would focus primarily on maintenance, refinement, or replacement of existing inventory.

Improved water quality has contributed to increased redevelopment interest for many riverfront neighborhoods. Growing interest in environmental amenities within residential/commercial settings contributes to the design of community oriented restoration projects that combine floodplain functionality, aquatic and riparian habitat enhancement, open space, recreational activities, stormwater detention, and related functions within multi-purpose or integrated aquatic restoration projects. Maximization of restoration opportunities may be realized by their inclusion within master-planning approaches to mixed-use community redevelopment.

Both lock extension/replacement and ongoing maintenance/repair of existing locks would contribute to positive SR impacts. Within the context of the larger economy of the Ohio River Valley, these actions would contribute fairly small, but cumulative impacts. Long term growth of navigation traffic will require more tugs and barges in operation, more terminals and related port facilities, more maintenance dredging for expanded

terminals, and expanded areas of fleeting operations. These expansions would convert existing floodplain lands (e.g., farmland, riparian woods, and wetlands) that now afford habitat protection, open space, and ecosystems values. Once converted, such lands are unlikely to revert to their former more natural states. Expansion of navigation infrastructure would also compete for space with expansion of riverfront industries, coal fired utilities, mining, and other commercial operations. Mixed-use urban waterfront developments, marinas, and other recreation-oriented developments would also compete for waterfront space. Waterfront development policies that support conversion of brownfields, unused or underdeveloped terminals, or other underutilized industrial sites could help minimize conversion impacts to existing agricultural uses or riparian habitats. **Figure 11-6** illustrates the historic through future trends for SR sustainability in the Ohio River study area.

Table 11-12 illustrates the relationship between applicable RFFAs and their effects on SR.

FIGURE 11-6
ES of Socioeconomic Resources

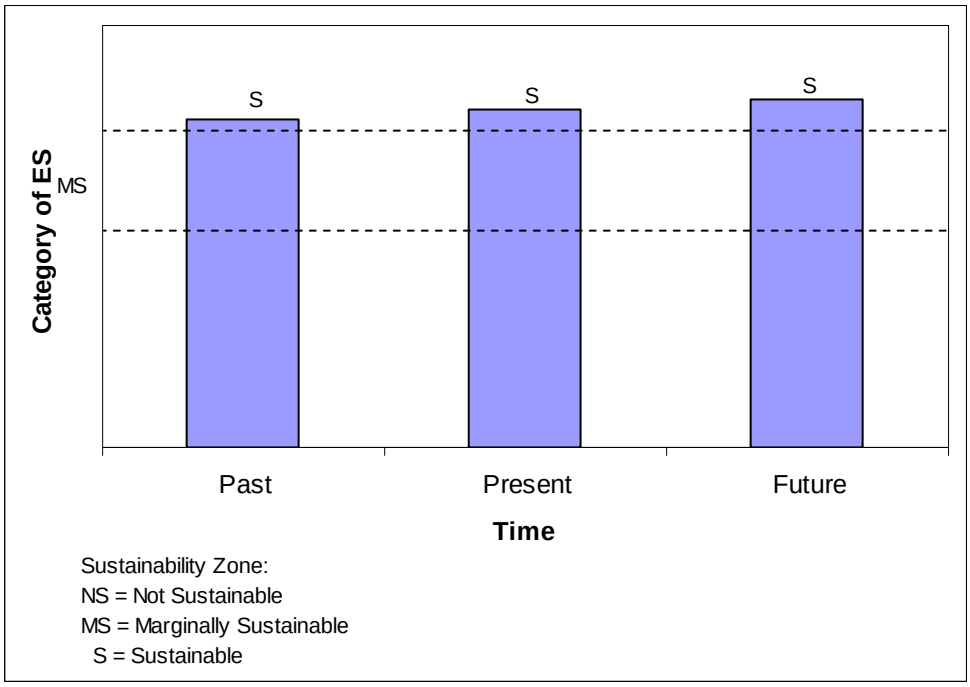


TABLE 11-12 AES Tiers for Actions Causing Socioeconomic Effects			
Actions Impacting SR Sustainability	Scientific Measures Of Socioeconomic Resource Factors	Composite Measures of Socioeconomic Resource Factors	Composite Indicators of SR Sustainability
• Actions that sustain SR viability – navigation system, coal utilities, mining, other industry, levees/floodwalls, other (e.g., bridges). • Actions that sustain navigation system – lock extensions, pool maintenance, channel dredging. • Negative SR impacts of navigation system – pool maintenance, channel dredging, fleeting, dispersed barge traffic, barge queuing, accidents & spills.	• Census counts of population, including minority and economically disadvantaged populations. • Census counts of income, educational attainment, health status, household composition, and other indicators of socioeconomic status.	• Census and BEA calculations of households in poverty, per capita income, employment levels by SIC code, and unemployment rates.	• Projections based on fertility, mortality, immigration, labor force participation, and growth of national productivity.

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Chapter 12
CULTURAL RESOURCES

12.1 CONTENTS

Definition of River-Related Cultural Resources (CR)

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Interactions with Other Valued Environmental Components (VECs)

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Cumulative Effects (CE) and Environmental Sustainability (ES

Conclusions

References

12.2 DEFINITION OF RIVER-RELATED CULTURAL RESOURCES

Cultural Resources (CR) reflect past cultural, historic, and environmental influences. For the Ohio River Main Stem System Study (ORMSS), CR include, but are not limited to districts, sites, buildings, structures, landscapes, and objects in or eligible for the National Register of Historic Places (NR). Such resources are associated with or representative of peoples, cultures, human activities, or events, either in the past or present, and include related artifacts, records, and material remains. Among the types of CR considered are:

- Prehistoric CR such as the remains of Native American villages, campsites, rockshelters, and petroglyphs;
- Historic resources such as farmsteads, mills, covered bridges, and foundations of early historic structures;
- Industrial resources such as railroad bridges and tunnels, factories, kilns, and the early river locks and dams;
- Historic landscapes such as parks, gardens, farms, quarries, etc.; and

- Districts where significant numbers of CR are grouped together.

Further, the U. S. Army Corps of Engineers (USACE), in its current Planning Guidance Notebook (PGN), published April 22, 2000, includes the following definition:

An historic property is any prehistoric or historic district, site, building, structure, or object included in or eligible for inclusion on the National Register of Historic Places (NRHP). Such properties may be significant for their historic, architectural, engineering, archeological, scientific, or other cultural values, and may be of national, regional, state, or local significance. The term includes artifacts, records, and other material remains related to such a property or resource. It may also include sites, locations, or areas valued by Native Americans because of their association with traditional religious or ceremonial beliefs or activities.

CR are identified among the Valued Environmental Components (VECs) in this CEA not only because they are part of the environment, but also because they reflect events and cultural values that were shaped by the response of humankind to the environment. Much of what is significant about a particular cultural resource is related to climatic conditions, natural setting, and locally available building materials.

Finally, while CR are generally associated with or representative of peoples, cultures, human activities, and events in the past, they are not immune to change and are in a sense evolving. Under the NRHP age criteria, any resource over fifty (50) years of age must be considered for potential inclusion in the NRHP (less than fifty years must be exceptionally significant). In fact, some CR being developed or constructed today may actually gain eligibility for listing on the NRHP within the ORMSS time frame, which extends through the year 2070.

12.3 OBJECTIVES AND SCOPE OF THE CULTURAL RESOURCES STUDY

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of Reasonably Foreseeable Future Actions (RFFAs) by the Corps and others. This chapter assesses the system-wide cumulative effects (CE) on CR of all likely major navigation improvements and other developments and trends along the main stem of the Ohio River from 2000 to 2070. Impacts directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and future actions. Future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, actions by non-governmental entities, and predictions of general economic expansion and development, as well as regulatory changes.

The results of the Cumulative Effects Assessment (CEA) will lead to further consideration of:

1) acceptability of impacts of the RFFAs on affected CR
2) how proposed navigation improvements contribute to those impacts and
3) what constitutes a sustainable system for CR of the main stem Ohio River.

12.3.1 Geographic Scope

The geographic focus for CR impacts includes those regions most directly impacted by operation and maintenance of the navigation system. This focus encompasses CR located in the river itself and on lands along either bank of the Ohio River lying "between the bluffs." This "floodplain zone" is defined as the meander channel of the Ohio River and includes the 100 and 500-year floodplains as well as terraces of level land lying above these flood zones. Because of their proximity to the Ohio River as a reliable water source, these floodplains and their associated terraces have long been recognized as potentially important areas for CR.

12.3.2 Time Frame

The established time frame for the assessment of most VECs is 1920 to 2070. The earlier date approximates initiation of modern Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the ORMSS. The CR discussed in this chapter, however, are not confined to the project time frame, but encompass both prehistoric and historic times.

12.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during the Summer of 2001 in communities along the Ohio River. The meetings created opportunities for the public, state, local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. A more detailed discussion of the scoping meetings is presented in Exhibits A and B of this report. The meetings were attended by 185 persons, and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Comments that directly and indirectly addressed CR are presented in **Table 12-1** below.

TABLE 12-1
Comments from Public Scoping Meetings

Direct Comments on Cultural Resources	Relevance to Cultural Resources	Total Comments
Need to address the Native American Grave Protection and Repatriation Act (NAGPRA)	Conformance of USACE action to this law	3
Need to contact State Historic Preservation Offices (SHPOs) when specific projects are proposed	Importance of notifying appropriate state agencies	1
Eligibility of locks for classification as historic structures	Appropriateness of designating locks as cultural resources	1
Other Comments with Implications for Cultural Resources	**Relevance to Cultural Resources**	
Potential adverse effects of higher pool elevations on bridges, other infrastructure and property	Potential loss or damage to cultural resources	6
Need to develop comprehensive plans for development along river	Potential loss or damage to cultural resources	3
Will USACE do site-specific documents for each action?	Potential loss or damage to cultural resources at specific sites	1

12.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

While indicators of ES, which vary by VEC, generally provide benchmarks for measuring cumulative effects on a given resource or VEC, most CR are unique and nonrenewable, because they were created or occurred at specific geographic locations at certain points in time by different individuals or groups. Often the circumstances that created each resource, consequently, are unique and cannot be duplicated. Bearing these circumstances in mind, indicators of sustainability for CR include:

- Number of properties/sites within the study area listed or eligible for listing in the National Register of Historic Places or listed in any special state listings;
- Physical condition of properties/sites within the study area listed or eligible for listing in the National Register of Historic Places or in any special state listings;
- Integrity/stability of the context of important CR, including factors indicative of carrying capacity (including auditory, visual, atmospheric encroachment, and overuse), if public access is provided;
- Site frequency/importance of a site (or collective grouping of certain sites) within the study area and at the state and national levels;
- Effectiveness of Federal regulations and SHPOs in preserving CR within the study area; and
- Level of efforts necessary to minimize impacts or recover artifacts and information from unavoidable past and future actions.

Because all materials deteriorate naturally over time, CR are not inherently sustainable. The indicators of sustainability presented above, therefore, represent efforts to prevent or slow natural deterioration. Carrying capacity of CR, as manifested by their

condition, must be closely monitored if the resources are to be sustained. Allowing public access to a cultural resource, for example, exposes that property to increased risk of deterioration or destruction. Furthermore, precautions must be taken to ensure that providing access to CR does not inadvertently contribute to the environmental deterioration of other VECs.

Preservation of representative CR throughout the full prehistoric to historic timeline is desirable. To achieve this goal, information on the frequency or importance of a cultural resource within the study area helps in allocation of energy and economic resources channeled toward preservation efforts, especially when fiscal resources are limited.

12.6 LAWS, REGULATIONS, ORDINANCES, AND PROGRAMS

Several regulatory actions influence CR in the study area. **Table 12-2** presents information on important laws, regulations, or established programs that influence CR in the Ohio River Valley.

TABLE 12-2
Institutional Actions Relevant to Cultural Resources

Law/Program (Lead Agency)	Key Components	Relevance to Cultural Resources
Archaeological Resources Protection Act 1979 (ARPA) (US Dept. of the Interior)	Protects cultural resources on federal and Indian lands.	Prohibits the removal, excavation, or alteration of any resource from federal or Indian lands except by permit issued from the DOI.
Historic Sites, Buildings and Antiquities Act 1935 (HSA) (National Park Service)	Established a national policy to preserve historic sites, buildings, and objects of national significance for the inspiration and benefit of the people of the U.S. The Act also authorizes and directs the Secretary of the Interior to make a survey of historic and archeological sites, buildings, and objects for the purpose of determining which possess exceptional value in commemorating or illustrating the history of the US	Created the National Historic Landmark (NHL) Program within the NPS. NHLs are designated unilaterally by the SOI, based on recommendations by an advisory council. NHLs are automatically listed in the NRHP. The SOI will consult with federal agencies and others before making an NHL designation.
Archaeological and Historic Preservation Act 1974 (AHPA) (US Dept. of the Interior)	Extends protection to scientific, prehistoric, and archaeological data from all federal undertakings and requires the federal agency to notify the DOI about adverse impacts.	Specifically provides for the preservation of historical and archeological data (including relics and specimens) which might otherwise be irreparably lost or destroyed.

Law/Program (Lead Agency)	Key Components	Relevance to Cultural Resources
National Historic Preservation Act of 1966 (NHPA) (Federal agency varies by project)	Established the primary policy; sections 106, 110, and 111; and authority for preservation activities.	Provided funding for the establishment of state preservation offices, restoration projects, surveys, and staff.
Native American Graves Protection and Repatriation Act (NAGPRA) (National Park Service)	Gives ownership of Native American cultural items- human remains, funerary objects, sacred objects, and items of cultural patrimony- to lineal descendants of the deceased, tribes on whose lands the items are recovered from, or to culturally affiliated tribes.	Requires on federal or tribal lands any intentional excavation of Native American burials and other cultural items or inadvertent discoveries of such items be carried out according to specific provisions and in consultation with the appropriate tribe.
Abandoned Shipwreck Act (ASA) (National Park Service)	Establishes US title to all abandoned shipwrecks on submerged State lands that are either embedded in such lands or included in or determined eligible to the NRHP.	Guidelines are intended to maximize the enhancement of cultural resources. State and Federal agencies are free to adopt the Guidelines in their entirety, make changes to accommodate the diverse needs of each State or agency, reject parts as inapplicable, or use alternative approaches. Creation of public underwater parks and preserves is encouraged, and investigations of historic shipwrecks which remain in federal jurisdiction require federal ARPA permits.
National Environmental Policy Act (NEPA) (Council on Environmental Quality and other agencies)	Requires preparation of an environmental impact statement for every major federal action affecting the human environment, which is defined to include cultural resources.	An EIS must include the comments of the Advisory Council on Historic Preservation for cultural resources identified for the project.
Corps' Permitting Statutes (U.S. Army Corps of Engineers)	Section 10 of Rivers and Harbors Act (1899) prohibits the unauthorized obstruction or alteration of any navigable water of the United States. Section 404 of CWA authorizes the Corps to issue permits for the discharge of dredged and fill materials into waters of the U.S..	Corps' permit analysis and resultant decision document must address cultural resources and any comments from SHPOS and/or the ACHP.

Law/Program (Lead Agency)	Key Components	Relevance to Cultural Resources
Executive Order 13287 "Preserve America"	This EO restates and emphasizes the policy originally established in the NHPA that calls for the federal agencies to take a leadership role in preserving America's heritage.	Seeks federal agencies to maximize integration of the NHPA into their programs, by using partnerships with state, local, and tribal governments and the private sector to promote preservation consistent with agency missions, and designating a senior policy level official to oversee the agencies historic preservation program, and promote the re-use of historic properties for heritage tourism and appropriate related economic development related to historic and natural sites on federal lands
State cultural resources regulations (PA Bur. For Historic Preservation, WV & OH State Historic Preservation Offices, KY Heritage Council, IN Div. Of Historic Preservation & Archaeology & IL Historic Preservation Agency)	Various regulations and programs administered by each state historic preservation office (SHPO). Includes excavation/survey permit requirements, documentation standards, penalties for disturbance or damage to cultural resources, criteria for historic designation, easements, etc.	Provides state-specific protection and preservation of cultural resources.

In 2004, a programmatic agreement was drafted between the Pittsburgh, Huntington, and Louisville Districts of the Corps, the National Advisory Council on Historic Preservation (ACHP) and the State Historic Preservation Officers (SHPO) of states bordering the Ohio River. This agreement was developed to ensure that projects related to modernization of the Ohio River navigation system shall be administered in accordance with the Corps' responsibility under Section 106 of the National Historic Preservation Act (NHPA).

12.7 PAST TO CURRENT BASELINE CONDITIONS

CR along the Ohio River are rich and varied, reflecting human occupation and significant events in the Ohio River Valley over many centuries. Both the prehistoric and historic CR of the Ohio River point to the central role of the river as a transportation artery in sustaining permanent settlements. In both prehistoric and historic times, human settlements developed along the Ohio River and its tributaries because its floodplains offered rich soils and the river offered food, water, and opportunities for trade. Later, the Ohio River and its tributaries were used in relation to early industries, river transportation, and trade routes.

12.7.1 Prehistoric Cultural Resources

The prehistoric periods of human occupation of the Ohio Valley are listed in **Table 12-3**.

TABLE 12-3
Prehistoric Periods in the Ohio Valley.

Period	Dates
Paleoindian/ Dalton	12000 – 8000 BC
Archaic Early Middle Late	8000 – 1000 BC 8000 – 6000 BC 6000 – 4000 BC 4000 – 1000 BC
Woodland Early Middle Late	1000 BC – AD 1000 1000 – 300 BC 300 BC – AD 400 AD 400 – 1000
Late Prehistoric	AD 1000 – 1600
Contact	Post AD 1600 (some overlap with Late Prehistoric)

The following prehistoric overview borrows heavily from Purtill et al. (2001), Weed (2004), Snyder et al. (2002), and Snyder and Anderson (2002).

The Paleoindians were the earliest inhabitants of the New World that archaeological research has been able to document unequivocally. These people entered the New World during the Wisconsinan glaciation and occupied a Midwest that was environmentally very different from current conditions. The climate was colder than at present, and much of the region was covered by a mosaic of tundra, grasslands, coniferous forests, and deciduous forests. Large mammals that are now extinct or confined to more northern regions of the continent, such as mammoths, mastodons, musk-oxen, giant moose, giant beaver, and caribou, ranged over much of the eastern United States (Brown and Cleland 1968).

The Paleoindian period is well documented in the western United States, where numerous archaeological sites have yielded distinctive Paleoindian fluted points in association with extinct Pleistocene mammals. The Paleoindian tool kit also includes end scrapers, side scrapers, gravers, drills, and large blades (Griffin 1967; Witthoft 1952). Largely by analogy with the Great Plains data, Midwestern Paleoindians are thought to have been specialized big game hunters who were organized into small, mobile bands that ranged over extensive territories (Ford 1974, 1977), but few sites have been identified that are sufficiently intact to permit testing these ideas (Chapman 1975). Data recovered at Kimmswick, Missouri (Graham et al. 1981), however, indicate a varied subsistence base for the Clovis culture, with the faunal remains from this site ranging from squirrels to mastodons.

In the Midwest, Paleoindian sites are usually recognized by the presence of fluted projectile point forms, such as the Clovis point, the Cumberland point, and, less

commonly, the Folsom point. Lanceolate forms such as Beaver Lake, Quad, and Agate Basin appear later in the period. While there is overlap of these point types Folsom tends to be a type found west of the Mississippi River while Cumberland points are found east of the Mississippi River. Clovis points have been recorded both from the west coast to the east coast. Recent research by Anderson and Faught (1998) for the contiguous United States has shown that 73.9 percent of fairly reliable provenienced Paleoindian points are located east of the Mississippi River while 26.1 percent are located west of the Mississippi River with points from Minnesota placed in the latter group. This research has also shown that distribution of fluted points across the lower 48 states is not continuous but clusters around major river catchments east of the Mississippi River, on either side of the Appalachian Mountains, the Southern Plains, and in central and southern California.

Evidence for Paleoindian occupation of the Ohio River Valley is meager. The only major Paleoindian site identified in the region is Meadowcroft Rockshelter in the upper Ohio River Valley in southwestern Pennsylvania. Radiocarbon dates from the site suggest an earlier occupation of the region than is generally accepted (Carlisle and Advasio 1982). Winters (1967) mapped distribution of approximately 100 fluted point finds in the Wabash Valley of the lower Ohio River Valley and discovered that they were almost equally divided between the uplands and the river terraces. The largest and most diversified Paleoindian sites in southern Indiana are found on terraces along the Ohio River and its major tributaries with a high concentration of sites also occurring in the "chert belt" region of Indiana where high quality Wyandotte chert was exploited (Cantin 1994). The Alton Site is located in eastern Perry County, Indiana, near the Ohio River and has been collected by amateur archaeologists. Curtis Tomak conducted test excavations at the site in 1984 (Tomak 1994). Two sub-plow zone features were identified but could not be definitely related to the Paleoindian occupation of the site. A single Clovis point in a private collection can be attributed to the site. However, most of the diagnostic projectile points/knives are Late Paleoindian types including Plano, Agate Basin, Beaver Lake, and Quad. These point styles suggest dates for the site in the range of 8,500 to 8,000 B.C. (Sieber et al. 1989).

Large Paleoindian sites found near floodplain ponds in Indiana suggests that floodplain and possibly aquatic/semiaquatic resources were being exploited along with the big game mammals (Higgenbotham 1983). Cultural material from the Paleoindian period has not been identified during recent cultural resource surveys in the western Shawnee Hills of Illinois. It is possible, however, that buried components dating to this cultural period may occur on high terraces within the major drainages of the region, or within some of the many rockshelters present in the uplands. In Ohio, several factors appear to influence the location of Paleoindian sites: (1) fluted points frequently are found in major stream valleys and confluences; (2) they tend to occur in proximity to quality flint resources; and (3) these points are rarely found in extensive swampy lowlands or in rugged highlands such as the unglaciated portions of southeastern Ohio (Purtill et al. 2001; Seeman and Prufer 1982). Gardner (1979) defined six Paleoindian site types: isolated finds; quarry sites; quarry reduction sites; base camps; base camp maintenance stations; and outlying hunting sites.

Paleoindians likely subsisted on a balanced hunting economy with the additional exploitation of wild plants. As the post-glacial climate and, in turn, the environment changed, humans were forced to adopt new subsistence strategies.

The Dalton period is recognized as a distinct transitional period between the Paleoindian and Archaic periods and appears to represent an adaptation to a warmer, post-glacial climate (Chapman 1975; Morse and Morse 1983; Wright 1987). Goodyear (1982) suggests a date range of approximately 8500 B.C. to 7900 B.C. for the Dalton period. Dalton type projectile points are commonly found in the lower Ohio River Valley in Illinois, Indiana, Kentucky, and to a lesser extent in the upper Ohio River Valley in Ohio and West Virginia. Dalton represents the transition phase between Paleoindians and the following period in archaeological chronology, the Archaic (Muller and Davy 1977). The Dalton period is characterized by a specialized knife form referred to by archaeologists as "Dalton Serrated." These artifacts resemble fluted points in shape, but their deep, concave bases are unfluted. Like Paleoindian societies, Dalton social organization was characterized by small mobile bands, but all faunal remains that have been found at Dalton sites to date are modern species (Chapman 1975). The Dalton tool kit indicates that a wide range of animal and plant foods were exploited, including small mammals, deer, nuts, berries, and seeds (Chapman 1975; Wright 1987). The Dalton tool kit includes distinctive concave base points as well as a small, distinctive adze, snubbed-end flake scrapers, bone needles and awls, mortars, manos, and hammerstones. The subsistence pattern of the Dalton period appears to have been considerably broader than that of the preceding Paleoindian period.

The division between the Paleoindian/Dalton periods and the Early Archaic period (8000-6000 B.C.) is an arbitrary one. It has been argued that Early Archaic lifeways were relatively unchanged from earlier Paleoindian/Dalton times throughout the Ohio River Valley (e.g., Adovasio et al. 1998; Raber et al. 1998). The climatic warming following the retreat of the glaciers around 8000 B.C. continued into the Archaic period in the Midwest. Deciduous forests containing oaks, hickories, walnuts, and other plant species that produced edible fruits and nuts expanded northward over much of the Midwest. In response to these environmental changes, prehistoric societies gradually broadened their subsistence strategies. Plant foods, particularly nuts, became increasingly important in the human diet (Ford 1974, 1977). Population tended to increase, and Archaic bands became larger and more sedentary. These trends were only beginning during the Early Archaic period, but they became more evident by Middle and Late Archaic times (Ford 1977).

The Early Archaic period was a time of significant change in the subsistence strategies in the Midwest as climatic changes continued to develop new ecological niches that produced new and varied food sources. Plant gathering and the harvesting of aquatic resources augmented traditional hunting and foraging strategies as floodplain lakes, sloughs, and marshes developed. The Archaic pattern of seasonal resource scheduling starts in the Early Archaic (Weed 2004; Caldwell 1958). Projectile point styles changed from unnotched lanceolate forms to corner- and side-notched forms. These forms include the Thebes, Kirk Corner Notched, Kirk Stemmed, Kirk Serrated, Hardin, St. Charles, McCorkle, and Lake Erie/Kanawha points (Justice 1987; Sieber et al. 1989). However, the Kirk, LeCroy, and Thebes projectile point types, which are present in this general area, indicate the continued exploitation of larger animals over vast territories by presumably small hunting bands (Dragoo 1976). Also characteristic of some projectile forms is the beveling of opposite blade edges, a product of resharpening. This may suggest that these tools were serving several different functions. Scrapers, burins, and chipped stone blades suggest an expansion of the tool kit and perhaps changes in tool function from earlier periods. The addition of sandstone abraders and mortars to the Early Archaic tool kit suggests that vegetable foods were becoming a more substantial part of their diet.

Early Archaic projectile points are numerous in the Midwest occurring on all locations of the landscape. Isolated points are found in large numbers in the uplands along secondary drainages, springs, and sinkholes (Sieber et al. 1989). The extensive use of rockshelters and caves also occurs about this time (Goodyear 1982; Kelly and Todd 1988). The majority of Early Archaic sites in the Midwest have been found on low terraces in major stream valleys. In the upper Ohio River Valley the Meadowcroft Rockshelter (Carlisle and Adovasio 1982) and the Goddard site (Koetje 1998) produced Early Archaic features. Excavations at buried, stratified Early Archaic sites in the lower Ohio River Valley of Kentucky (Collins 1979), and the Swan's Landing site in Indiana (Smith 1986) suggest a subsistence strategy organized around short-term, seasonally occupied camps. Swan's Landing in Harrison County was an extraction camp where chert reduction and tool manufacture took place near exposures of Wyandotte chert. In southern Illinois, Early Archaic sites are much more common than Paleoindian and Dalton sites, but many are shallow and prone to disturbance. A number of Early Archaic projectile points have been collected during several recent surveys within the Shawnee Hills (Canouts et al. 1984; Moffat et al. 1985; Penny 1983; Pulcher et al. 1987). Early Archaic components were also recorded at the Rose Hotel in Hardin County, Illinois (Wagner and Butler 1999). It is likely that Early Archaic sites within the floodplain of the Ohio River Valley are buried by Holocene alluvium.

A single Early Archaic phase has been defined in southwestern Indiana. The Jerger phase was established based on excavations at the Jerger site in Daviess County (Tomak 1979). The Jerger site functioned as a mortuary complex and contained crematory basins and grave goods including red ocher, perforated teeth, bone artifacts, marine shells, bifacial chert objects, drills, and Jerger projectiles (Tomak 1986). Presence of marine shell suggests that some form of long distance exchange was established by this date.

The Middle Archaic period coincides generally with the Hypsithermal, a period of higher average temperatures and reduced precipitation that occurred during the Middle Holocene (Wendland 1978). During this period, the expansion of grasslands opened new ecological niches and human settlement and subsistence strategies adapted to these drier conditions. The arboreal composition of Midwestern forests was essentially modern by 6000 B.C.

The Middle Archaic has been characterized as continuing the trend toward a broad-spectrum pattern of subsistence and toward more efficient adaptation to forested environments (Caldwell 1958; Ford 1977). This trend is reflected by the diversification of tool kits and the appearance of more groundstone tools, including full-grooved axes (Griffin 1967). In many of the larger river valleys of the Midwest, Middle Archaic populations apparently became larger and more sedentary (Jefferies 1987). The Middle Archaic tool kit closely resembles that of the earlier period with the inclusion of ground stone tools. Projectile points of this period are characterized by side-notched forms such as the Faulkner/Raddatz, Godar, Karnak, and Matanzas. Sites throughout the Ohio River Valley show changes in projectile point styles and usage of a greater variety of lithic raw materials. Groundstone artifact types include pendants, bannerstones, nutting stones, pestles, and plummets. Bone and shell artifacts such as awls, antler projectile-points, antler atlatl-hooks, bone fish-hooks, engraved bone pins, tortoise-shell cups and rattles, mussel-shell pendants, and necklaces of mammal teeth also were commonly made during the Middle Archaic period. The presence of mortars, pestles, and manos on Middle

Archaic sites suggests an increased reliance on nuts and grains. Along with the ground stone tools used in the processing of food resources most diagnostic of the Middle Archaic period is the appearance of the atlatl weight (Ballweber 1990). Aquatic resources also increased in importance as indicated by bone fishing hooks, net sinkers, and extensive shell middens. Hunting small animals and collecting nuts and seeds appear to have been the focus of Middle Archaic food-gathering practices, but the emphasis given different resources appears to have varied depending on local environmental conditions. Large, year-round occupations have been documented in river valleys in some regions of the Midwest, but small, briefly occupied sites from other topographic and environmental zones are also known.

Evidence from across the Midwest suggests that populations during the Middle Archaic became concentrated along the major river valleys with the large expanses of upland prairie and forest being largely abandoned (C. Chapman 1975; Conrad 1981; Munson 1988; Sieber et al. 1989; Stafford et al. 1988). Munson (1988) and Stafford et al. (1988) have recognized a similar shift in settlement strategies in southwestern and southern Indiana with camp sites being relocated in the principal stream valleys with upland areas apparently being restricted to short hunting and gathering forays. This shift in settlement appears to be an adaptive response to environmental change. In the uplands, conditions became warm and dry while in the major river valleys slack water lakes, ponds, and sloughs provided rich and diverse ecosystems (Brown and Vierra 1983). The exploitation of fresh water mussels became important. Large numbers of discarded mussel shells in camp middens produced large shell mounds, a tradition that would continue into the Late Archaic. The Shell Mound Archaic, as these cultures are often referred, suggest cultural affiliations with traditions in the Southeast along the Tennessee and Cumberland rivers where shell mound villages appear during the Middle Archaic period (Lewis and Kneberg 1959).

Preliminary information from a deeply stratified site, 36AL480, being investigated along the upper reaches of the Ohio River near Leetsdale, Pennsylvania, indicate human populations were repeatedly utilizing resources along the Ohio River floodplain there as early as 8,000 years ago (http://www.lrp.usace.army.mil/lmon.htm). Geomorphological studies undertaken in association with this site point to the area being an island in the Ohio River during the Middle Holocene. A 1998 archaeological and geological assessment of the Ohio River Islands National Wildlife Refuge classified Ohio River islands into three different types with regard to CR: 1) islands with sediments having recent origins not likely to contain prehistoric archaeological sites; 2) islands with Holocene sediments likely to contain historic archaeological sites close to the surface and deeply buried prehistoric sites; and 3) islands which contain a core area of Pleistocene sediments overlaid by shallow Holocene age sediments, which are likely to contain prehistoric and historic resources closer to the surface (USFWS 2000). Information on island formation is relevant to what kinds of prehistoric sites could exist on individual islands. For example, if an island contains only late Holocene sediments (i.e., 4,000 years before present to present), then sites from earlier prehistoric periods would not exist on the island.

Large-scale excavations by Southern Illinois University-Carbondale at the Carrier Mills Archaeological District in Saline County, Illinois uncovered a major late Middle Archaic occupation dating from approximately 4000 to 3000 B.C. at the Black Earth site (Jefferies and Butler 1982). Subsistence data indicate the site was probably a semi-permanent base camp. The site was characterized by a deep midden, abundant floral and

faunal remains, and numerous human burials (Jefferies 1987; Jefferies and Butler 1982). The plant foods exploited by the Middle Archaic occupants of the site include fruits, wild bean, and a wide range of nut species, most notably hickory nuts and acorns. In contrast to many Middle Archaic sites in areas to the southeast and northwest, however, the Black Earth site contained no evidence of the early cultivation of plants such as sumpweed, squash, and gourd. The faunal assemblage from the Black Earth site includes the remains of white-tailed deer, elk, turkeys, various marsh birds, reptiles, amphibians, and fish. White-tailed deer remains dominate the faunal assemblage, and provides evidence of the year-round hunting of this animal. Fish were an especially important subsistence resource, suggesting the exploitation of the swampy lakes surrounding the sites in the Carrier Mills Archaeological District was a major site location criterion for the Middle Archaic occupants of this area. Excavations at the Rose Hotel in Hardin County, Illinois recorded Middle Archaic use of this bluff area above the Ohio River (Wagner and Butler 1999). Horseshoe Lake in Alexander County, Illinois at the confluence of the Ohio, Cache, and Mississippi rivers has also provided information on the Middle Archaic in that area (Koldehoff and Wagner 2002).

Much of our current knowledge about this period has been derived from investigations of Middle Archaic sites in West Virginia and the Carolinas. Little is known about the Middle Archaic occupation of the central Ohio River Valley, and this has been confined to the recovery of isolated artifacts or the identification of Middle Archaic manifestations in multicomponent sites. A similar lack of Middle Archaic data has been noted regionally (Purtill et al. 2001; Adovasio et al. 1998; Raber et al. 1998).

The beginning of the Late Archaic period generally coincides with the end of the Hypsithermal. The regional climate moderated, rainfall increased, and conditions in the Midwest became similar to present conditions. The Late Archaic period demonstrates intensive adaptations to ecological niches not exploited earlier (C. Chapman 1975). It has been suggested that the Late Archaic represents the climax of the long Archaic hunter/gatherer traditions in the Midwest that were replaced by strategies favoring the intensive exploitation of local resources. Caldwell (1958) has referred to this subsistence strategy as the primary forest efficiency of the Late Archaic people with extensive shellfish exploitation and nut collection and processing. Several phenomena that characterize the following prehistoric cultural periods can be traced to the Late Archaic. During this period the emergence of a plant-forager economy, incipient gardening, increased sedentism, and population growth set in motion trends that would eventually lead to complex and dynamic political and social systems in the Midwest. While gardening is thought to have added to the subsistence strategy, the question over the appearance of domesticated forms of cucurbits and native starchy seed plants remains argued. Kay et al. (1980) have reported squash at the Phillips Spring site in southwestern Missouri in a Late Archaic context. Winters (1969) also reported a fragment of squash from the Riverton site in Crawford County, Illinois.

Many Middle Archaic projectile point forms pervaded into the Late Archaic. Tool kits became more diversified, and the groundstone and worked bone industries became fully developed (Sieber et al. 1989). Extensive trade networks were developed as marine shell, copper from the Great Lakes, steatite from the Appalachians, and other exotic materials arrived in the Ohio River Valley (Sieber et al. 1989). Cultural material from the period indicates that cultural change was taking place throughout the Late Archaic and became more pronounced during the later stages of the period. For unknown reasons, the

use of locally available, high grade cherts declined as lower quality cherts, including glacial gravels, were exploited. The quality of the chipped-stone industry also declined (Seeman 1975). People moved out of the main river valleys, at least seasonally, and began to exploit upland resources. Suggestions are that small, intensively occupied, seasonal camps were established along small upland streams and springs (Munson 1988). So intense was the exploitation of aquatic resources during the Late Archaic that Dragoo (1976) has referred to it as the Riverine Archaic tradition. Large quantities of mussel shells, discarded over time in camp middens, produced large shell mounds on which villages and camps were located. These Late Archaic shell mound sites are common along the Ohio River and tributaries.

Late Archaic sites in southwestern Indiana have been grouped into the French Lick phase (3,500–1,500 B.C.) (Munson and Cook 1980). This phase represents a period of intensive occupation in southwestern and south-central Indiana. These sites are located in a variety of environments from main stream valleys and secondary drainages to dry dissected uplands and rockshelters (Sieber et al. 1989). The settlement pattern suggests summer and fall base camps located on perennial streams. Fall and winter hunting camps and large summer camps were located next to major rivers where the procurement of large quantities of river mussels produced shell midden sites (Sieber et al. 1989). This suggests a subsistence model involving a broad-based economy involving hunting/collecting and harvesting of aquatic resources. This model is similar to that proposed by Winters (1969, 1974) for the Midcontinent Archaic tradition. Other Late Archaic sites that have contributed to the prehistoric record of Indiana include the Bono site in Lawrence County (Tomak 1983, 1984), the Crib Mound in Spencer County (Kellar 1956; Brinker 1982), the McCain site in Dubois County (Miller 1941), the Prairie Creek site in Daviess County (Munson 1980), and the Turpin site in Gibson County (Morrison 1975).

In the lower Wabash River Valley, its major tributaries, and extending into southern Indiana, a cultural manifestation appeared toward the end of the Archaic that has been defined as the Terminal Late Archaic Riverton culture (Winters 1969). The majority of our information on these people comes from excavations and testing conducted by the Illinois State Museum in the early 1960s at the Riverton site (11-Cw-170) and the Swan Island site (11-Cw-319) in Crawford County, Illinois, and the Robeson Hills site (11-Lw-1) in Lawrence County, Illinois. The Riverton culture is represented by a radical change in lithic technology from that identified with the earlier Archaic lithic industry. Very small projectiles such as the Trimble, Merom, and Robeson points were typically produced from heat-treated chert pebbles found in glacial gravels. Deep, shell-rich middens, characteristic of base camps, provided excellent site preservation so that bone tools including hide scrapers, flaking tools, bone awls, and shuttles have been preserved (Winters 1969). Prepared clay platforms, interpreted as the floors of structures, and clay plugs on deep storage pits both suggest a degree of sedentism. Well-preserved burials indicating different burial methods and small caches or bundles of grave goods found with some burials may suggest a form of social differentiation had developed in these societies. Important work has been conducted in southern Indiana on these Late Archaic sites. Anslinger (1986) conducted a much needed analysis of the lithic assemblage of the Wint site (12B95) in Bartholomew County, Indiana. His work involved an examination of the lithic procurement strategy as well as heat treatment and chipped-stone tool reduction technology. This work also has provided a source book of sorts that compiles references and information on the Riverton culture that has came to light since the work of Winters in the 1960s. A review of relevant data on the settlement and subsistence strategies of the

Riverton people suggested to Anslinger that while some modifications to the model proposed by Winters are necessary, the basic dispersed and linear model is supported by recent evidence. The clustering of Riverton villages/camps along major river valleys and prominent tributaries suggests a settlement and resource procurement strategy different from that known for earlier Archaic manifestations (Anslinger 1986). Additional information on Riverton sites in Gibson and Posey counties, Indiana, can be found in Higgenbotham (1983).

In southern Illinois, Late Archaic components are recognized by the recovery of Trimble, Merom, Karnak, Saratoga, and Cypress points. Late Archaic occupations were identified in the Carrier Mills Archaeological District (Jefferies and Butler 1982) and along the Ohio River (Butler et al. 1979). A recent site excavated along the Ohio River in Illinois that contained a Late Archaic component was the Rose Hotel (Wagner and Butler 1999). The Horseshoe Lake area near the confluence of the Mississippi and Ohio Rivers also has a Late Archaic presence (Koldehoff and Wagner 2002).

For the mid-Ohio River Valley, several contemporary, geographically distinct Late Archaic complexes or phases have been forwarded (Purtil et al. 2001). For southwestern Ohio, Vickery (1980) has identified the Central Ohio Valley Archaic (2750 B.C. to 1750 B.C.) and Maple Creek Phase (1750 B.C. to 1000 B.C.). The Central Ohio Valley Archaic is marked by a predominance of McWhinney Heavy-stemmed points, lower frequencies of Laurentian Archaic types (e.g., Brewerton series), hafted scrapers, and various ground stone tool types. These sites tend to be large base camps concentrated along major river systems (Purtil et al. 2001). Large numbers of roasting pits, hearths, storage pits, and burials are known to occur at these locales. The Maple Creek Phase appears in southwestern Ohio at the end of the Central Ohio Valley Archaic approximately 1750 B.C. This phase is closely related to Riverton Cultures to the west (Winters 1969) and is characterized by Merom/Trimble points and a micro-tool industry. Settlement patterns appear similar to preceding Late Archaic phases (Purtil et al. 2001).

The picture in southeastern Ohio is considerably more confusing regarding the Late Archaic (Purtil et al. 2001). Phases (e.g., Dunlap Phase) are poorly defined and are often based on nonintensive surface collections without excavations (Murphy 1975; Purtill et al. 2001). Artifacts are usually associated with the Laurentian Archaic Tradition of New York such as Brewerton Corner-Notched and Side-Notched points (Murphy 1975; Cinadr 1985; Purtill et al. 2001). Laurentian Archaic sites date from 3200 B.C. to 2000 B.C., although data from the Davisson Farm Site in Lawrence County, Ohio, has suggested that these point types may have been in declining use well past 1000 B.C. (Purtill et al. 2001; Purtill 2002). Late Archaic manifestations in southeastern Ohio appear influenced, to varying degrees, by neighboring complexes, especially Riverton-like groups to the west and Laurentian Archaic-like groups to the north (Purtill et al. 2001).

The Terminal or Transitional Archaic period (2000 B.C. to 1400 B.C.) represents the last manifestation of the Archaic period for Ohio (Purtil et al. 2001). Also poorly defined, these late cultures have seen little attention. It is unclear at this time whether this time period is a transition between the Late Archaic and Early Woodland or whether it is a distinct period (Purtil et al. 2001).

In north central Kentucky, the Terminal Archaic is represented by the Cogswell phase (Ison 1988; Ledbetter and O'Steen 1991) which dates between ca. 1250 to 800 B.C.

Diagnostic projectile points include Cogswell, Buck Creek Barbed, Wade, Little Bear Creek and McIntyre-like points and ceramic may appear at the end of the phase (Purtil et al. 2001). Feature types include charcoal-filled/lined pits; fire-cracked rock-lined pits, and chert filled cache pits. A circular feature cluster at the Grayson Site (Ledbetter and O'Steen 1991) suggests structures were in use. Subsistence data from carbonized plants include nutshell (primarily acorn and hickory), wood charcoal (hickory, oak, and ash), and seeds (cultivated sumpweed, wild sunflower, squash, knotweed, goosefoot, maygrass, and ragweed). Data from the Cloudsplitter Shelter (Cowan et al. 1981) suggest that during the Cogswell phase, incipient cultivation of plants was well under way. Faunal remains are not common in the site settings (likely due to poor preservation); however, mammals such as bear, deer, squirrel, rabbit, and woodchuck comprise the bulk of the edible meat with turtles, turkey, and grouse making up most of the remainder. Fish and mussels are minimal contributors according to the data presented (Ledbetter and O'Steen 1991; Purtil et al. 2001).

Within the upper Ohio River Valley the recent excavations at site 36AL480 in Leetsdale, Pennsylvania, contained both Late Archaic and Terminal Late Archaic components. These deposits were recorded from 1 m to 4 m below the present ground surface. The Transitional Archaic period appears to consist of two distinct groups a late Transitional Archaic at ca. 3100 BP and an early Transitional Archaic at ca. 3400 BP. A series of Late Archaic camps was identified that date to ca. 5500 BP. Specific diagnostic material recovered from the late Transitional Archaic groups consists of Fishtail and Forest-notched points and pottery. Diagnostic material from the earlier Transitional Archaic groups consisted of Broadspears and small points. The steatite was recovered from levels associated with these groups as well. Late Archaic materials consisted of Brewerton side-notched, corner-notched, and eared points. Little faunal and floral material was recovered from the features at 36AL480. This site may have been a series of short duration camps. Based on all of the evidence, it was occupied from Middle Archaic through Early Woodland (http://www.lrp.usace.army.mil/lmon.htm). Based on excavations it appears that the Late Archaic is the best represented period at the site where excavations took place. Features recorded consisted of basin shaped pits with numerous cracked rock. Also present were stains that appeared to be surface fire hearths. The Scenery Hill site, a semi-permanent or permanent base camp within the upper Ohio River Valley, was excavated by East et al. (1996). It appears that there were defined activity areas at the site based on the excavations. Similar features were recorded at this site as at 36AL480. Features from the Scenery Hill site contained hickory and black walnut.

Cultural changes thought to have occurred during the Terminal Late Archaic period include an increased emphasis on ceremonialism. Projectile points are typically well made and exhibit skilled craftsmanship. Point types associated with this time period include the Adena Ovate-base and Turkey Tail points, along with precursors of the Early Woodland stemmed points. Turkey Tail points were widely distributed in eastern North America and have been found in caches and burial contexts. The Late Archaic period represents the blossoming of a great diversity of cultural traditions throughout eastern North America. This recognized cultural differentiation was based primarily on adaptations to stabilized regional and local environments "that made maximum use of all resources within restricted areas" (Dragoo 1976; Purtill et al. 2001). Toward the end of the Late Archaic period and continuing into the beginning of what is known as the Early Woodland period, a mortuary tradition occurred throughout the mid-Ohio River Valley that was characterized by the placement of shaft graves into glacially derived rises. Known as the Glacial Kame

manifestation, these cemetery sites have often produced evidence of long-distance trade in the form of copper from the Upper Great Lakes and conch shell from the Florida Keys. Habitation sites associated with these mortuary complexes have yet to be defined (Purtill et al. 2001).

The Woodland period is characterized by a trend toward increased sedentism, intensified horticultural activity, expanding regional exchange networks, and the elaboration of ceremonial activities and mortuary practices (Griffin 1967). The origin of these trends can be traced to the Late Archaic, but elaboration of cultural elements became the hallmark for the time. These developmental trends form the basis for distinguishing the Early, Middle, and Late Woodland substages. Regional variations in the timing and extent to which these traditions were expressed, however, make this tripartite subdivision difficult to employ in certain areas. The Early Woodland period is usually demarcated by the introduction of pottery manufacture; the timing of its appearance seems to vary spatially across the landscape. For instance, in the upper Ohio River Valley, thick-walled coarse-tempered ware first appears around 1,000 B.C., whereas in the lower valley in Indiana and Illinois, dates suggest pottery did not appear until around 500 B.C. (Seeman 1986). Projectile points typically associated with the Early Woodland period include contracting stem varieties such as the Adena Stemmed and the notched Turkey-tail types. Highly crafted ground and polished stone items such as gorgets, amulets, celts, and tubular pipes were also made (Sieber et al. 1989).

In contrast to the Late Archaic settlement pattern, Early Woodland occupations in the Midwest are typified by relatively small, short-duration camps located adjacent to specific environmental locales. This pattern suggests that small social groups using seasonally occupied, specialized extraction camps were exploiting resources within defined localities (Emerson and Fortier 1986; Roper 1979; Seeman 1986). Rockshelters continued to be used and possibly served as hunting camps (Sieber et al. 1989). Evidence exists that gardening increased in importance as native starchy seeds such as maygrass (*Phalaris caroliniana*), knotweed (*Polygonium erectum*), goosefoot (*Chenopodium bushianum*), and marshelder (*Iva annua*), along with sunflower (*Helianthus* sp.) and gourds (*Cucurbita* sp.) added to the traditional hunting/gathering economy.

The Adena Culture is the best known Early Woodland complex for the Ohio River Valley (Purtill et al. 2001). The burial mounds associated with this cultural manifestation are typically small and are usually located on either high terraces, bluffs, or within the valley bottoms (Murphy 1975; Abrams 1992; Carskadden and Morton 1997; Waldron and Abrams 1999). Adena mounds have long been the subject of archaeological investigations (Purtill et al. 2001). Adena mounds are conical in shape and often contain various structural elements including bark lined crypts, layered mound construction, extended burials, cremations, and associated grave furniture (Purtill et al. 2001). Many were accretional and attained great size, such as the Grave Creek mound in Ohio that is 21 m high by 90 m in diameter (Seeman 1986). Murphy (1975) also notes that stone mounds, which are restricted to hilltop locations, appear by the end of the Early Woodland period. Recent GIS based analyses of distributional patterns of Adena-aged mounds suggests a high degree of intersite visibility potentially signifying inter-hamlet communication (Waldron and Abrams 1999; Purtill et al. 2001).

Adena habitation sites, on the other hand, are usually small villages or hamlets located along low terraces and in the floodplains of stream valleys (Purtill et al. 2001).

Abrams (1992) has proposed an Adena Settlement system that consisted of dispersed clusters of 1 to 2 mounds associated with small habitation sites. In the Muskingum Valley, Carskadden and Morton (1997) indicate that "Adena hamlets covered areas ranging from .28 to .32 ha, with a scattering of postmolds, usually in no readily identifiable pattern, in the immediate vicinity of cluster of cooking/thermal features...there is no real indication that these sites were occupied for great lengths of time." (Purtill et al. 2001).

Recent research in northern Kentucky at the West Runway Site (Bergman et al. 1998) provides some of the best information regarding the earliest ceramic producing Early Woodland (pre-Adena) cultures. Importantly, this pre-Adena site was characterized by a co-association of Kramer projectile points and Fayette Thick ceramics as early as 770 B.C. (Purtill et al. 2001). In southeastern Ohio, Fayette Thick ceramics derive from dated contexts consistently between 1000 B.C. to 700 B.C. and have been dated as early as 1560 B.C. at Rais Rock Shelter in Jackson County, Ohio (Murphy 1975; Purtill et al. 2001).

A series of excavations at the Boudinot #4 Site (33At521) and Boudinot Farm (33At41/80) by Abrams (1992) have provided some of the best examples of Early Woodland hamlets for the region (Purtill et al. 2001). The site is characterized by a wide range of domestic tool types including hammerstones, pestles, a mano, Robbins points, and thick-walled ceramics (likely Adena Plain) (Purtill et al. 2001). Post molds and cooking/roasting pits were also documented. Seasonal data suggest that these occupations were not occupied year round. Abrams (1992) suggests that these sites acted as warm weather locales intermittently being occupied from mid-spring through mid-fall.

Several pottery types are associated with Adena, including Adena Plain and Montgomery Incised (Chapman and Otto 1976). Projectile point types include large, stemmed triangular blades and leaf-shaped blades. Murphy (1975) notes that iron oxide materials such as hematite play an increased role for the manufacture of mortuary goods. There is evidence that the Early Woodland diet was supplemented by the domestication of various native and non-native cultigens such as sunflower, chenopodium, various carbonized nut species, squash, and cultivated maygrass (Purtill et al. 2001). However, it is now known that the domestication of plant foods had its antecedent during the Late Archaic (Purtill et al. 2001).

The Crab Orchard ceramic tradition is presently recognized as an expression of the Early and Middle Woodland periods in southern Illinois. In southern Illinois the Early Woodland period remains poorly understood. The earliest Woodland sites usually contain a few thick, crude, cordmarked or fabricmarked potsherds that have coarsely crushed grit temper and reddish paste colors as well as stemmed projectile points assigned to the Adena, Kramer, or Cypress types (Butler and Jefferies 1986; Denny 1972; Moffat et al. 1992). Cypress points are also found at Late Archaic and Middle Woodland sites (Moffat et al. 1992; Woods and Denny 1980). Unlike other areas of the Midwest, the interior of southern Illinois has yielded no Early Woodland burial mounds. Work at Horseshoe Lake in Alexander County, Illinois, at the confluence of the Ohio, Mississippi, and Cache rivers has a documented Early Woodland presence, (Koldehoff and Wagner 2002) as does, the Rose Hotel in Hardin County, Illinois (Wagner and Butler 1999). In general, Early Woodland life ways in this area do not seem to have differed much from those characteristic of the Late Archaic period.

In southwestern Indiana the uplands and smaller river valleys appear to have been virtually abandoned during this time, with the populations concentrating along major river valleys and their tributaries (Sieber et al. 1989). Rockshelters continued to be used and possibly served as hunting camps (Sieber et al. 1989). The first pottery in central and southern Indiana is similar to the Marion Thick, Fayette Thick, Baumer, and early Crab Orchard types (Dragoo 1963, 1976; Farnsworth and Emerson 1986; Jefferies 1987; Kellar 1983). This pottery is characteristically thick-walled, coarse-tempered, cordmarked, fabricmarked, or plain. Vessel shape consists of a simple, flat-bottomed jar. Marion Thick ceramics appear in the area around 500 B.C. (Sieber et al. 1989).

In the upper Ohio River Valley Adena mounds occur but not as commonly as within the middle Ohio River Valley and below (Weed 2004). Early Woodland site types in the upper Ohio River Valley are dispersed across the landscape and larger sites, such as villages and earthworks, seem to occur most frequently in lowland or valley settings (Weed 2004). It therefore appears that the Early Woodland settlement system was focalized in the lowlands with a dispersed system of smaller specialized sites (Weed 2004). Early Woodland house forms in this area were not standardized and include oval, round, and rectanguloid shapes (Weed 2004). It needs to be remembered that in Pennsylvania there are two Early Woodland groups present: the Adena and the indigenous Late Archaic groups.

The developmental trends characteristic of the Woodland tradition are most strongly expressed in many regions of the Midwest during the Middle Woodland Hopewellian stage. The Hopewellian stage within the Ohio River Valley is exemplified by the Hopewell of southern Ohio. Hopewell cultural groups lived throughout the Ohio River Valley in southern Illinois, southern Indiana, southern Ohio, northern Kentucky, northern West Virginia, and western Pennsylvania. Hopewell is most prominently marked by the appearance of large village and ceremonial sites containing geometric earthworks and conical burial mounds, an emerging pattern of social status differentiation (Moffat 1990), and a remarkable expansion of interregional exchange (Brose and Greber 1979; Muller 1986). In addition to the Ohio Hopewell core area, an important expression of the Hopewell complex is also represented by a late Hopewellian variant in the lower Wabash-Ohio River Valley (Brose and Greber 1979). The Hopewell exchange network, or Hopewell Interaction Sphere (Struever and Houart 1972), linked the diverse Middle Woodland societies of these regions during the period from about 100 B.C. to 350 A.D.

Large quantities of exotic materials, stylistic concepts, and, to a lesser extent, finished trade goods, were exchanged through the Hopewell Interaction Sphere. Hopewellian trade items include such exotic materials as obsidian from Wyoming, mica sheets from the Appalachian Mountains, copper from the western Great Lakes, and marine shell from the Gulf of Mexico, as well as finished goods such as clay figurines, Havana trade vessels, stone platform pipes, copper and silver panpipes, copper breastplates, and copper reels (Brose and Greber 1979; Struever 1964). These trade items are usually found in association with burials. The occurrence of these items at a Middle Woodland site is regarded as evidence of participation in the Hopewellian exchange network or of Hopewellian contact.

Several less exotic markers of Hopewellian influence include certain distinctive ceramic decorative techniques, corner-notched points of the Snyders type, high-quality, nonlocal chert, and blades and conical cores. Locally made pottery exhibiting elaborate

zoned dentate-stamped, rocker-stamped, and incised-line designs is typical of Hopewellian influenced sites (Griffin 1967). The wide-spread occurrence of these Hopewellian decorative elements indicates that "stylistic concepts...were moving through the [Hopewellian exchange] network" (Struever 1964) together with raw materials and finished goods. Similarities in the burial programs of regionally distinct Hopewellian societies provide additional evidence that the Hopewell Interaction Sphere served as a channel for the dissemination of both ideas and trade items (Struever 1964). The spread of blade core technology may represent another example of this process (Morrow 1988).

It has long been realized that the Middle Woodland societies participating in the Hopewell Interaction Sphere represent a diverse group of regionally distinct cultural traditions rather than a single, panregional Hopewell culture (Griffin 1979; Struever 1964; Struever and Houart 1972). These Middle Woodland regional expressions are distinguishable on the basis of their adaptation patterns, formal aspects of the utilitarian component of their material culture, and their separate histories. Consequently, artifactual evidence of participation in the Hopewell phenomenon generally appears as an overlay on the base culture.

Evidence of increased sedentism, intensified horticultural activities, increased population aggregation in major river valleys, and a concomitant reduction of the resource procurement range is present in the archaeological record of many communities participating in the Hopewell phenomenon (O'Brien 1987). Therefore, establishment of exchange relationships with groups located in other subsistence resource areas can be viewed as a response to the increased risks of resource shortfalls attending a subsistence/settlement strategy involving decreased residential mobility and localization of resource procurement activities (Morrow 1988). From this perspective, exchange of exotic trade items appears to have served the function of establishing and stabilizing exchange relationships with distant groups to ensure access to alternate subsistence resources in times of emergency or famine.

A model of the structural organization of the Hopewell Interaction Sphere has been developed by Struever and Houart (1972). Two types of sites, regional transaction centers and local transaction centers, are described as focal points in the distribution of Hopewellian materials and goods. Regional transaction centers are large, complex sites containing burial mounds and large amounts of Hopewellian materials and goods. These sites are regularly distributed along the major waterways throughout the Midwest. Regional transaction centers served as points of entry for Hopewellian trade items entering regional networks from other regions and as exit points for trade items leaving local networks for other regions (Morrow 1988). The smaller, local transaction centers functioned as distribution points within the regional network, both for Hopewellian materials and goods produced within the local network and those coming from the regional transaction centers (Struever and Houart 1972).

Two Middle Woodland cultural traditions are recognized in Illinois: the Crab Orchard tradition, which is centered in southern Illinois and encompasses adjacent portions of Indiana, Kentucky, and Missouri, and the Havana tradition, which is centered in the Illinois River Valley and extends over much of central and northern Illinois north of the Crab Orchard region (Butler and Jefferies 1986; Fortier et al. 1984; Griffin 1967; Struever 1965). The Crab Orchard and Havana traditions are distinguished by basic differences in ceramic decorative styles and vessel forms, as well as, by differences in adaptation patterns

(Hargrave et al. 1991; Struever 1964). The Middle Woodland societies associated with these two traditions also differ in the extent to which they participated in the Hopewell phenomenon.

Characteristic Middle Woodland ceramics in southern Illinois are grit-tempered and fabricmarked, but some cordmarked vessels are present. Early Middle Woodland ceramics are typically undecorated but have darker pastes and are better fired than Early Woodland vessels. Late Crab Orchard pottery commonly consists of thin, well fired, fabricmarked vessels that are decorated with rim nodes. Vessels with smoothed exteriors that are decorated with incised or stamped designs are also occasionally found. Well-made, corner-notched projectile points (Snyders or Affinis Snyders), Cobden biface blanks, and formal, unifacial scrapers are also commonly found at Middle Woodland sites in southern Illinois (Snyder et al. 2002).

Parker (1990) describes Crab Orchard subsistence patterns as representing a generalized adaptive strategy focused on hunting and nut gathering, with the cultivation of several cultigens, principally indigenous starchy seed cultigens, playing a minor supplemental role. Blanton (1989) notes there is general agreement among area researchers that the Crab Orchard pattern of seasonal movement within major environmental zones involved the creation of few permanently occupied sites.

One large regional center of the Hopewell Interaction Sphere within the lower Ohio River Valley represented by the Crab Orchard tradition in southern Illinois is the Wilson-Hubele-Rutherford complex in the lower Wabash-Ohio River Valley. The Wilson Mound Group and Hubele village sites are located on the Wabash River in eastern White County, Illinois. The Rutherford Mound overlooks the confluence of the Saline and Ohio Rivers in eastern Hardin County, Illinois. The Rose Hotel in southern Hardin County was found to have an intensive occupation during the Early to Middle Woodland Crab Orchard period when a series of very deep storage pits and other features were constructed at the site (Wagner and Butler 1998). At the confluence of the Ohio, Mississippi, and Cache rivers at Horseshoe Lake in Alexander County, Illinois, Crab Orchard Middle Woodland sites have also been recorded, (Koldehoff and Wagner 2002) as well as, up the Cache River Valley (Howe et al. 1994).

The most remarkable manifestation of the Wabash Hopewellian complex is the Mann site in Posey County, Indiana (Kellar 1979). This site is located approximately 40 km southeast of the Wilson Mound Group. The Mann site has been characterized as "the most important link between the southern Ohio Hopewell sites and the Havana-Hopewellian sites in the Illinois Valley" (Griffin 1979). This site covers an area of at least 175 ha and contains the largest concentration of geometric earthworks and mounds outside of Ohio (Griffin 1979). Aside from the circular earth embankments enclosing two of the Wilson site mounds, the Mann site earthworks are the only geometric earthworks recorded in the region (Kellar 1979). Ceramics from the site display a variety of Hopewellian decorative motifs, including incised and paddle-stamped pottery whose designs show affiliation with Marksville in the lower Mississippi River Valley and Swift Creek-Santa Rosa groups in the Southeast (Kellar 1979). In addition to Hopewellian trade goods and Hopewellian-influenced ceramics, a large amount of obsidian and a large number of locally-made clay figurines have been recovered from the Mann site (Kellar 1979). Blades and blade cores are also abundant, as is nonlocal chert (Kellar 1979).

Another important Mann phase site, the Mount Vernon site (12Po885), is located approximately 8 km west of the Mann site. Discovered during road construction, the site represents a ceremonial and burial complex that contains a loaf-shaped mound, the GE mound, that is one of the five largest Hopewell mounds in the Midwest (Ruby 1993). Large bifaces, copper earspools and celts, and obsidian blades indicate the inhabitants of the Mount Vernon site were actively involved in the Hopewell Interaction Sphere. The results of ongoing research at the site continue to provide new insights into the ideology, mortuary customs, and ceremonialism associated with the Hopewell phenomenon (Ruby 1993; Tomak 1990).

Crab Orchard sites of the southern Illinois interior present little evidence of participation in the Hopewell exchange network (Muller 1986). Muller (1986) suggests that the limited participation of Crab Orchard populations in the Hopewell exchange system reflects a cultural conservatism that may relate to differences in the economies and organization of Hopewellian and Crab Orchard societies.

The investigations by Cole et al. (1951) in the vicinity of the Kincaid Mounds on the lower Ohio River recovered additional Middle Woodland artifacts that appeared to be stylistically similar to Maxwell's (1951) Crab Orchard material. However, Cole et al. (1951) defined another cultural complex, the Baumer focus, to include this material. Whether Middle Woodland sites in the eastern Shawnee Hills are more closely related to Baumer or to the Crab Orchard culture is an unresolved problem (Butler and Jefferies 1986). Middle Woodland remains recovered during the Carrier Mills project were called Crab Orchard rather than Baumer (Jefferies 1987). Recent excavation at the Kincaid Mounds by the Center for Archaeological Investigations at Southern Illinois University-Carbondale recovered evidence of Baumer components (Brian Butler personnel communication 2004; Butler and Welch 2003). He stated that, “From the beginning we were aware that some Middle Woodland occupation would be present within the area of investigation, but we were surprised by the extent and intensity of it, as evidenced by a high density of large pit features. The old Baumer living surface is differentially preserved over the area, with much of it removed under the ridge crest Mississippian mound construction. Elsewhere, the layer appears to have been incorporated to various degrees within the Mississippian occupation zone. The many pit features associated with this occupation are, however, intact, and these are mostly large pits with a high refuse content. Clearly, if it were ever doubted, the front slope of Avery Lake at Kincaid was a major Baumer habitation site.”

In the later part of the Middle Woodland, the Allison-Lamotte culture appears in the lower Wabash River Valley (Pace 1974; Winters 1967). This culture was centered along the Wabash River and its major tributaries in Indiana and Illinois. The culture is characterized by the Lowe Flared Base; lamellar blades; sand- and grit-tempered, cordmarked, plain, and check stamped Embarrass Series pottery; and permanent to semi-permanent villages along major rivers (Pace and Apfelstadt 1980). Wyandotte chert was widely used by these groups in the Wabash River Valley and may have been obtained through some yet unknown, elaborate exchange system. While some Hopewell-like ceramics have been found at Allison-Lamotte sites, the degree of association–direct, indirect, or none–with Hopewell centers such as the Mann site is presently unknown.

In the middle Ohio River Valley the predominant Middle Woodland culture is known as the Hopewell Tradition (Prufer 1964). It is characterized by elaborate geometric

earthworks, enclosures, and mounds that are often associated with multiple burials and a wide array of exotic ceremonial goods. Materials used in the manufacture of these ceremonial items were acquired from various regions of North America: at least six species of marine shell from the Atlantic and Florida Gulf coasts; barracuda jaws, turtle shells, shark and alligator teeth from Florida; mica from southwestern North Carolina; chlorite from the southern Appalachians; meteoric iron from several sources; native copper from Lake Superior deposits; and silver from the vicinity of Cobalt, Ontario. Exotic lithic materials include large quantities of chert from Harrison County, Indiana; obsidian from the Yellowstone area in Wyoming; and Knife River chalcedony from North Dakota (Griffin 1978). Diagnostic lithic artifacts include thin, expanding base points, leaf-shaped blades, prismatic blades and associated polyhedral cores. Ceramics were manufactured with grit or limestone tempering and have plain or cordmarked surfaces (Purtill et al. 2001).

Historically, data on Illinois Hopewell settlement systems has been more complete than Ohio counterparts (Purtill et al. 2001). Over the past 20 to 30 years, survey and excavations within several drainage systems in central and southern Ohio have generated abundant settlement evidence for Ohio Hopewell populations. A lack of evidence for long-term, residential populations within ceremonial complexes has been argued recently for Ohio (Dancey and Pacheco 1997). This model argues for dispersed farmsteads that shared a central ceremonial center within each watershed. Investigations at the Jennison Guard site in southeastern Indiana (Kozarek 1987) and the various Murphy sites near Columbus, Ohio (Dancey and Pacheco 1997) appear to support the dispersed farmstead model of Ohio Hopewell settlement. It is argued that these farmsteads/hamlets are parts of a seasonal settlement system that was based on low group mobility with populations residing in good food resource producing areas throughout the year (Purtill et al. 2001).

In southeastern Ohio, a considerable amount of Hopewell settlement data has derived from the central Muskingum Valley (Purtill et al. 2001). These data suggest several trends including evidence of Hopewell hamlet clustering dispersed along floodplain locations, a distribution noted elsewhere (Abrams 1992). Carskadden and Morton (1997) argue that previous Adena period occupations often were re-used by Hopewell groups demonstrating a high degree of continuity between Early and Middle Woodland societies (Purtill et al. 2001).

In the upper Ohio River Valley the Middle Woodland is defined as a transition from the Adena to the Late Woodland Monongahela (Weed 2004). As with the middle Ohio River Valley the settlement patterns of Middle Woodland groups in the upper Ohio River Valley are poorly understood. While the Middle Woodland groups are using the same topographic settings as the Early Woodland groups, the Middle Woodland groups use of the floodplain significantly increases. Sites of the Middle Woodland period remain poorly investigated likely because of the poorly defined temporal parameters for the period in the upper Ohio River Valley (Weed 2004).

The end of the Middle Woodland period was marked by a reduction in interregional trade, a decrease in the complexity of ceremonial/mortuary practices, and a reduction in the elaborateness that marked the period. A traditional view has been that the Late Woodland was a time of de-evolution in the cultural development of the Midwest. However, important and dynamic cultural and organizational changes were taking place that set the stage for the development of the Mississippian period in the region. Some of these

changes include changes in ceramic technology, the development of an agricultural economy, and the introduction of the bow and arrow.

Subsistence during the Late Woodland period was characterized by an intensive exploitation of local wild plant resources, supplemented by a variety of domesticated seed crops and meat resources. Maize gardening continued through this period but appears to have been only a minor garden crop (Ford 1974, 1977; Fritz 1992; Kelly et al. 1984). Gardening probably consisted of a starchy seed complex (Ford 1981) of goosefoot (*Chenopodium bushianum*), knotweed (*Polygonium erectum*), smartweed (*Polygonium* sp.), and maygrass (*Phalaris caroliniana*). Through the Late Woodland period, gardening became more important as suggested by the relocation of villages to floodplains with highly productive soils and the increased size and frequency of pits (Kelly et al. 1984). It was perhaps the increased importance of garden crops that promoted an increase in population throughout the period and a nucleation of the population into larger, more permanent villages (Sieber et al. 1989). In addition, evidence for tobacco, squash, gourd, and maize has been documented. There appeared to be a rise in maize consumption during the later stages of the Late Woodland period and also an increase in hunting of large mammals (e.g., deer) is evidenced during this period (Purtill et al. 2001).

The Late Woodland period in the middle Ohio River Valley is characterized by technological advances, increased sedentism, and the escalating dependence on cultigens as a subsistence base. In many ways, the Late Woodland period can be viewed as a cultural continuum from the proceeding Middle Woodland (Hopewell) period minus the elaborate burial ceremonialism. Traditionally, fieldwork on Late Woodland sites focused on delineating regional phases, complexes or traditions such as the Cole Complex (Baby and Potter 1965), the Peters Phase (Prufer and McKenzie 1966), the Chesser Phase (Prufer 1967), and the Intrusive Mound Complex (Seeman 1980, 1992; Purtill et al. 2001).

During the early Late Woodland period, large, nucleated settlements in floodplain and terrace settings appear for the first time within the middle Ohio River Valley. Settlements located in environmentally rich ecological zones, such as within the Little Miami River Valley, appear to have been occupied year round and continuously for several generations; whereas, other sites appear to have been inhabited for shorter periods of time (Purtill et al. 2001). Ditches or earthen embankments have been documented encircling several larger sites such as the Zencor and Water Plant sites in Franklin County, Ohio. These features, along with the concomitant rise in lethal projectile wounds, are thought to represent a rise in regional hostilities not witnessed in preceding Middle Woodland times. By the later stages of the Late Woodland period, large settlements are no longer established as local populations again concentrate in smaller, dispersed sites (Purtill et al. 2001). Throughout the entire Late Woodland period, intensive use of upland areas, most notably rockshelters throughout the Ohio River Valley, have been documented (Purtill et al. 2001; Snyder et al. 2002).

In contrast to earlier Middle Woodland Hopewell burial ceremonialism, Late Woodland mortuary practices are less elaborate in design although mound construction continues. Many of these mounds contain stone architecture such as rock cysts, slab-lined vaults, and pavements. For the first time, stone mounds are utilized in association with burials (Purtill et al. 2001). In many of the major drainage systems of southern Ohio, stone mounds appear directly associated with large nucleated sites. In addition, several middle Ohio River Valley sites have yielded human remains recovered from general midden areas

and not associated with formal cemetery zones (Shott et al. 1990). Mounds in the lower Ohio River Valley, located on blufftops overlooking rivers, often contain burials with grave goods, but no evidence would suggest differential burial based on status. Mortuary offerings are less exotic and suggest a reduction in long-distance trade items. Several artifacts do appear important in regional trade networks including “limestone and sandstone elbow pipes, narrow Chilton-style gorgets of bone and slate, late pentagonal pendants, and small sheets of mica” (Seeman and Dancey 2000).

Diagnostic projectile points of the period include the Lowe Flared Base, Jack's Reef Corner Notched, Jack's Reef Pentagonal, Raccoon Notched, and very late in the period, small triangular forms (Sieber et al. 1989). Wyandotte chert declined in use through the Late Woodland period as chert cobbles of glacial origin were used to produce the small points. Late Woodland ceramics include thin-walled, grog- or grit-tempered, cordmarked or paddle-impressed vessels that tend to represent simple utilitarian ware. The highly decorated vessels with incised motifs of the Middle Woodland period disappear.

Three Late Woodland cultural manifestations have been defined in southern Indiana within the lower Ohio River Valley—the Albee Complex of southwestern Indiana, the Newtown phase in southeastern Indiana, and poorly defined Late Woodland groups around the Falls of the Ohio (Sieber et al. 1989).

Late Woodland sites in southern Illinois are identified by the presence of thin-walled, well-made, cordmarked, grit- and/or grog-tempered ceramic vessels (Denny 1972; Maxwell 1951). Point types diagnostic of the period include the Lowe Flared Base point, the Mounds Stemless point, and small, corner-notched points, including the Jamestown point. The appearance of small triangular and side-notched projectile points sometime after A.D. 600 indicates the adoption of the bow and arrow. Late Woodland materials were recovered from the Rose Hotel in Hardin County, Illinois (Wagner and Butler 1999) and at Horseshoe Lake in Alexander County, Illinois, at the confluence of the Ohio, Mississippi, and Cache rivers (Koldehoff and Wagner 2002).

The Lewis focus, now referred to as the Lewis phase, was defined by Cole et al. (1951) to include Late Woodland materials in the lower Ohio River Valley in extreme southern Illinois. Lewis pottery displays some red filming and incised line decoration (Hargrave 1992) and are tempered with fine grit, crushed clay, or both. Vessel shapes are characterized by rounded bases and constricting rims. Surface treatment is characterized by punching or notching with dowels on the lip and cordmarking.

Winters (1967) suggests that Lewis materials are rarely found outside the lower Ohio River Valley in Massac and Pope counties. However, investigations at several of the so-called "stone forts" in the Shawnee Hills suggest that these specialized sites might sometimes be associated with the Lewis phase. This affiliation has been proposed for Hog Bluff (Brieschke 1972) and Cypress Citadel (Klein 1981). Lewis phase pottery sherds have also been recovered from rockshelters in the Shawnee Hills (Latham and Baer 1997; Wagner et al. 1992).

Toward the end of the Late Woodland in the lower Ohio River Valley, the Yankeetown phase appears in southwestern Indiana, southeastern Illinois, and northwestern Kentucky (Sieber et al. 1989) The Yankeetown phase represents the true transition between the earlier Woodland traditions and the developing Mississippian

tradition. Ceramic forms increase in diversity as bowls, pans, pottery trowels, human figurines, and ceramic discs appear. Typical decorations on vessels include incised or filleted lines with rectangular or curvilinear zoned motifs. Bar stamping also occurs (Redmond 1986; Kellar 1983). Yankeetown settlements appear as sizable sedentary farming villages and small hamlets scattered among the floodplains of larger streams. Small extraction camps occur both in the bottomlands and uplands. The location of the villages on prime soils, the appearance of large storage pits and chert hoes, and an increase in maize production, all point to a shift toward an agricultural economy. Investigations in the Carrier Mills area of Saline County, Illinois, have shown that Yankeetown components are present in the Saline River Valley (Jefferies 1987), as have excavations at the Great Salt Spring in Gallatin County, Illinois (Peithman 1953). The Duffy site (11G132), type site for the Duffy complex (now included in the Yankeetown phase), is located on the Wabash River in northeastern Gallatin County, Illinois, and Yankeetown potsherds have also been recovered from a few rockshelters in the eastern Shawnee Hills during Forest Service CR surveys (Moffat et al. 1985; Wagner et al. 1992).

In the upper Ohio River Valley, radiometric assays from Late Woodland, Late Prehistoric, and Protohistoric groups overlap significantly. Consequently, these groups are generally discussed together. There is a lack of Mississippian influenced cultures such as Fort Ancient in the upper Ohio River Valley (Weed 2004). Of all the prehistoric cultural periods in the upper Ohio River Valley the Late Woodland/Late Prehistoric/Protohistoric is the most thoroughly investigated (Weed 2004). Two phases are represented in this region of the valley during this period and they are the Whittlesey and Monongahela (Weed 2004). Of these two, the Monongahela phase is the major presence in Pennsylvania and West Virginia (Weed 2004). Generally, the settlement pattern for the Monongahela sites is one of large sites on the floodplains and smaller sites in the uplands. Village sites tend to have palisades with round to oval shaped houses arranged around an open plaza (Weed 2004). Shell tempered, cordmarked and plain pottery appears for the first time during the Late Woodland/Late Prehistoric/Protohistoric period.

It was during the Mississippian period that the prehistoric cultures in the Southeast and middle Mississippi River Valley reached their peak of sociopolitical complexity. The period is marked by the development of complex chiefly societies characterized by hereditary authority and social ranking. This period is best known for the large, fortified civic/ceremonial centers constructed along major rivers valleys. Large, earthen, substructure mounds were constructed on which the houses/temples of the elite were built. Extensive exchange routes were established along which exotic, nonlocal materials were widely exchanged. An agricultural economy became firmly established with maize, beans, squash, and pumpkin being grown to augment traditional hunting and gathering. Typifying the Mississippian period is shell-tempered pottery, small triangular projectiles, a wide diversity of ceramic forms, and square to rectangular houses (many with subterranean floors). Exotic, nonlocal cherts were widely exchanged, including Dover chert from Tennessee and Mill Creek chert from Union County, Illinois (Sieber et al. 1989).

Mississippian organization was based on a domestic economy with the household forming the basic economic unit of the Mississippian community. Settlements consisted of large, fortified towns containing mounds, unfortified villages, hamlets, and individual households (Muller 1986; Smith 1978). Small special purpose structures that possibly served as farming stations may have been attached to households (Finney 1993).

In the middle Ohio River Valley after A.D. 1000 the Fort Ancient complex is defined. Current research suggests that Fort Ancient developed out of the local Late Woodland cultures, although varying degrees of Mississippian influence and inter-regional migration (Purtill et al. 2001) have been forwarded. Within the Ohio River Valley, Fort Ancient extends from western West Virginia to southeastern Indiana. In Kentucky it is divided into three separate time spans: Osborne, Middle Fort Ancient, and the Madisonville Horizon.

Fort Ancient is characterized by large permanent villages located along major drainages on terrace and blufftop landforms. From A.D. 1000 to 1400, villages tend to be organized around a central plaza with concentricallly arranged rings of storage/refuse pits and houses. Burial mounds were not used extensively and by ca. A.D. 1250/1300 are not constructed at all (Cowan 1986, 1987; Purtill et al. 2001). Contexts for non-mound burials are varied and may occur around the central plaza, in cemeteries away from villages, or beneath house floors.

Fort Ancient pottery is characterized by an increase in the use of shell tempering through time (Purtill et al. 2001). Up to A.D. 1300, ceramic decorations show an increasing amount of decoration as designs such as curvilinear and rectinlinear guilloche designs become popular. Vessel shapes are restricted to elongated and gobular jar forms, although some pan forms have been documented. Projectile points are mostly thin, triangular forms that indicate the dominance of bow hunting (Purtill et al. 2001).

Subsistence during the Fort Ancient period became more heavily dependent on beans, maize, and squash, although evidence suggests that wild plant foods also remained an important part of the diet (Wheelersburg 1992; Purtill et al. 2001). Population increase occurred as a result of increased sedentism and a shift to a more intensive agricultural base. Settlement continued in stockaded villages, many on blufftop areas of floodplains. Although village sites have received the bulk of archaeological investigations, recent research has documented the existence of several small, seasonally occupied extractive/hunting camps (Brose and White 1983; Purtill 1999; Purtill et al. 2001).

Beginning around ca. A.D. 1400, Fort Ancient sites demonstrate a drastic reorganization of lifeways that differ from earlier periods. Archaeologists have termed this the Madisonville Horizon to reflect increased pan-regional interactions in artifact styles, including ceramic and lithic tools, with various groups within, and surrounding, the Fort Ancient culture area (Henderson 1992; Purtill et al. 2001). The traditional circular village pattern is replaced by roughly linear, poorly organized village plans (Cowan 1987). Evidence from the Driving Range site (33Ha586) in southwestern Ohio suggests that seasonal abandonment of summer villages for winter camps, referred to as the Miami-Potwatomi settlement system (Fitting and Cleland 1969), was being practiced for the first time in the Fort Ancient culture area (Purtill 1998, 1999; Purtill et al. 2001).

After A.D. 1400, a number of trends in artifact styles have been documented. Ceramic decorations become dramatically plain as curvilinear and rectilinear guilloche designs cease to be used in high frequencies (Cowan 1986, 1987). The incidence of ceramic salt pans occurs in high frequency for the first time (Purtill et al. 2001). Similar trends in ceramic styles have been observed in Kentucky (Henderson 1992) and West Virginia (Graybill 1981). Tool types that are argued to be diagnostic of the Madisonville

Horizon include bifacial, tear-drop end scrapers, bi-pointed knives, and carved bone pins (Cowan 1987; Henderson 1992).

There is evidence that some Late Woodland and Fort Ancient sites were occupied into the proto-historic period. The Madisonville site (33Ha14) in Hamilton County, Ohio, and the Morrison Village site in Ross County, Ohio, have yielded European trade goods suggesting occupation well into the seventeenth century (Drooker 1997). However, beginning in the mid-seventeenth century, aboriginal occupation of Ohio was disrupted when groups involved with the European fur trade in the Northeast began to expand the geographical range of their activity (Purtill et al. 2001).

Two coeval expressions of the Mississippian period existed in Indiana and the lower Ohio River Valley that represented different economic, political, and social adaptations. The Middle Mississippian culture is derived from influences from the southeast and involves the development of complex chiefly societies and the creation of one of the most complex prehistoric sociopolitical organizations to develop in North America. Middle Mississippian sites are limited to the southern half of the state with most sites occurring in southwestern Indiana. The Upper Mississippian is used to designate groups contemporaneous with, but outside, the Middle Mississippian cultural sphere. In essence these groups represent the "Mississippianization" of local Late Woodland groups (Sieber et al. 1989). This includes the Fort Ancient Aspect (Griffin 1943; Sharp and Turnbow 1987) centered in southeastern Indiana, southern Ohio, and northern Kentucky. Containing many Middle Mississippian attributes, the Fort Ancient sociopolitical organization never reached the complexity of settlements to the south. The Fort Ancient and Middle Mississippian cultures mixed in southwestern Indiana so that aspects of both traditions can be found in the region. The Oliver phase and the Vincennes culture are represented by this mixing (Dorwin 1971; Barth 1982; McCullough 1991, Redmond 1991; Redmond and McCllough 1993).

In southern Indiana the Upper Mississippian period is represented by the Angel (A.D. 1050–1450) and Caborn-Welborn phases (A.D. 1400–1600) (Sieber et al. 1989). The Angel phase is dominated by the Angel site in Vanderburgh County on the Ohio River. It encompasses more than 100 ac. and consists of residential areas, plazas, mortuary mounds, and elite zones associated with substructure mounds (Black 1967). The Angel phase has a diverse ceramic assemblage containing elaborate, well-made vessels. Angel and some surrounding villages were fortified with a surrounding stockade that may suggest conflicts, perhaps intermittent, between polities of the Mississippian period.

The later Caborn-Welborn phase is centered on the confluence of the Wabash River and the Ohio River. This regional variant is restricted in area, occurring only along a 50 km stretch of the lower Wabash River Valley. It is not known whether the Caborn-Welborn represents the breakdown of the Mississippian tradition or, more likely, a remnant of the Vincennes culture (Winters 1967) which was centered at the mouth of the Embarrass River. Caborn-Welborn populations were dispersed into large and small villages, individual homesteads, and hamlets (Sieber et al. 1989). Fortified villages or substructure mounds have not been found associated with these sites. European trade goods, glass beads, and brass items have been found in context with Caborn-Welborn sites. Whether direct contact took place with Europeans or whether these items arrived through exchange with neighboring native groups is not presently known (Sieber et al. 1989).

An important site in the southern Illinois region is the Kinkaid Mounds. Located in the Black Bottom area of the Ohio River, this site is composed of a number of hamlets located around a cluster of mounds, with evidence of a palisade construction along at least the north side of the site (Muller 1978). Additional areas of occupation and/or utilization have been identified in various portions of the Black Bottom area. While occupation of the area may have ranged from A.D. 900–1500+, recently obtained radiocarbon dates indicate that Mississippian exploitation of the locality likely climaxed during the 1200s (Muller 1978). Studies attempting to model Mississippian settlement patterns in the Black Bottom locality have met with some success (Butler 1977; Lafferty 1976; Muller 1978), while efforts to understand, or even identify, settlement patterning in the adjacent upland areas have proven more difficult. Recent excavations at Kincaid Mounds by Southern Illinois University-Carbondale took place for a proposed parking lot (Butler and Welch 2003). This investigation showed a Mississippian low platform mound definitely was built on the ridge terminus, although the size and ultimate height of the construction are uncertain. It has been largely leveled due to deflation and erosion under long-term farming. Outside of the immediate confines of the mound construction there is a layer of heavy Mississippian refuse with associated habitation features on the south slope of the ridge. Similar deposits on the north slope of the ridge with embedded houses and other features were recorded by earlier investigations. How much of this is the accumulation of refuse in a habitation area, and how much of it is mound fill (or displaced mound fill) is not certain (Butler and Welch 2003). These midden-like deposits have a high refuse content that includes considerable faunal material. It is evident that from the mid-slope south toward the road, the Mississippian and even some Baumer deposits have been progressively truncated by the earthmoving associated with the 1953 road work.

The Rose Hotel in Hardin County, Illinois, also has a Mississippian presence (Wagner and Butler 1998). Occasional finds of shell-tempered pottery or triangular projectile points also have been made in rockshelters located in the eastern Shawnee Hills (McCorvie 1991; Moffat et al. 1985; Penny 1983). These finds suggest occasional use of the Shawnee Hills by Mississippian peoples. There is also some evidence of Mississippian occupation in the Saline River Valley to the north of the Shawnee Hills. Several Mississippian farmsteads were excavated during the Carrier Mills project. The Saline Springs in Gallatin County were extensively utilized during the Mississippian period (May 1984).

Most petroglyphs in the Ohio River Valley are likely late prehistoric in origin, however, Woodland and Archaic petroglyphs sites are known. Mississippian period petroglyphs are generally situated in relatively inaccessible locations, possibly indicating a setting for ceremonial activity. The petroglyphs include anthropomorphic figures, foot/hand prints, various animals-in particular bird designs, bi-lobed arrow designs, and assorted circles and crosses. All of these designs are considered typical of the Southeastern Ceremonial Complex, which is a wide-spread complex of specific motifs and ceremonial objects associated with Mississippian period religion and ritual (Wagner et al. 1990). Such sites are documented from West Virginia to Illinois within the Ohio River Valley. Additional information on Ohio River Valley petroglyphs can be found in the following: Braley 1993; Cochran and Wepler 1994; Collins 1874; Coy 1991, 1995; Coy et al. 1997; Fowler 1977; Mallery 1893; Murphy 1978; Swauger 1961, 1968, 1974, 1984; and Wellman 1979.

12.7.2 Historic Cultural Resources

Archaeologists have worked to reconstruct the cultural and historical threads that knit together the native cultures of the Late Prehistoric and early historic periods in the Ohio River Valley with the more familiar named tribes associated with the historic contact period. As the above text indicates, the Late Prehistoric peoples of the Fort Ancient culture, for example, were once numerous in the Ohio River Valley. However, the rare historical and even more limited archaeological data for the immediately succeeding Protohistoric period, just prior to the time of the first contacts between Native Americans and Europeans; indicate that by A.D. 1650-1700 few Native Americans permanently resided in the upper Ohio River Valley. In fact, early European explorers and Euro-American settlers coming to the Ohio River Valley in the mid to late eighteenth century found few Native Americans who had been long-time residents of the region. Only small hunting camps and a few villages were found. Hunting parties ranged throughout the area as wild game abounded. Near the headwaters of the upper Ohio River at the confluence of the Monongahela and Allegheny rivers, early European surveyors, traders, and settlers encountered members of the Seneca, Delaware, and Shawnee tribes who used the area during hunting expeditions. There were, however, indications of earlier, more extensive human occupations from the periods described above including stone implements, pottery, human burials, and well-worn trails. The most dramatic signs of earlier permanent human occupation were the large earthen mounds and mound groups, which often occurred at or near the confluence of tributaries with the Ohio River.

The archaeological literature suggests that the lower Ohio River Valley was sparsely settled after the decline of the Mississippian civilization around A.D. 1500. There is little evidence of settlements of any size or duration of occupation during the period of initial contact with white settlers and explorers. A number of tribes used the area for hunting and fishing, following the rivers and their tributaries as well as the buffalo traces that crossed the region. Along the lower Ohio River these tribes included the Creeks, Chickasaw, Choctaw, Shawnee, Yuchi, and Cherokee.

As a result of the initial exposure to Europeans and diseases from which the native peoples had no natural immunity, all these tribes suffered from various contagious diseases during the eighteenth century. The severe and sudden population decline resulting from these diseases disrupted their traditional way of life and reduced their ability to resist incursions by European settlers (Carlisle and Mulligan, 2001). In the *New History of Kentucky,* it is estimated that by 1750 there were no more than 3,000 to 4,000 Shawnee in all of Kentucky (Klotter and Harrison 1997) .

Islands comprising the upper Ohio River Islands National Wildlife Refuge figure prominently in the history of the river based on early accounts by explorers of contemporary Indian groups, survey expeditions by George Washington, the settling of the Ohio River by pioneers and traders, strategic battles during the Civil War, and river development for navigation and industry. Many islands were large enough to be permanently settled or industrialized. Neville Island, about five miles downstream from Pittsburgh, became an active industrial site during the late 1800s. In 1798, a large Palladian mansion, in the style of Mount Vernon, was built on Blennerhassett Island near Parkersburg, West Virginia. Harman Blennerhassett, the builder of the mansion, later was accused of conspiracy with Aaron Burr. The 7,000-square foot mansion burned in 1811,

but has since been reconstructed as the centerpiece of Blennerhassett Island State Park, a distinctive cultural resource in West Virginia (USFWS 2000).

As early as 1780, a military party noted the large mounds at the mouth of the Muskingum River, at the site of the future Marietta, Ohio (Carlisle and Mulligan 2001). In fact, these mounds were incorporated into the new plans of the town when the construction of Marietta began in 1787-1788. Prehistoric mounds and mound complexes also once stood at the location of many other Ohio cities including Circleville, Chillicothe, and Cincinnati, though most were ploughed away in the early days of settlement (Jakle 1977). Extant Ohio River mounds listed by the U.S. National Park Service as National Historic Landmarks include Grave Creek Mound (Moundsville, West Virginia), which dates to 500 B.C. representing the Adena culture and Angel Mounds (near Evansville, Indiana), which date to A.D. 1000-1600 representing the northeastern most extension of the Mississippian culture.

Beginning in the eighteenth century, various explanations to account for Native American artifacts, trails, and earthen mounds were developed and debated. The architectural complexity and sophistication of the mounds and the numerous abandoned sites across the landscape provided a sharp contrast to the simpler, then current Native American condition, which was interpreted to be the result of a cultural disjunction. Early explorers and settlers were unaware that the comparatively simple bands of migratory native hunters and horticulturists of their own day were the products of more than a century of cultural upheaval, dissolution, and widespread geographical relocation. This cultural turmoil beyond the Appalachian Mountains had been precipitated by the development of sustained European settlement on the eastern seaboard beginning in 1607 and by related socio-political changes within other Native American cultures (Carlisle and Mulligan 2001).

French and British fur traders frequented the Ohio River Valley early in the eighteenth century, but permanent occupation by Europeans did not begin until the mid-eighteenth century when a few isolated military outposts were established in the valley. These outposts included the French Fort Duquesne (1754) and, and a few years later, the British Fort Pitt (1758) at the Forks of the Ohio, the site of present day Point Park in Pittsburgh. Far down river, near the confluence of the Ohio with the Mississippi River, the French built Fort Massac in 1757 near present-day Metropolis, Illinois, later occupied by both the British and Americans. Three major factors, however, delayed extensive settlement in the Ohio River Valley during much of the eighteenth century: (1) larger ongoing European political struggles; (2) nearly constant hostility between settlers and (3) Native Americans; and the American colonists' struggle for independence from Great Britain. Several cities along the lower and middle Ohio River were founded in the late 1700s including Louisville in 1779 at the Falls of the Ohio, the most significant break in navigation on the river, East Liverpool (1797); Steubenville (1798); Marietta (1788); and Cincinnati (1788) – all in Ohio; Wheeling, West Virginia, had been settled somewhat earlier (1770s) while the communities of Parkersburg and Huntington, West Virginia, both remained small until well into the nineteenth century. Pittsburgh was founded in 1758 at the headwaters of the Ohio River.

Following the Treaty of Paris (1783), formally ending the American Revolution, the Land Ordinance of 1785 provided for the administration and subdivision of land in the Northwest Territory. The new territory consisted of land north of the Ohio River, west of

Pennsylvania and east of the Mississippi, including all of present-day Ohio, Indiana, and Illinois and parts of Michigan and Wisconsin. East Liverpool, Ohio, on the Ohio-Pennsylvania border, was the point from which the rectangular-grid land survey system was developed under the ordinance. The search for good agricultural land was the major impetus to westward migration and settlement of the Northwest Territory (USFWS 2000). Many settlers to Kentucky, Indiana, and Illinois came overland from the southeast through the Cumberland Gap.

The Battle of Fallen Timbers (1794) near Maumee, Ohio, and the subsequent Treaty of Greenville were key events leading to the cessation of hostilities between settlers and Native Americans in the upper Ohio River Valley and opened the way for more extensive settlement. Within the lower Ohio River Valley Cantonment, Wilkinson in Pulaski County, Illinois, was established during 1801-1802 and was archaeologically located by SIU-C recently (Wagner 2003a). Some 1,000 men were stationed there out of a total of 3,500 for the entire U.S. Army. At the time, it was the largest post in the United States. Several of the men stationed there went on the Lewis and Clark expedition (Wagner 2003a). A cemetery with approximately 80 burials of soldiers who died of malaria and dysentery has never been located at the location of the cantonment. Another major event that opened the way for the development of settlements in the lower Ohio River Valley was William Henry Harrison's victory over the Shawnee at the Battle of Tippecanoe in Northern Indiana in 1811. The event was a turning point in British-inspired Indian problems since following that battle the confederation of the eastern tribes disintegrated.

Additional lower Ohio River Valley communities were founded during the same era near the confluence of significant tributaries, including the Kentucky communities of Owensboro (late 1790s), Henderson (1797), and Paducah (1795). The second largest city on the lower Ohio River for most of its history, Evansville, Indiana, was not founded until 1812. The eastern banks of the Ohio River became the departure point for many settlers down the Ohio River and into the territory to the west. Flatboats were an important mode of transportation for settlers heading to the Northwest Territory from Pittsburgh, Wheeling, and other ports in the upper Ohio River.

Flatboats were sturdily constructed, flat-bottomed craft about 50 feet long, typically only capable of traveling downriver. Ohio River Valley farmers and merchants constructed flat-bottomed vessels known as "flatboats" for over 125 years from the 1770s to 1900 (Wagner 2003b). Prior to the Civil War, thousands of these boats transported people, animals, farm produce, and manufactured goods down the Ohio River as far south as New Orleans (Wagner 2003b). There the vessels were broken up and sold for their lumber with the crews walking or riding steamboats back home. No intact examples of this vessel type are known to exist today. In 2000 local residents discovered the first physical remains of a flatboat yet found along the Ohio River shoreline a few miles above Cairo, Illinois. This vessel, called the America, was investigated by SIU-C. It is an estimated 45 ft. long x 12 ft. wide flatboat dating to ca. 1812-1820 (Wagner 2003b).

The invention of the steamboat in the early nineteenth century was highly significant in transforming the settlement of the entire Ohio River Valley because steamboats were capable of two-way transportation. The 1815 voyage of the steamboat *Enterprise* from New Orleans to Louisville in 25 days made the potential for steamboats clear (Carlisle and Mulligan 2001). Share (1982) reinforces the significance of steamboats for the Ohio River Valley in this passage:

By slashing distance and travel time, steam navigation transformed the Ohio Valley into a settled and cultivated region in a single generation. A northward and eastward movement of goods came to supplement downriver commerce, as steamboats and a series of canals constructed in the 1820s and 1830s connected the Ohio Valley to the Great Lakes and the Atlantic seaboard.

The two-way transport of agricultural products and industrial supplies greatly contributed to the economic growth of the region. Louisville became pivotal for the rapidly expanding trade between Pittsburgh and New Orleans, and all points in between, because the Falls of the Ohio remained an obstacle to navigation until a canal around the falls was completed in 1833. As river traffic increased, pirates preyed upon travelers and slow-moving steamboats. Cave-in-Rock, a 55-ft. wide limestone cave visible from the Ohio River in Hardin County, Illinois, was notorious as a lair of river pirates and criminals from the late 1790s until the mid-1830s. It is now a state park. Pirates also occupied some of the numerous islands located within the river.

The development of communities and trade during the early steamboat era transformed the Ohio River Valley within a few decades. Consequently, by the middle of the nineteenth century, fine homes and public buildings were erected in communities all along the Ohio River.

12.7.3 National Historic Landmarks

Many nineteenth century buildings have been preserved in historic districts within the Ohio River Valley. Several of the finest surviving residences are on the list of National Historic Landmarks (NHL), which are considered to possess exceptional value or quality in illustrating or interpreting the heritage of the United States. The Industrial Revolution affected the Ohio Valley and left outstanding architectural examples that represent nineteenth century efforts to include symbolic and monumental functions in industrial architecture. Two such NHL, visible from the river, are: the Louisville Water Company Pumping Station, constructed from 1858-1860 in the Classical Revival style with an engine room in the form of a temple and a 169 ft.-tall standpipe tower that imitates Roman columns; and the Cannelton Cotton Mills, begun in 1849 in Cannelton, Indiana, one of the most impressive pre-Civil War mills in the Midwest, topped by 100-ft. sandstone Italianate towers.

The nineteenth century also witnessed the construction of two suspension bridges over the Ohio River that continue to be important as both historic and active transportation resources. The Wheeling Suspension bridge, begun in 1849, was the first bridge to cross the Ohio River, allowing the National Road (which became U.S. 40) to move forward. With a span of 1,010 feet, it was the longest suspension bridge in the world upon completion. The NHL program describes the bridge as possibly the most significant extant ante-bellum engineering structure of the nation and adds that its construction established American leadership in the building of suspension bridges (http://tps.cr.nps.gov/nhl). An even longer suspension bridge was completed between Covington, Kentucky, and Cincinnati, Ohio, in 1867. The bridge is now named the John A. Roebling Bridge, after its designer. With its 1,057-ft. span, vertical suspenders and diagonal stays, the bridge became Roebling's prototype for the Brooklyn Bridge (1883).

Throughout the nineteenth century and during the Civil War, the Ohio River was an important geographic and cultural boundary between slavery and free labor. Bigham (1998) notes the legacy of that boundary continued to be felt many decades after the Civil War. With its islands, fords and lower water level, the pre-impounded Ohio River offered opportunities for slaves to escape to freedom. Many places on both sides of the Ohio River served as stations on the Underground Railroad. Two of the better known sites that are listed as NHLs are in the small river town of Ripley, Ohio (Brown County):

- the Rankin House, considered one of the first stations on the Underground Railroad and the place where Harriet Beecher Stowe heard the escaping slave's story which became the basis for *Uncle Tom's Cabin*; and
- the Parker House, where former slave, John Parker, lived and operated a foundry while rescuing slaves along the Ohio River.

Upriver in the old community of Maysville, Mason County, Kentucky, the National Underground Railroad Museum preserves and displays artifacts that document activities of the Underground Railroad. Interest in the Underground Railroad is further documented at the National Underground Railroad Freedom Center on the Cincinnati riverfront at the foot of the Roebling Bridge. The 160,000 square-foot-center documents the history of the Underground Railroad and encourages Americans to ensure freedom in the twenty-first century. Among the CR from the Ohio River during the twentieth century are three floating NHLs that represent different aspects of life on the river:

- the *W.P. Snyder, Jr*., originally built as a towboat in 1918, is the last intact steam-powered, stern-wheeled towboat in the U.S. It is currently a floating exhibit of the Ohio River Museum in Marietta, Ohio
- the *Majestic*, built in 1923, is one of only two surviving American showboats. Earlier in its history, the Majestic carried theater productions to river towns along the Ohio and Kanawha rivers. Moored at the Cincinnati Public Landing, it still offers theatrical productions during warmer months; and
- the *Mayor Andrew Broaddus*, completed in 1929, is the only floating lifesaving station in the U.S. The *Broaddus* is the third such station located on the Louisville waterfront. It now serves as the wharfboat for another historic vessel, the *Belle of Louisville.*

During the twentieth century, high-lift dams constructed along the length of the Ohio River transformed the river. The decades-long construction process will be completed when the most downstream project, Olmstead Lock and Dam (replacing Dams 52 and 53), is completed in 2011. By raising the level of the river, high-lift dams have inundated fords, portions of islands and mouths of tributaries that were above water during prehistoric and early historic times (USFWS 2000). The older locks and dams on the Ohio River are of sufficient age to now be evaluated for eligibility for placement in the NRHP, thus representing a new generation of CR along the ever-changing Ohio River.

12.7.4 National Register of Historic Places

The NRHP was established by the NHPA of 1966 (**Table 12-2**). Prior to that date, no official national list of CR worthy of preservation existed. The NRHP and state CR registries list hundreds of CR found to be significant to the history of the country. **Figure**

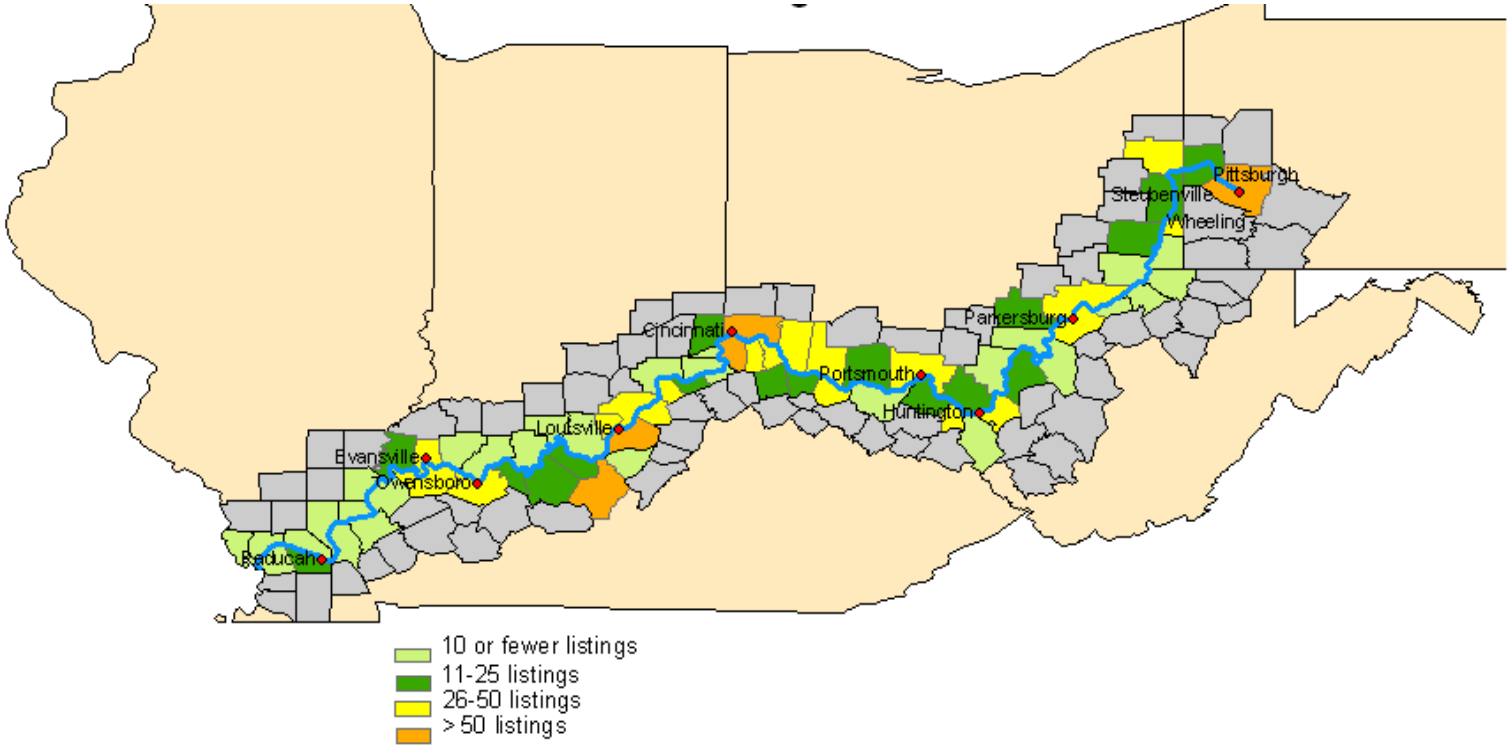
12-1 illustrates the number of listings on the NRHP by county along the Ohio River. Listings ranged from only one in a rural county of West Virginia to approximately 500 listings in the Louisville region, Jefferson County, Kentucky. Not surprisingly, the highest number of listings on the NRHP is associated with the most populous areas. Conversely, **Figure 12-1** shows that the least populous counties, such as the six counties along the Ohio River in Illinois, have fewer than 10 listings each. According to NRHP coordinators contacted for the states along the Ohio River, numbers of listings also reflect local and state levels of interest, effort, and funding for historic preservation.

The annual number of new listings has remained relatively stable in the past decade in Pennsylvania, Ohio, Indiana, and Illinois and is predicted to remain at a similar level in the coming decade. Kentucky, in contrast, has observed a decline in numbers, related in part, to a different listing process used during the 1970s and 1980s. Regarding the future of NRHP listings in Ohio River counties, some historic preservationists believe the more transitory nature of structures currently being built will translate into fewer structures being eligible for listing by the mid-twenty-first century. A contrasting view holds that appreciation is growing for historic structures, in general, while new specific areas of preservation (e.g., vernacular architecture) are emerging.

Included on the NRHP are historic districts. The NHPA defines a historic district as "a geographically defined area, urban or rural, possessing a significant concentration, linkage or continuity of sites, buildings, structures or objects linked by past events or aesthetically by plan or physical development. A district may also comprise individual elements separated geographically, but linked by association or history." Such historic districts have been designated in both small communities and large cities along the Ohio River. The metropolitan counties associated with Pittsburgh, Cincinnati, and Louisville have dozens of listed historic districts while the smaller cities of Steubenville, Ohio (Columbiana County), Wheeling, West Virginia (Ohio County), Parkersburg, West Virginia (Wood County), and Evansville, Indiana (Vanderburgh County) each have five to 10 historic districts. Other smaller communities and counties that have listed historic districts include Beaver, Pennsylvania (Beaver County); Belmont County, Ohio (near Wheeling); Sistersville, West Virginia (Tyler County); Marietta, Ohio (Washington County); Huntington, West Virginia (Cabell County); Aurora, Indiana (Dearborn County); New Albany, Indiana (Floyd County); Henderson County, Kentucky (Henderson County); and Paducah, Kentucky (McCracken County). Downtown Madison, Indiana (Jefferson County) is the largest historic district along the Ohio River, encompassing over 1,000 nineteenth century structures.

Like historic districts, archaeological districts encompass areas where significant numbers of archaeological resources are concentrated. Archaeological districts are rarer than historic districts and are not specifically defined in the NHPA. An archaeological district essentially is a geographical cluster of archaeological sites that may or may not be linked by a common culture. The distribution of archaeological districts is uneven state-by-state and may be more reflective of state policies or the scale of a given project. Within the ORMSS study area, archaeological districts are listed on the NRHP for Greenup County, Kentucky and Hamilton County, Ohio.

FIGURE12-1
National Register of Historic Places Listings for Counties Along the Ohio River



12.7.5 Historic Navigation Structures

Section 110 of the NHPA requires federal agencies to assume responsibility for preservation of historic properties owned or controlled by them and to locate, inventory, and nominate all properties that qualify for the NRHP. Consequently, many of the locks, dams, buildings, and equipment originally built by the Corps on the Ohio River are themselves considered to be CR. As modern engineering and technology are fast replacing many early engineering designs, some early structures are deemed worthy of preservation or documentation for future generations (http://www.lpr.usace.army.mil/lmon/cult_resources.htm).

During 1999, the Corps evaluated 69 facilities associated with the navigational system along the Ohio River for potential inclusion in the NRHP (Hampton et al. 2003). Of the 69 facilities, seven that are active were determined eligible for the NRHP, while 31 that are inactive were determined to be eligible. The remaining facilities were determined to be ineligible for the NRHP.

The historic engineering evaluation in the Ohio River Context Study (McVarnish 2001) described the Ohio River navigation system as a "living laboratory of twentieth century lock and dam technology" and concluded that it clearly meets Criterion C of the NRHP, which states that structures that embody the distinctive characteristics of a type, period, or method of construction may be eligible. Because of its extensiveness and complexity, the Ohio River Navigation System pioneered the evolution of several significant areas of engineering, including:

- lock filling and emptying technology
- cofferdam technology and
- power generation in navigation complexes in the United States.

Other important engineering achievements on the Ohio River system include:

- movable Chanoine wicket navigable passes, still in place at Dams 52 and 53 and soon to be superseded by Olmsted Dam, which will include a modern, improved version of the navigable pass
- the first use of steel wall armor to protect concrete lock walls from the impact of vessels
- construction of the largest roller gates (125.5') in the U.S. at Gallipolis Dam and
- first use of a Sidney gate (with moving or sliding trunnion pins) in the back channel dam at Emsworth.

12.8 INTERACTIONS WITH OTHER VECS

CR are associated to varying degrees with several other VECs, but appear to be most closely related to those VECs associated with human communities, including socioeconomics, land use, transportation, and recreation. The most significant interactions and potentially adverse impacts to CR occur because of land use changes in the floodplain, which in turn are driven by socioeconomics. River transportation and traffic, also closely linked to socioeconomics, appear to directly affect CR primarily through bank erosion with

its attendant resource loss and to indirectly affect CR through the development of marinas, terminals, and multimodal sites that rely on river commerce.

Recreation is becoming increasingly important as cities and towns once again consider their riverfronts as community assets. Riverfront recreation areas have a mixed effect on CR. Land disturbance with potential damage or destruction of CR is somewhat counterbalanced by the enhanced knowledge and educational opportunities afforded by CR surveys undertaken during riverfront development.

A medium level of interaction occurs between CR and floodplain hydrology and terrestrial resources. As floodplain hydrology and terrestrial resources are modified by land use changes, CR also can become vulnerable to inundation, burial, or destruction.

12.9 RELEVANT ACTIONS AFFECTING CULTURAL RESOURCES

Of 87 actions included in the RFFA matrix, 23 actions were ranked "high importance," 17 actions were ranked "medium importance," and the remaining 47 actions were ranked "low importance." **Table 12-4** lists all actions ranked high or medium, indicates if the action is generally beneficial (+) or detrimental (-), and lists the effects of the action according to the following key:

I = causes inundation
C = causes covering or burial
D = disturbs soils resulting in CR damage or destruction
A/C = changes aesthetics or context
U = impacts potential underwater CR
BE = causes bank erosion
RP = resource protection/preservation
O = other, including acid rain, floods, and other climatic events

TABLE 12-4
RFFAs Ranked High or Medium for Cultural Resources

RFFA	Net Effect	Types of Effects
Actions of High Importance		
Lock extensions/new locks/replacement/rehabilitation	-	C, D, A/C
Lock and dam operation and maintenance	-	I
Dam replacement and rehabilitation	-	I, C, D, A/C
Levees/floodwalls	-	C, D
Dry dams/other projects off mainstem	+/-	RP, I
Nonstructural flood damage reduction measures	+/-	RP
Corps recreation facilities – Construction and O&M	+/-	C, D
Port development (Sec. 107) and maintenance dredging	-	U, C, D, I
Fleeting areas/barge storage	-	BE, U, C, D
Terminals	-	U, C, D, A/C
Multi-modal sites	-	U, C, D, A/C
Instream sand and gravel mining	-	U, C, D, A/C

RFFA	Net Effect	Types of Effects
Floodplain sand and gravel mining	-	C, D, A/C
Limestone aggregates mining	-	C, D, A/C
Non-Corps recreation facilities – Construction and O&M	+/-	C, D
Residential floodplain development	-	C, D, A/C
Commercial floodplain development	-	C, D, A/C
Industrial floodplain development	-	C, D, A/C
Private recreational sites, including campgrounds, docks and seasonal trailer parks	-	C, D
Casinos	-	C, D, A/C, RP
Floods	+/-	O, RP
Earthquakes	-	C, D, A/C
COE permitting programs	+/-	C, D, A/C, RP
Actions of Medium Importance		
Channel dredging/dredged material disposal	-	U, C
Channel modifications	+/-	RP, D
Modification of Corps structures for environmental improvements (sec. 1135)	-	I, D
Environmental restoration of aquatic ecosystems (Sec.206)	+/_	RP, D
ERP projects – 5 categories	+/-	RP, D
Coal utilities	-	C, D, A/C, O
Other coal industries	-	C, D, A/C, O
Hydropower on dams	-/+	C, D, RP
Bridges	-	C, D, A/C
Utility crossings	-	A/C
Industrial crossings	-	A/C
Marina development and operation	-	U, C, D, A/C
Silviculture	-	D
Agriculture	-	D
Trail/bikeway development	+/-	RP, C, D
Severe storms	-	O
Wetland mitigation banking	-	D

The following discussion focuses on RFFAs ranked high or medium in the CR RFFA matrix. RFFAs are grouped according to their primary effects, but it should be understood that most actions have multiple interrelated environmental effects.

12.9.1 Actions Causing Inundation

Actions that cause long-term flooding may damage, wash away, or inundate CR, making them off limits to future analysis or recovery. Continued lock and dam operation and maintenance is an RFFA of high importance that causes long-term inundation along the length of the Ohio River. Other RFFAs, aimed at protecting human safety, may have similar effects at specific locations. For example, from a CR perspective, nonstructural

flood damage reduction measures, such as relocation of housing from the floodplain, may result in loss of significant architectural structures or neighborhoods. Dry dams or other off main stem projects aimed at flood protection downstream similarly may result in the loss of CR at the off-main stem sites where flood damage reduction projects actually occur. On the positive side, the Section 106 NHPA requirement for federal projects to consider CR may result in the recovery and curation of historic or prehistoric artifacts that may have otherwise remained unknown.

Activities that produce localized changes in hydrology also cause damage or loss of CR through inundation. Such activities include wetland restoration during modification of Corps structures for environmental improvements and floodplain sand and gravel mining.

12.9.2 Actions Resulting in Damage or Destruction of Underwater Cultural Resources

Because CR associated with the streambed of the pre-impoundment Ohio River are largely unknown, it is possible that activities that alter or remove bottom substrates may result in damage or destruction to underwater CR, including prehistoric artifacts. Channel maintenance dredging and in-stream sand and gravel mining both directly remove bottom substrates and inadvertently any CR associated with them. Further, land disposal of dredged materials and land-based activities related to in-stream mining can bury CR on unsurveyed disposal or processing sites. Likewise, port development and maintenance dredging can potentially affect both in-stream and land-based CR.

Terminals and multimodal facilities also typically involve dredging during their development and operation, with potential attendant damage to unknown CR. Associated land-based activities can result in damage or destruction of CR caused not only by construction of the terminals or multimodal facilities themselves, but also compounded by land transportation facilities, including new roads and rail spurs that service them.

12.9.3 Actions Causing Damage or Destruction through Burial or Land Disturbance

Our incomplete knowledge of CR along the Ohio River, as well as, their lack of visibility, makes CR near the land surface particularly vulnerable. **Table 12-4** lists the broad range of important RFFAs that can damage or destroy CR through covering, burial, or land disturbance. Any type of construction activity that involves establishing laydown yards for materials and equipment, clearing, grading, disposal areas, or excavation has the potential to damage, destroy, or bury historic and prehistoric CR. Such construction-related RFFAs include lock extensions/rehabilitation, dam replacements/rehabilitation, levees, all types of floodplain development (residential, commercial and industrial), as well as energy-related and river commerce development and operation. To a lesser extent, even Environmental Restoration Projects, designed to restore natural resources, may have negative construction effects on unknown CR.

Construction of recreation facilities, including Corps and non-Corps parks and playfields, trails/bikeways, and private seasonal trailer parks and campgrounds similarly can have negative impacts on CR. Further, human intrusion or overuse may lead to degradation of CR that may be incorporated into recreation areas. On the other hand,

recreation facilities sometimes benefit CR by affording opportunities to heighten public awareness through interpretive exhibits and programs.

Agriculture and silviculture, although not construction activities, are ranked as having a medium impact on CR because of plowing, planting, and possible intrusion of root systems on buried CR. Earthquakes, though infrequent, are also ranked medium for their potential to causing cracking, destruction, or burial of resources through land disturbance.

12.9.4 Actions Causing Bank Erosion

Erosion occurring through wave and water action can cause loss when river banks slough and associated CR are damaged or disappear. Prehistoric and historic artifacts are vulnerable to loss through erosion when channel modifications alter currents and affect riverbanks and islands. Fleeting areas/barge storage was ranked of high importance on **Table 12-4** primarily because of the potential for bank erosion to affect CR. Barge queuing, although rated low in the CR matrix, is another RFFA that may cause bank sloughing and loss of CR.

12.9.5 Actions that Alter Aesthetics or Context

As mentioned under Indicators of Environmental Sustainability (ES), CR not only are evaluated by their individual condition but also by the stability or integrity of their context. Context, as pertinent to this discussion, involves several factors including auditory, visual and atmospheric encroachment, and overuse. Because integrity of context of CR is somewhat subjective, changes in surrounding land use that compromise or obliterate the contextual significance of an historic structure may be interpreted negatively. **Table 12-4** indicates that bridges, utility crossings, and industrial crossings are examples of RFFAs considered to have important aesthetic/context impacts on CR.

12.9.6 Other Actions

Included in this section are RFFAs that do not readily fit into the previous categories, such as certain natural climatic events. Floods (ranked high) may directly damage CR through floodwaters, erosion, or sedimentation. Floods also may expose previously unknown resources, potentially contributing to our knowledge of CR within the Ohio River Valley. Severe storms (ranked medium) can damage or destroy CR through heavy winds, lightening strikes, tree uprooting, and water damage.

Another weather-related RFFA with singular impacts is related to power generating facilities and other coal utilities located along the Ohio River. The emissions of such facilities have been linked to acid rain and resultant damage to CR located northeast of the Ohio River Valley, but within the Ohio River Valley air shed.

12.10 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve ES. ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design,

construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of cumulative effects can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An Analysis of Environmental Sustainability (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps: (1) identification of "common effects" on CR from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix; (2) selection of indicators for ES of CR, and their grouping, as appropriate; and (3) consideration of the "connections" between common effects and indicator groups. The output of the AES consists of a qualitative (descriptive) discussion of the "connections," with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for CR, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – the composite conditions for the selected indicators of ES for CR do not reflect conditions that would sustain CR in the Ohio River mainstem study area
- Marginally sustainable – the composite conditions for the selected indicators of ES for CR are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for ES
- Sustainable – the composite conditions for the selected indicators of ES for CR are good and exceed regulatory thresholds or other pertinent measures.

Several common effects of multiple actions have been previously discussed in the section entitled "Relevant Actions Affecting Cultural Resources"; they include actions causing inundation, actions causing damage or loss of underwater CR, actions causing burial or land disturbance, actions causing bank erosion, and actions that alter aesthetics or context.

Six indicators of ES were identified earlier in the section entitled "Indicators of Environmental Sustainability," and relevant information on them has been presented in the section entitled "Past to Current Baseline Conditions."

12.11 CONCLUSIONS

In summary, the ES of CR associated with the Ohio River mainstem, as illustrated in **Figure 12-2**, can be depicted and characterized as follows:

- In the period from 1920 and continuing until passage of the National Historic Preservation Act of 1966 and other preservation acts later in the twentieth century, limited measures were in place to preserve and protect CR; most resources remained unsurveyed. Widespread razing of potentially historic structures during this time is viewed by some SHPO

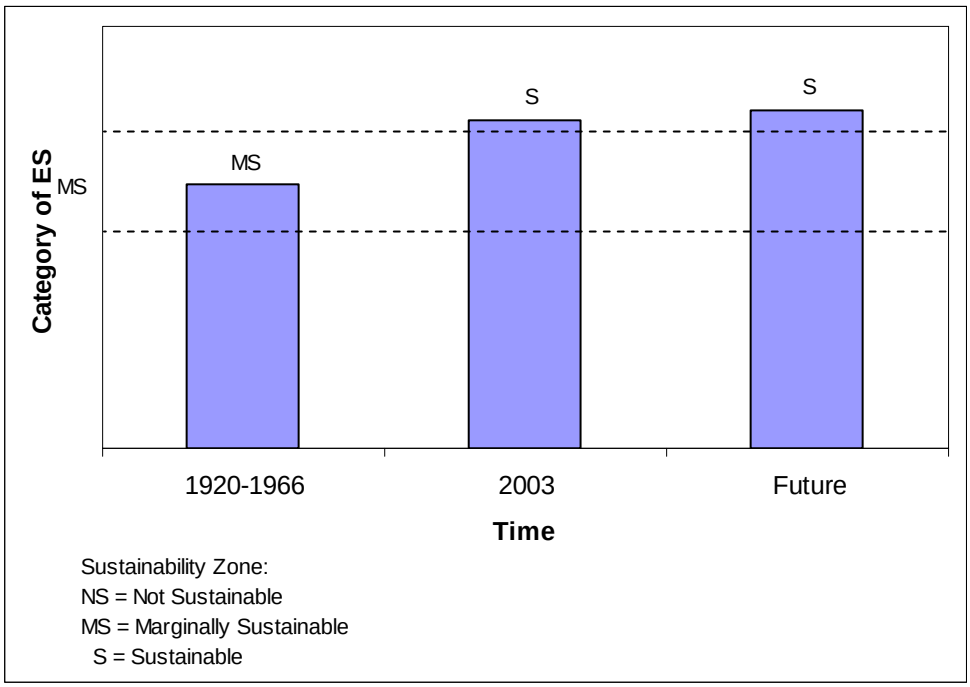
professionals as having contributed to a decline such that CR may overall have been at the "marginally sustainable" level.

- The implementation of CR legislation, including creation of the NRHP and establishment of the SHPO, has heightened awareness of the need to preserve historic structures in communities along the Ohio River. Simultaneously, NHPA provisions that require consideration of CR where federal involvement occurs have led to the discovery and preservation of previously unknown CR. Accordingly, the ES classification for the current time is "sustainable."
- Regarding the future, federal and state regulations concerning CR are expected to remain in place and help maintain a "sustainable" condition. During each year of this study, additional resources will become eligible for possible placement on the NRHP, although some SHPO professionals have observed that numbers of NRHP candidate properties may be limited due to societal trends toward disposability, tear down, and sprawl. Additional riverfront development, including recreational areas, may result in covering or damage to CR near the land surface.

Positive trends related to CR include

- the development of predictive models to determine probability for CR occurrences
- recent emphasis on context integration of historic districts and
- an increasing number of river festivals and other events (e.g., the Lewis and Clark Commemorative Trail, Cincinnati's Tall Stacks, etc.) through which residents of the Ohio River Valley are rediscovering the rich cultural heritage of the river

FIGURE 12-2
ES of Cultural Resources



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Chapter 13
ADAPTIVE MANAGEMENT FOR THE OHIO RIVER

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13.2 INTRODUCTION

An emerging theme for strategic-level or programmatic environmental impact studies is use of an Adaptive Management (AM) approach to address large-scale issues and long future timeframes that involve both policy and scientific uncertainties. AM refers to a relatively new concept that recognizes that scientific uncertainties and unforeseen environmental changes are inevitable when various plans, programs, or policies are implemented in particular environmental settings. Interest in AM has developed in response to the perceived limitations of natural resources management approaches in the US and around the world and also may reflect a growing realization of the limits of science and engineering to solve complex public policy problems (National Research Council 2004). Accordingly, the application of the concept in environmental management entails:

> "…the use of carefully designed and monitored experiments, based on input from scientists, managers, and citizens, as opportunities to maintain or restore ecological resilience and to learn more about ecosystems. These actions are monitored for scientific findings to help improve understanding of how policy decisions affect ecosystems. Findings from ecosystem monitoring are then to be used to appropriately adjust management policies. Adaptive management requires that clear goals and desired outcomes be established so that progress toward desired future conditions can be assured." (National Research Council, 2002)

AM has been applied, or is being considered for application, in environmental management efforts related to several large-scale water resources projects and programs. For example, it is included in the Comprehensive Everglades Restoration Plan in Florida, the Glen Canyon Dam in Arizona, the Upper Mississippi River Basin navigation study in the Midwest, and the Coastal Louisiana project; and it has been proposed for the Missouri River Basin ecosystem management program.

Applying AM concepts to the Ohio River system acknowledges uncertainties and offers a systematic way for stakeholders, the Corps, and other federal agencies to explore the relationships and trade-offs between river ecology, navigation, recreation, and other uses. A post-ORMSS AM program could include periodic reviews of navigation traffic relative to the Corps' traffic growth scenarios and adjustments in planned investments for lock replacements, maintenance, and rehabilitation. Such a program could also include monitoring of environmental indicators and adjustments to navigation traffic management and environmental policies, as appropriate (Canter and Swor 2003).

13.3 ELEMENTS IN AN ADAPTIVE MANAGEMENT PROGRAM

Like a functioning AM program, the theories and concepts related to AM represent a work in progress. There is no prototype for AM implementation or standard format that will assure success, because AM is context-specific. Further, recognition and acceptance of uncertainty in AM enhances learning in ways that contribute to the uniqueness of each AM program. Nevertheless, several key elements are associated with AM in general and are applicable to an AM program for ORMSS (See National Research Council 2004; Canter and Swor 2003: Gunderson, 1999; Light 2001; and Walters 1986). These key elements include, but are not limited to:

- The assembly of information on historical and current conditions of key indicators for environmental resources that are potentially subjected to impacts from a plan, program, or project; along with quantitative prediction or qualitative description of these anticipated impacts, along with impacts from other past, present, and reasonably foreseeable future actions (i.e., the cumulative effects), on key indicators. Many factors should be included in the assessment and management process: environmental, ecological, economic, historical, political, physical, social, and cultural.

- Active involvement of a spectrum of stakeholders. Common ecological management goals should be socially defined through a collaborative vision process that involves all interested participants and that incorporates ecological, economic, and social considerations. Flexibility and commitment of stakeholders over a long timeframe are critical to the success of an AM program.

- Multiple quantitative models can be used to generate hypotheses about the system under consideration. The models, however, cannot substitute for the realities of field testing. Large, complex systems, such as the Ohio River, are constantly changing and are inherently uncertain with potential multiple futures.

- A range of management options linked to appropriate temporal and spatial scales. Because data rarely point to a single "best" management policy, the range of management options for each decision should be considered at the outset in light of stated objectives and models of system dynamics.

- A scientifically-designed monitoring program focused on measuring changes in key indicators of environmental resources subjected to potential cumulative effects. Monitoring should help distinguish between natural perturbations and perturbations caused by management actions.

- A strategic framework that includes periodic evaluations of the implementation of features of the System Investment Plan (SIP), the monitoring data and other related policy information, and decision-making, as appropriate, relative to adapting management policies or measures for the environmental resources of concern. Through such a strategy, AM becomes an iterative process in which management objectives are regularly revisited and revised accordingly.

- Collaborative long-term agreements among pertinent federal, state, tribal, and local environmental agencies; along with a program steering committee comprised of representatives from these agencies. Given that most ecosystems and watersheds transcend conventional geopolitical boundaries, ecological management requires coordination among federal, state, tribal, and local governmental entities, as well as collaboration with other interested parties.

- Adequate budgetary and personnel resources. Given the finite nature of public funds and other resources, ecological management enables agencies to engage in careful targeting to select achievable goals and to allocate resources efficiently.

- A peer group of reviewers with expertise in public policy analyses, planning and conducting environmental monitoring and research, and environmental decision-making.

- A commitment to learning. This is the essence of adopting an effective AM program and ensuring transferability of acquired knowledge to future efforts.

Each of these elements are being considered, as appropriate, in the AM program for ORMSS.

13.4 SITUATIONAL CONTEXT FOR AM OF THE OHIO RIVER SYSTEM

13.4.1 Regulatory and Rulemaking Foundations for Adaptive Management and Monitoring

Although AM and monitoring have developed slowly and only recently begun to receive widespread attention, elements of this approach can be found in the original language of NEPA, which includes policy '…to create and *maintain* conditions under which man and nature can exist in productive harmony…' (Section 101(a) of NEPA). Section 102(2)(B) calls for 'methods…which will insure that presently unquantified environmental amenities and values may be given appropriate consideration…' Section 102(2)(C) specifies that an EIS shall include 'the relationship between local short-term uses of man's environment and the *maintenance* and enhancement of long term productivity…' The CEQ is to define and *analyze* changes in the environment and interpret their causes (Section204(6)),” (NEPA, 1969; Carpenter, 1997).

By 1974, CEQ noted very little progress towards improved understanding of ecological systems, finding that “ecological efforts were scattered throughout the government with little coordination or definition of priorities. 'Without a federal focus, response to problems which require ecological information or capability will continue to

be fragmented, costly, redundant, and reflexive rather than strategic, efficient, and contributory to national goals and productivity'" (CEQ, 1974; Carpenter, 1997). However, CEQ regulations did not directly address elements of AM and monitoring until 1992: "a monitoring and enforcement program shall be adopted and summarized where applicable for any mitigation" (Section 1505.2(c)) and "agencies may provide for monitoring to assure that their decisions are carried out and should do so in important cases" (Section 1505.3) (CEQ, 1992; Carpenter, 1997).

The CEQ again addressed the potential for using AM in the NEPA process in 1997, concluding that a "major difficulty with the traditional environmental impact analysis process is that it is a one-time event; i.e., results from intensive research, modeling, and other computations or expert opinions are analyzed, the analysis of potential environmental impacts is prepared, mitigation measures are identified, and a document is released for public review" (CEQ, 1997). Unfortunately, this process does not account for unanticipated changes in environmental conditions, inaccurate predictions, or subsequent information that might affect the original environmental protections. By incorporating the AM model into the NEPA process, the traditional "predict-mitigate-implement" model was expanded to incorporate the "predict-mitigate-implement-monitor-adapt" model. Although not all Federal actions lend themselves to incorporating AM into the NEPA process, the CEQ 1997 task force focused on certain actions where AM would be an appropriate model for the NEPA process to provide agencies with another tool to improve their NEPA implementation (CEQ 2003).

The CEQ 2003 NEPA Task Force initiated agency interviews and review of public comments anticipating that CEQ's 1997 NEPA effectiveness study had fostered an understanding of the value of integrating AM into the NEPA process. However, the Task Force discovered that incorporating AM into the NEPA process was a relatively new concept for many NEPA practitioners. The 2003 study also found that some agencies had applied the term AM to programmatic NEPA documentation, but without integrating 'monitor & adapt' components. This approach can result in a series of NEPA analyses that incorporate only the predict-mitigate-implement model. The 2003 Task Force also concluded there was strong consensus among agencies that guidance was needed in integrating AM into NEPA documents. The Task Force report recommended that the CEQ convene an AM work group to consider revising existing regulations or establishing new guidance to help agencies in exercising the option of incorporating AM into their NEPA process. Further, it was recommended that the CEQ should compile all guidance and regulations pertaining to AM in a handbook.

13.4.2 Monitoring and Adaptive Management in the Corps of Engineers

The Corps has established a leadership role in the application of AM, despite impediments from both internal and external sources. This progress stems in large part from Congressional action in the 1990s that added an ecosystem restoration mission to the Corps' responsibilities. As previously stated in 13-2, examples of AM applications include the Florida Everglades ecosystem restoration program, plans to restore Louisiana's coastal ecosystems, and applications in the Upper Mississippi and Missouri River Systems.

13.4.3 Planning Guidance

Several Corps guidance documents address some aspect of monitoring and AM (Laufle, 2003). The most extensive discussions appear in ER 1105-2-100 (Planning Guidance Notebook, 22 April 2000) and EC 1105-2-210 (Ecosystem Restoration in the Civil Works Program, 1 June 1995).

Corps guidance cites the "relative newness of restoration science and uncertainty in ecosystem restoration planning, theories, and tools" and the potential applicability of AM "in restoration projects recognized during planning to have the potential for uncertainty in achieving restoration objectives." Monitoring is called for "when new, unproven restoration techniques are being applied, and when significant levels of uncertainty prevail at the time of implementation" (EC 1105-2-210).

However, all the Corps guidance tends to categorize monitoring and AM as exceptional measures outside the normal realm of operations, to be employed only when special circumstances warrant. Monitoring is generally confined to examination of post-construction effects for a limited period of time (e.g., not to exceed 5 years) and within a limited budget (e.g., 1% of total first cost of ecosystem restoration features). AM, with a budget limited to 3% of total project costs excluding monitoring, may be recommended only for complex projects that have high levels of risk and uncertainty of obtaining the proposed outputs.

The NRC notes that Corps planning guidance and procedures contain few direct references to AM principles. The *Principles and Guidelines for Water and Land Resources Implementation Studies* (often referred to as the *"Principles and Guidelines"* or *P&G*), and the Corps *Planning Guidance Notebook* (or PGN; USACE, 2000a), also known as ER 1105-2-100 are largely based on concepts that pre-date the emergence of formal AM strategies. AM's emphasis on uncertainties, learning, and flexible policies represents a departure from the Corps' traditional planning approaches, and AM principles have only begun to be incorporated into the agency's planning guidance (NRC, 2004).

13.4.4 Environmental Operating Principles

Recognition of inadequacies in the Corps' guidance documents contributed in part to promulgation in March 2002 of the Corps' Environmental Operating Principles, which are intended to guide the Corps in all of its work. Many aspects of the AM approach are recognized, at least implicitly, in these principles. They include:

- achieving environmental sustainability
- recognizing the interdependence of life and the physical environment
- seeking balance and synergy among human development activities and natural systems
- seeking ways to assess and mitigate cumulative impacts on the environment
- bringing systems approaches to the full life cycle of Corps' processes and work, and
- building and sharing an integrated knowledge base that supports a greater understanding of the environment and impacts of Corps activities.

The commitment of the Corps to fully integrate the Environmental Operating Principles into all aspects of Corps programs and operations was reinforced by issuance of

EC 1105-2-404 "Planning Civil Works Projects under the Environmental Operating Principles" on 1 May 2003. Further reinforcement came with issuance of ER 200-1-5 "Policy for Implementation and Integrated Application of the U.S. Army Corps of Engineers (USACE) Environmental Operating Principles (EOP) and Doctrine" on 30 October 2003. The purpose of these documents is to "reaffirm the USACE general policy and further describe specific procedures…..consistent with environmental sustainability as defined in the Corps Environmental Operating Principles and Implementation Guidance."

13.4.5 Strategic Plan

The Corps' Civil Works Strategic Plan of March 2004, describes five national water resources challenges:

1) Achieving greater balance between traditional water resources demands and environmental/ecosystem objectives
2) Restoring the vitality of the environment from degradation caused by past development
3) Addressing the performance and safety implications of an aging water resources infrastructure
4) Ensuring the capability to respond to natural disasters and terrorism threats to water resources infrastructure, and
5) Minimizing institutional barriers to efficient and effective water resources planning, decision making, and management.

These challenges incorporate several recommendations found in recent NRC/NAS studies conducted for the Corps. The Plan also states that "it is beyond the scope and capability of any single agency to solve these challenges. We need innovative and collaborative ways to stretch resources and capabilities. The approach advocated in this strategic plan emphasizes:

- A holistic focus on water problems and opportunities
- Attention to the watershed as a logical geographic area for managing water resources
- A systems approach for analyzing problems and solutions
- Collaboration, partnerships, and teamwork for deriving and implementing solutions, and
- An emphasis on efficiencies to achieve more within existing resources.

Finally, three of the five goals of the Plan address issues relevant to AM:

Goal 1 - Provide sustainable development and integrated management of the Nation's water resources.

Goal 2 – Repair past environmental degradation and prevent future environmental losses.

Goal 3– Ensure that projects perform to meet authorized purposes and evolving conditions.

While the Strategic Plan does emphasize sustainable development and mentions AM, no detailed discussion is included. However, many listed strategies for Goals 1 through 3 are associated with "good practices" related to AM. Examples of "good practices" include collaborative planning and evaluation efforts with other governmental agencies and stakeholder groups, information dissemination, and adjustments to changing conditions via the AM process.

13.4.6 NRC Recommendations

Further evidence of commitment to implementing AM is evidenced by the Corps' request to the NRC for a study and recommendations addressing AM in the Corps. The NRC's AM panel was tasked to:

> Review the Corps of Engineers' efforts in applying AM concepts to project and program planning and operations, identifying AM's potential and its limitations. The panel will consider the range of Corps of Engineers' responsibilities that relate to AM concepts, including ecosystem restoration, flood damage reduction, and navigation enhancement. The panel will review the Corps' methods for implementing and practicing AM and will identify barriers to implementing the concept. The panel will also recommend ways in which AM might be usefully applied in Corps project planning and operations (NRC 2004).

The NRC report notes that AM is a multi-disciplinary, evolving concept whose core principles emphasize concepts such as uncertainty, surprise, and resilience. These concepts run counter to traditional engineering planning concepts of deterministic systems, precision, and model predictions. AM stresses the value of variability and extremes in sustaining healthy ecosystems. The Corps, on the other hand, has long sought to reduce hydrologic variability by providing reliable navigation channels, reducing high flows, and stabilizing coastal areas and beaches. AM will thus entail changes in operational styles and in organizational accountability as well as changes to Corps guidance, staffing, and procedures.

The NRC report also noted that the following opportunities may result from implementation of AM by the Corps:

- AM practices can be relevant and useful across a variety of scales and settings. In tracking experiences with AM, the Corps will benefit by a better understanding of the settings in which an adaptive approach—which may not always be appropriate—is merited and useful.

- AM may be particularly suited to large, complex ecosystem restoration projects, which entail large degrees of risk and uncertainty, multiple, and changing objectives, and phased components. AM can be especially important in multi-phase activities, as it can promote adaptation of ends and means based on lessons learned that lead to model improvements to support future decisions.

- AM entails a spectrum of approaches. These range from "passive" programs, which focus on monitoring and evaluating outcomes from a particular policy choice, to more formal and rigorous "active" AM, which designs management actions to test competing models of system behavior so that models can be improved for future decision making. Ever-improving guidance could help provide advice concerning the degree to which AM is applicable to various types of projects. This could range from limited monitoring programs (passive) to more formal (active) AM programs with carefully-structured operational alternatives and ecosystem models.

- Although AM has been linked primarily with natural resources management, it can be used to manage other types of systems. AM concepts could thus be useful within the Corps' navigation and flood management programs, as well as to its efforts in ecological restoration. Additionally, AM could be applicable in broader, but smaller scale settings such as small projects, infrastructure management (includes dam decommissions), and permitting activities. Recommendations for these broader applications include the following:

  Small Projects Authority: Small project programs are excellent candidates for experimentation and concerted learning in connection with AM efforts. The Corps has the ability to change administration of these programs to allow for cost-shared modifications in project features based on long-term monitoring results of physical project outputs and ecological outcomes. Such changes would require no additional congressional authority. These changes could generate important demonstrations of the value of AM and provide a basis for seeking additional congressional authority to revisit completed and ongoing projects that could benefit from AM. Such settings would also allow the Corps to gain experience with smaller-scale and less controversial projects, lessons from which could be valuable in their efforts in more controversial situations.

  Managing Existing Infrastructure: Effective operations of existing dams and other water resource infrastructure in the United States presents a challenge and an opportunity to the Corps and other federal water management agencies, as well as state and local governments and non-governmental organizations. Three key issues in management of this infrastructure could benefit from management criteria or guidelines that incorporate AM: (1) monitoring and evaluating dam and project performance; (2) retrofitting, redesigning and operating dams to improve infrastructure safety and project performance; and (3) decommissioning, where warranted by costs and benefits. The Corps, with its varying involvement in design, permitting, construction, and operation of many of these structures, is the logical agency to assume the necessary responsibilities.

  Passage of the Dam Safety and Security Act in 2002 points to increased congressional concern for dam safety issues. The Federal Emergency Management Agency (FEMA) coordinates federal dam safety efforts, helps finance research, coordinates technology transfer, and assists states with their dam safety programs (which cover approximately 95 percent of dams listed in the National Inventory of Dams). FEMA is not responsible, however, for improving dam safety technology or the engineering and science on which that technology is based. That would be a logical responsibility for the Corps, in cooperation with other organizations.

  A promising area of application of AM involves dam decommissioning and de-authorization. Although a dam cannot be incrementally removed, adaptive learning based upon the experiences with past dam removals should be used to refine the criteria and approaches for removals, and to

improve methods for post-removal mitigation. As the Corps' Inventory of Dams describes, over 75,000 dams have been erected on U.S. waterways, many of which are outdated, unsafe, and no longer active. Some of these structures have also caused significant impacts on river ecosystems. In recent years, the decommissioning and removal of dams has become more common. Hundreds of U.S. dams were removed in the 1990s, and removal of many more is being considered. Not all of these are small structures. A seminal case was the Quaker Neck Dam on North Carolina's Neuse River, where the Corps worked with the U.S. Fish and Wildlife Service and other federal and state agencies to remove a dam that had blocked migratory fish routes since 1952. In addition to ecological impacts, maintenance of Quaker Neck Dam had become hazardous and expensive. After the Corps designed alternative means of providing cooling water to the related power plant, a cooperative effort resulted in dam removal in 1997-98.

Permitting Activities: AM could also be usefully applied to the Corps' permitting activities. For example, the Corps is responsible for evaluating applications for wetland fill permits under the Clean Water Act Section 404. Corps regulations prohibit any filling unless appropriate and practicable steps have been taken to minimize adverse impacts on aquatic ecosystems. When the Corps issues a permit, it requires that discharges to wetlands be avoided or minimized to the extent practicable. Remaining impacts must be mitigated, often through compensatory mitigation, in which other wetlands are created or restored. A previous NRC committee concluded that compensatory mitigation was not fulfilling its goal of achieving no net loss of wetlands because clear performance standards were not being defined within permits and performance was not being monitored (NRC, 2001a). Although detailed evaluation of the regulatory program is beyond this report's scope, AM principles could help the Corps improve its wetland mitigation program. Performance goals could be set in permits, and permitees could be required to implement a monitoring program focused on wetland functions. Alternatively or additionally, the Corps could conduct a retrospective study(s) of mitigation projects, and use the results to improve design of future mitigation efforts. AM principles could also be used to guide permitting decisions and mitigation requirements in which cumulative impacts are an issue, such as where multiple permits are issued for the same water body.

13.4.7 Stakeholder Collaboration

The NRC report also notes that Corps' successes with stakeholder participation appear to be paying some dividends. In the Upper Mississippi, the agency's responsiveness to stakeholder input may be enhancing public trust in the agency. By contrast, a lack of this type of support for broad, meaningful stakeholder participation may be contributing to decision making gridlock on the Missouri River.

There is much to be learned about how to successfully incorporate the concept, and the Corps should continue to move forward in its collaborative efforts. The agency could, for example, publicize examples where stakeholder-driven AM actions led to beneficial effects that were largely unanticipated, and seek to learn from past experiences throughout

the agency. Stakeholder and agency involvement should begin at the onset of AM programs and should include stakeholder participation in periodic review of monitoring results and management models.

13.4.8 Institutional Constraints

Despite considerable progress to date, the NRC report also identifies a number of internal factors that can inhibit successful implementation of AM. The Corps' highly decentralized organization offers one significant impediment. A drawback of this structure is that district offices focus largely on planning their own new projects and working closely with local project sponsors, without benefiting from the knowledge and experience of colleagues in other district offices. There are limited incentives and resources, and few precedents or traditions, for district offices to seek information from one another or from experts outside the organization, or to communicate lessons from their experiences throughout the organization. Although many Corps district offices and personnel are pursuing AM activities, these experiences are not being explicitly shared throughout the agency.

In many ways, AM represents a departure from traditional Corps planning approaches and disciplinary strengths. The Corps is in the midst of a broad shift from construction toward increased emphasis on operating a large, existing infrastructure, which controls a large portion of the nation's hydrologic systems and distributes significant benefits. The Corps must maintain its engineering expertise to safely operate this infrastructure, but sound management of Corps' projects today also calls for expertise in fields such as ecology and economics.

AM is consistent with this broadening mission and it represents a promising means for making better decisions under uncertainty and facilitating stakeholder cooperation and input. It aims to fuse knowledge and understanding of economics and other social sciences, engineering, and ecology. Just as important as broadening disciplinary expertise is the incorporation of these broader perspectives within Corps decision making. Enlisting experts in social and ecological sciences, or commissioning studies in these areas, is of little use if the agency does not have the appropriate capacity to meaningfully incorporate these perspectives and knowledge into the project planning and management cycle.

A broader range of personnel and disciplinary perspectives should be included within all phases of project management in order to implement AM within the agency. For example, some Corps staff members are occasionally involved in projects and tasks that transcend their expertise, such as when engineers are asked to conduct economic analyses or to facilitate public meetings regarding controversial studies or projects. Moreover, there is no evidence that AM efforts in district offices are proceeding consistently in accord with a set of guiding principles, or with sharing experiences and knowledge across district offices or throughout the agency. Not every Corps office need employ experts from a wide range of disciplines, but the Corps needs broader expertise that its staff can turn to in implementing and sustaining AM practices. One proposal worth further consideration is the creation of a small center specializing in AM housing an interdisciplinary team to provide advice to all Corps offices and to synthesize results of the Corps' AM efforts across the nation.

13.5 DIFFERENCES BETWEEN ADAPTIVE MANAGEMENT AND TRADITIONAL MANAGEMENT APPROACHES

Because AM represents a departure from traditional planning approaches and disciplinary strengths, several conceptual barriers to its implementation may arise. Defenders of the status quo, for example, may view AM as indicating failures of past decisions; some may view it as a means of circumventing environmental and other standards or as an excuse for taking minimal actions, and budgeters may be concerned about the costs of related monitoring and science-based programs.

Decisions made within traditional management systems may be difficult to change because managers may resist recognizing and learning from their own errors. AM can help reduce decision-making gridlock by emphasizing that decisions are provisional, often with no "right' or "wrong", and that modifications are expected (NRC 2004). The multi-faceted, collaborative framework of AM promotes the search for common ground and goals definition, which should ease the tension of agencies or individuals who perceive their interests are at risk. This in turn enhances cooperation among participants.

A 1997 CEQ review of the effectiveness of NEPA after 25 years concluded that a major difficulty with the traditional environmental impact analysis process is that it is a one time event. Consequently, such a process does not account for unanticipated changes in environmental conditions, inaccurate predictions, or additional information that might affect the original environmental analyses. By incorporating AM into the NEPA process, the CEQ suggests that the traditional "predict-mitigate-implement" model can be expanded to a "predict-mitigate-implement-monitor-adapt" model.

13.6 ADAPTIVE MANAGEMENT – A USEFUL APPROACH FOR THE OHIO RIVER SYSTEM

The reality of changing conditions which AM recognizes is especially relevant to public works projects measured in decades. For example, the Ohio River system, as studied in the System Investment Plan (SIP), extends through the year 2070. Among many reasons AM is a useful approach for the Ohio River system are:

1) It is a large system which transcends conventional geopolitical boundaries and requires coordination among federal, state, and local agencies, Non-Governmental Organizations (NGOs), etc., (Canter 2003 in Woolpert compilation).

2) Ecological management policies and decisions should be based on integrated and scientific information that addresses multiple resources, such as that provided in the ORMSS Cumulative Effects Assessment (CEA), rather than addressing single resources (Canter 2003).

3) Given finite public resources for possible environmental mitigation and restoration projects along the Ohio River, AM is a way for agencies to allocate resources efficiently to affect measurable results.

4) AM recognizes the scientific uncertainty that occurs in large river systems such as the Ohio River. There may be opportunities to apply lessons learned from AM programs for other large river systems in the US that could be applied to the Ohio River.

5) AM does not postpone actions until enough is known, but enables learning and action despite limitations, even taking advantage of unanticipated events (Lee 1999). Accordingly, momentum gained during the ORMSS process can be a catalyst to launch a long-term AM program.

6) AM can increase the ability to respond in a timely fashion to new information concerning the Ohio River, in part because stakeholders and other institutional structures are already in place.

7) AM can reduce decision-making gridlock by making it clear that decisions are provisional (NRC 2002). The climate of trust developed by the Interagency Working Group (IWG) during ORMSS meetings over several years could facilitate group decision-making in a future AM program.

8) AM promotes monitoring that focuses on significant and detectable indicators of progress towards management objectives (NRC 2004). Many indicators were identified during the ORMSS CEA process, while other indicators and indices are under development or are being studied by ORSANCO and other organizations.

9) AM is compatible with the developing science of ecosystem restoration embodied in the Corps Environmental Operating Principles (EOPs) and outlined in the Ohio River Ecosystem Restoration Program (2000). It is important that the Corps allocate sufficient funds to monitor effects of future restoration efforts and generate and disseminate information that will enhance success of these efforts.

10) Because AM supersedes smaller spatial and temporal scales and individual projects, it focuses on the interconnectedness of resources as is emphasized in the CEA. Likewise, the holistic, multi- and interdisciplinary nature of AM integrates Ohio River Valued Environmental Components (VECs).

11) AM considers the cumulative effects that occur in river basins that, like the Ohio, are exposed to multiple stressors both from human activities and natural disturbances such as storms and floods.

12) AM goes beyond piecemeal environmental mitigation to consider hydrological processes, sediment transport, and other dynamics driving the river ecosystem (Light 2001). The ORMSS CEA has sought to integrate these processes.

13) Finally, in addition to ecosystem applications, operation of existing locks and dams on the Ohio River could benefit from guidelines that incorporate AM.

13.7 THE ROLE OF MONITORING IN ADAPTIVE MANAGEMENT

As suggested previously, a key feature of AM is planning and implementation of monitoring programs aimed at addressing identified environmental uncertainties. Sadler

and Davies (1988) describe three types of environmental monitoring which might be associated with the life cycle of a plan, in this case, the SIP. These include baseline (current conditions) monitoring, effects or impact monitoring, and compliance monitoring. Baseline monitoring is measurement of environmental variables during a representative pre-project or pre-plan period to determine existing conditions, ranges of variation, and processes of change. Effects or impact monitoring involves measurement of environmental variables during construction and operation of one to several projects to determine changes that may have been caused, and to develop or evaluate mitigation measures. Finally, compliance monitoring takes the form of periodic sampling and/or continuous measurement of levels of waste discharge, noise, or other emissions, to ensure that conditions are observed and standards are met. It could also include compliance auditing with regulatory permit programs of the USEPA, the Corps, and the involved states. Pre-Programmatic Environmental Impact Statement (PEIS) monitoring includes baseline monitoring, while post-PEIS monitoring encompasses effects or impact monitoring, and/or compliance monitoring. All three types of monitoring should be included in an AM program for the Ohio River. Several monitoring programs already in progress for the Ohio River are described in the following section on implementing an AM program for the Ohio River.

Careful planning and implementation of a monitoring program is necessary for meeting the various purposes of monitoring. Three considerations are important in planning monitoring programs in the United States. First, there is an abundance of environmental monitoring data routinely collected by various governmental agencies and the private sector. These data need to be identified, aggregated, and interpreted since information is often compiled but never interpreted relative to the quality of the environment being monitored. Second, because environmental monitoring programs are expensive to plan and implement, every effort should be made to use or modify extant monitoring programs. Third, owing to overlapping environmental management and monitoring responsibilities of many local, state, and federal governmental agencies, it will be necessary to carefully coordinate environmental monitoring planning with several agencies.

To illustrate the scientific considerations that may be involved in planning a monitoring program, a generic seven-step conceptual framework for developing a plan is highlighted (Spellerberg 1991). The framework can be adapted to monitoring environmental media and socioeconomic and/or social impacts. The following describes the 7 steps described by Spellerberg:

1. Step1 is to define the monitoring objectives. In many monitoring schemes, the objectives are either not stated or are so complex that they become meaningless.
2. Step 2 is to determine the spatial locations where the monitoring will take place.
3. Step 3 is to make sure the data collected are documented for future use. When monitoring programs extend over long periods of time, such as for the SIP, professionals working on the AM program will change. Therefore, the need arises for methods to assure retention of such data, which should be accessible and understandable to successive professionals.
4. Step 4 entails various arrangements for data collection and storage. The success of a monitoring program depends not only on good planning and logistical support, but also on coordination with other related programs.

5. Step 5 involves the process of selecting the indicators to be measured. The ideal indicator and process would be completely field-based, but logistic limitations (finances, time, and effort) may override these considerations. Due to such logistic limitations, methods for collection of data from the field or assemblage of data from other sources should therefore be considered along with the choice of indicators. Monitoring data can be aggregated into pertinent indices to reflect the composite quality of different environmental categories. For example, several indices for the biological environment have been developed, including indices of biotic integrity (IBIs) for stream fish assemblages. CEA Chapter 4 – Fish, describes the Ohio River Fish Index (ORFIn), which ORSANCO recently has developed for the Ohio River.
6. Step 6 involves preliminary data gathering and baseline surveys. Before biological monitoring starts, information from published sources or preliminary field studies should be assembled.
7. Step 7 involves analysis and presentation of the data. Who will use the data to make management recommendations should be considered when the form of data presentation is selected. For an AM program, it is anticipated that the program steering committee will use the information to adapt management efforts, as appropriate.

13.8 RESOURCES FOR IMPLEMENTING AN ADAPTIVE MANAGEMENT PROGRAM FOR THE OHIO RIVER SYSTEM

Implementation of an AM program for aquatic and riparian/floodplain resources of the Ohio mainstem could be facilitated by a framework already in place, which encompasses institutional relationships, monitoring programs, ecosystem and economic models, and various educational efforts. The following section describes the components comprising this framework and their potential applications to an AM program for the ORMSS study area.

13.8.1 Organizations with Coordinating Roles Related to Ohio River Management

No long-term entity for AM of the Ohio River system has been established; however, several organizations and agencies currently are involved in various aspects of Ohio River management. Development of the ORMSS CEA has provided opportunities to become better acquainted with these organizations and their missions.

The lead agency for ORMSS, the Corps, is the federal agency responsible for planning, construction, operation, and maintenance of navigation structures along the Ohio River. Additionally, the role of the Corps has expanded in recent years to include ecosystem restoration. The Corps cannot typically carry out these projects by itself, however, since current authorities require a non-federal cost sharing partner.

Recognizing limitations within their agency, the Corps' Environmental Planning Team for ORMSS, developed an Interagency Working Group (IWG) to help identify scientific information and guidance for the CEA process. The IWG consists of approximately 40 members representing federal and state agencies, as well as several NGOs. Agencies and organizations represented on the IWG include the U.S. Fish & Wildlife Service, U.S. Geological Survey, U.S. Environmental Protection Agency, Ohio

River Valley Water Sanitation Commission (ORSANCO), along with several state resource agencies and NGOs. It may be appropriate for the IWG, which has coalesced over several years, to continue their involvement with the Corps by serving a similar role with the Ohio River AM even beyond completion of ORMSS because of the IWG's grounding in AM issues through participation in:

- Identifying key issues and cumulative effects for the Ohio River system
- Delineating and prioritizing key research needs relative to environmental issues and natural resources
- Identifying scientific information on emerging issues throughout the ORMSS process, and
- Participating in early stages of the planning and implementation of a long-term strategy for environmental monitoring and AM for aquatic and riparian/floodplain resources within and along the Ohio River mainstem.

The synergy and ideas generated by this group are important assets that support the concept of continuing the IWG as part of a long-term decision-making body instrumental to AM program implementation. Additional access to data and institutional knowledge is available though several IWG members who serve on the following specialized resource management teams for the Ohio River:

1) The Ohio River Fisheries Management Team (ORFMT), a group including representatives from fisheries resources agencies of the six states bordering the Ohio River. Activities of ORFMT have included coordination of state fishing regulations, development of management plans for sport fishes and species of special concern and, more recently, participation in developing an Asian carps management/control plan.

2) The Ohio River Valley Ecosystem Team (ORVET) consists of U.S. Fish & Wildlife personnel participating in eight subgroups relevant to Ohio River ecosystem management, including wetlands, migratory birds, fisheries resources, mollusks, endangered species, law enforcement, outreach, and cave/karst habitat. The ORVET has an extensive network of cooperators including universities, NGOs, and state resource agencies.

3) Because of its long-term role in resource monitoring and promulgation of standards on the Ohio River, ORSANCO is an important collaborator in an AM program for the river. Since its creation in 1948 though an interstate compact aimed at controlling pollution and improving the river's water quality, ORSANCO's programs have grown to include extensive monitoring, spill prevention and detection, fish consumption and recreation advisories, TMDL development, river cleanups, and public outreach. Its multi-state governing body provides a forum for interstate issues and policies and opportunities for interactions with federal agencies and funding authorities. The role of ORSANCO will be expanded upon in subsequent sections on monitoring, modeling, and education.

4) The Ohio River Basin Commission (ORBC) is another interstate group charged with coordinating and managing the water resources and related land resources of the Ohio River watershed. ORBC membership consists of gubernatorial representatives from nine participating states; the ORBC also has a Citizens' Advisory Council. In

addition to discussing and developing regional policies related to Ohio River resources, the ORBC seeks to encourage coordinated and cooperative actions among the participating states and federal agencies. Further, the ORBC represents interests of the Ohio Basin before Congress and federal agencies. The ORBC has not been represented in the IWG for ORMSS.

4) The Ohio River Basin Consortium for Research and Education (ORBCRE), an association of universities, colleges, industries, and agencies was established 20 years ago with the goal of promoting inter-institutional research and education in water related concerns and other environmental issues in the Ohio River Basin. Throughout the ORMSS, the environmental study team has actively participated in ORBCRE events.

13.8.2 Models and Other Tools Applicable to Ohio River AM

Computer models, habitat indices, and other quantitative tools are inherent in successful AM programs. Development, evaluation, modification, and eventual application of such quantitative tools in AM distinguishes the directed learning characteristic of AM from the more evolutionary trial-and-error approach to ecosystem management. Applying modeling and other tools to the AM process helps focus management options and identify alternatives for further evaluation and testing (Walters 1997).

Lee (1999) and others have emphasized that an explicit baseline understanding and assumptions about an ecosystem being managed can provide a foundation for learning by AM. Such a system model helps to explain responses to management actions and to identify knowledge gaps and limits (NRC 2004). Because it assesses cumulative effects for a spectrum of actions and identifies areas of uncertainty for further study, the ORMSS CEA in effect provides a model for the Ohio mainstem. Although qualitative in many respects, the ORMSS CEA offers future participants in an Ohio mainstem AM program a comprehensive, integrated understanding of the VECs or resources that compose the river system.

Walters notes that the "learning by doing" objectives of AM should begin with “a concerted effort to integrate existing interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies” (Walters, 1997). This modeling step is intended to serve three functions:

(1) problem clarification and enhanced communication among scientists, managers, and other stakeholders;
(2) policy screening to eliminate options that are most likely incapable of doing much good, because of inadequate scale or type of impact; and
(3) identification of key knowledge gaps that make model predictions suspect.”

In this context, characterization of past to present conditions, current trends, and predictions of environmental sustainability for individual VECs provided by the ORMSS CEA provides a close approximation to Walters’ description of a dynamic model appropriate to an AM approach.

In contrast to the ORMSS CEA, many ecosystem and hydrological models applied to AM are numerical, in which elements and processes of a given system (e.g., river corridor)

are quantitatively expressed within a computer program. The more accurately such models are able to simulate reality, the greater their credibility. Field testing of ecosystem models is critical, however, because model results should neither be equated with reality nor viewed in isolation from other integrating factors (NRC 2004).

Three quantitative assessment tools with applications to AM are currently under development or evaluation for the Ohio mainstem. These tools, which conform to the above criteria, are briefly described as follows:

1) NAVPAT

As discussed in further detail in Chapter 4 Fish of this CEA, over the past 20 years, the Corps- Louisville District developed the Navigation Predictive Analysis Technique (NAVPAT) model to assess potential incremental habitat effects of various navigation planning scenarios. The goal of NAVPAT is to provide quantitative results, which can assess positive or negative changes in available aquatic habitat quality for a specific area of a river cross-section or for an entire reach of river. In general, NAVPAT links tow movements to possible biological effects, which result from habitat disruption. The NAVPAT model consists of four primary input components: river reach characteristics, traffic scenarios, physical forces, and biological species life-stage models.

2) ORFIn

Also discussed in Chapter 4, the Ohio River Fish Index (ORFIn), an index of biotic integrity (IBI) developed by ORSANCO and other agencies during the past several years, is specifically tailored to the distinctive ecological characteristics of the Ohio River. The ORFIn measures 13 attributes of fish communities that either respond predictably to measures of human disturbance or reflect desirable features of the Ohio River. ORFIn is sensitive to a wide range of habitat and water quality conditions and is being used to develop numeric biological criteria for the Ohio River for eventual incorporation into ORSANCO's Pollution Control Standards (Emery and Vicory 1998). Evaluation and refinement of ORFIn as a sustainability assessment tool will continue over the next several years.

3) ORNIM

The Ohio River Navigation Investment Model (ORNIM) is a tool specifically developed by the Corps to identify and evaluate the structural and nonstructural alternatives that yield the optimal combination of navigation capacity enhancement and nonstructural investments for the Ohio River system (Frechione & Walker 2003). As explained in Chapter 10, Transportation and Traffic. ORNIM is used to determine the proper mix of navigation improvement actions that maximizes economic return from Federal investments in the Ohio River System.

13.8.3 Monitoring Programs Applicable to Ohio River AM

As mentioned in the preceding section, ORSANCO has conducted a broad range of water quality and biological monitoring activities since the mid-20th century that have documented conditions and illustrated trends. ORSANCO's current monitoring activities focus on bacteria monitoring near six major urban areas along the river, fish and

macroinvertebrate monitoring, fish tissue sampling, metals sampling, detection of organics, and algae and nutrient sampling related to drinking water supplies and the development of criteria for nutrients.

Both ORSANCO and the University of Louisville are participating in the USEPA's Environmental Monitoring and Assessment Program (EMAP) which includes the Ohio River. EMAP's goal is to develop the scientific understanding for translating environmental data from multiple spatial and temporal scales into assessments of current ecological conditions and forecasts of future risks to natural resources (EMAP web site). Development of indicators to monitor the condition of ecological resources is one of several AM concepts incorporated into EMAP. EMAP's study of the Great Rivers of the central U.S. (encompassing the Upper Mississippi, Ohio and Missouri rivers) began in July 2004 and includes monitoring the Ohio mainstem. The Great Rivers EMAP is currently underway on the Ohio River.

Since the mid-20th century, regulated industries (including power companies, drinking water companies, and industrial waster dischargers) also have conducted studies of mussels and other resources (e.g., fish, bacteria, temperature, and pH) near their facilities along the river, often in collaboration with university researchers. Some of these studies were cited in the CEA; further, representatives of this sector contributed to discussions on aquatic and riparian sustainability during ORMSS. This sector will continue to perform impact assessments and compliance monitoring (e.g., studies related to §316(a)&(b) of the Clean Water Act) as required by their individual permits.

However, the uncoordinated accrual of data collected to meet permit requirements may have only marginal value to the system-wide focus of an AM program. Additional industry participation in collaborative development of an AM program for the Ohio River could result in restructuring of some aquatic studies conducted by this sector. For example, such restructuring could contribute to more effective monitoring of key indicators for mussels and other aquatic resources. As more information is assembled on the locations and characteristics of mussel beds in the mainstem, planning and implementation of targeted and long-term mussel monitoring programs can be more effectively accomplished. Further, the results can be used in an AM program focused on enhancing and maintaining the ES of the mussel resource.

13.8.4 Mapping Programs Applicable to Ohio River AM

Large-spatial mapping efforts also provide information of potential value to AM programs when such maps help identify trends and cumulative effects. Among such mapping efforts are the USGS/LANSAT/National map as well as the USFWS's National Wetlands Inventory (NWI) which produces information on the characteristics, extent, and status of U.S. wetlands. Geographical Information Systems (GIS), including systems developed by the Corps' Districts, can track permits, help identify spatial and temporal trends, and assess cumulative effects. Concurrent with these coordinated mapping programs are various efforts to improve the accessibility of such information to the general public.

13.8.5 Public Information Initiatives Applicable to Ohio River AM

Public education initiatives applicable to AM of the Ohio River mainstem potentially range from professional and university initiatives to environmental education activities for young students. At the research/higher education end of the spectrum is the Ohio River Basin Consortium for Research and Education (ORBCRE), an association of universities, colleges, industries and agencies established 20 years ago with the goal of promoting inter-institutional research and education in water related concerns and other environmental issues in the Ohio River Basin (www.ent.ohiou.edu/~orbcre/main1.html).

The organization's annual meeting may serve as a forum for introducing AM concepts and establishing initial priorities for a river-wide program. Several members of the ORMSS IWG either are directly affiliated with ORBCRE or attend its annual meetings.

Throughout development of the CEA, the ORMSS Environmental Planning Team contacted river researchers at several universities and identified projects relevant to AM of the Ohio River. A potentially relevant program recently developed is the Rivers Institute at Hanover College, Madison, IN. Three other institutions of higher learning – Marshall University, Thomas More College and the University of Louisville – either have research facilities on the Ohio River or plan to establish such facilities. Other efforts related to the Ohio River are underway at the University of Cincinnati, Northern Kentucky University, and Southern Illinois University,

Among the informal opportunities to learn about the Ohio River are those provided by:

- ORSANCO through its mobile aquarium, River Watchers school program, annual Riversweep, and other efforts,
- NGOs, including the Nature Conservancy and Ohio River Foundation, and
- Citizens' organizations such as the Riverlife Task Force (Pittsburgh), the Ohio River Way (Cincinnati) and River Fields, Inc. (Louisville).

13.8.6 Small Scale Applications of Adaptive Management

Small scale applications are an integral component of any AM program, regardless of the resource scales and timeframes being addressed. AM recognizes the need to implement actions at local, project specific levels and to link project managers to AM roles. Opportunities for lower costs, more flexible design, and quicker results can enhance the 'learning by doing' aspects of adaptive experimentation, point the way toward more promising approaches, and potentially demonstrate the value of continued support for the AM program.

Smaller scale approaches to impact analysis, restoration, and experimentation may also serve to enhance stakeholder participation. The use of pragmatic or 'conceptually accessible' models can allow virtually any group of stakeholders to assess:

- The scale/spectrum of resource impacts associated with proposed actions and alternatives,
- Impact tradeoffs of project alternatives or modifications,
- The context of project impacts relative to the broader spectrum of impacts affecting resources at local and system-wide scales,
- Feasibility of linkages between potential resource management actions and desired outcomes, and

- Accountability requirements to assess the degree to which desired outcomes are achieved

Implementation of an AM approach can potentially benefit from the synergistic effects of two 'alternative' strategies referred to as 'trickle down' and 'bubble up.' Trickle down starts from the large scale resource perspective (watershed, main stem corridor) and long time frame, and develops a resource model at this broad scale. This strategy works to:

- Develop a collaborative, multi-agency program approach,
- Identifies affected stakeholders (and may empower or assist some stakeholder participation), and
- Involves stakeholders in developing a description and model of resource issues, conditions, trends, and desired outcomes

These activities provide a framework for implementation of coordinated management actions at local, project specific scales.

The 'bubble up' approach starts from a local or grass roots perspective that recognizes the AM principle of taking action based on limited information and planning projects to learn from unanticipated outcomes. This approach includes an effort to identify and incorporate best available information about local issues in the context of broader resource management issues, often via case studies and various information networking strategies. The primary focus is to design and implement resource management strategies to meet local needs, but includes monitoring and documentation strategies to communicate the learned experience from the local focus to other settings.

13.9 AN ADAPTIVE APPROACH TO STAKEHOLDER INVOLVEMENT

13.9.1 ORMSS Environmental Sustainability (ES) Workshops – A Prototype for Future Stakeholder Activity

Two special workshops were convened during development of the ORMMS CEA to catalyze discussions leading to formulation of recommendations to improve environmental sustainability (ES) and initiate AM of the Ohio River system. Although these special workshops focused on aquatic and riparian/floodplain resources, they served as prototypes for stakeholder involvement while demonstrating that a similar participatory approach can be applied to any VEC.

As the process unfolded, it became apparent that the special workshops and collaborative thinking they generated were consistent with the key elements of AM in several important respects:

- Workshop participants represented a broad spectrum of stakeholders from state and federal agencies, universities, and electric utilities. The workshops were designed to engage participants in a collaborative visioning process that incorporated ecological, economic, and social considerations.

- Although individual participants had distinct interests, they comprised a cohesive peer group with expertise in public policy, planning and conducting environmental

research, and environmental decision-making. All group members had scientific/engineering backgrounds relevant to aquatic and/or riparian/floodplain resources issues.

- The workshops created a climate for continuing dialogue that ultimately may result in a strategic planning framework for AM of the Ohio River system. Although the workshop discussion was purposely open-ended, the participants may later be involved in developing collaborative long-term agreements, as well as in securing funding to implement an AM program.

13.9.2 Workshop Details and Syntheses of Workshop Discussions

The aquatic resources workshop (encompassing water quality, fish, mussels, and other aquatic life) was convened in Frankfort, Kentucky, on February 11, 2004. It included 14 participants with professional expertise in aquatic resources and was led by the ORMSS CEA team leader. The riparian/floodplain resources workshop followed a similar format and was held in Frankfort on October 20, 2004. It included 22 participants with professional expertise in riparian resources and likewise was led by the ORMSS CEA team leader.

To facilitate the workshop discussions, the CEA planning team developed a few guidelines communicated to each participant prior to the workshop. Secondly, a list of several open-ended questions was developed for discussion at the workshops themselves. Thirdly, workshop discussion was conducted within clearly defined constraints.

13.9.3 Aquatic Sustainability Workshop

The three questions developed to guide the group discussion were:
"What do we want the resource to look like?"
"What needs to happen to attain this vision of the Ohio River?"
"What are possible indicators of environmental sustainability?"

What do we want the resource to look like?

Discussion of the first question resulted in the following description of the resource: "A complex and interconnected system of physical habitat features accompanied by balanced nutrient and energy cycling and minimal amounts of chemical and bacteriological contamination. These habitats would support a diverse, self-sustaining, and resilient aquatic biological community dominated by native species."

The above description was derived from a perspective that connectivity, hydrology, and habitat quality all had two common themes, related in some way to provision of a "complex" set of habitat features "interacting" with each other. The water/sediment factors did not seem to fit with the idea of complexity; rather, they appeared to describe a sense of "balance" wherein individual constituents in the water do not overload the system. These habitat features would maximize opportunities to achieve the composition and functional characteristics associated with healthy biological communities.

What needs to happen to attain this vision of the Ohio River?

In discussing management, the group considered a series of "actions" rather than descriptors of a desirable state. Some of the major actions addressed and discussed in the workshop are listed below:

- Actions related to habitats:

  -Enhance fish passage around or through dams on the mainstem and tributaries.
  -Dismantle tributary dams and restore floodplain functions wherever feasible.
  -Reconnect and restore floodplains on the mainstem and tributaries.
  -Increase seasonal flooding in grasslands, bottomland hardwoods, and other habitats.
  -Maintain or restore tributary deltas and connections between rivers and embayments.
  -Protect existing aquatic habitats, restore lost habitat and diminished resources (woody debris, gravel, shallow nearshore wetlands and embayments, emergent and submergent vegetation, stable shoals, and spawning/nursery areas).
  -Protect or restore riparian habitat diversity, including islands, on the mainstem and tributaries.
  -Allow more natural flows to mimic natural regimes including seasonal and extreme floods and droughts.
  -Address runoff sources affecting aquatic nutrient balance: stormwater, nonpoint, CSOs and SSOs, and agricultural, including concentrated operations.
  -Minimize catastrophic contamination events through reduction of spills, accidents, and improvement of spill response procedures.
  -Continue remediation of CERCLA, brownfields, and other contaminated sites.

- Biological actions:

  -Reintroduce native fauna and expand the range and populations of native fauna from reduced levels.
  -Control exotics, including minimization of existing populations and prevention of new introductions.

- Policy/Procedural Actions:

  -Review and improve the consistency and effectiveness of regulatory actions and enforcement through review of state and federal regulatory processes, use of environmental Best Management Practices (BMPs) and better implementation of CWA.
  -Expand the role of ORSANCO participation on consistency issues, standards and state implementation, designated use attainment/agreement.
  -Conduct economic valuation of watershed functions and benefits.[1]

[1] Suggests an early AM need to assess the extent and value of environmental functions currently provided by the Ohio River and its riparian corridor, plus value of riparian, wetland, and aquatic habitats of tributaries. Helps establish a baseline for estimating environmental function values of restoration efforts.

-Expand the range of policy actions available to increase the public land base[2] or to effect changes in floodplain land use.
-Achieve collaborative arrangements among states, agencies, and landowners to accomplish equitable resources uses – human, recreation, and environmental functions.
-Identify and expand environmentally sound practices at locks, dams, and reservoirs.

- Communications actions:

-Improve/facilitate communications and processes with regulatory entities.
-Increase public awareness/appreciation or aquatic resource issues.
-Document standard operating procedures, EOPs, and BMPs and communicate to concerned institutions.

What are possible indicators of environmental sustainability?

The discussion of candidate indicators generated a broad spectrum of items as well as some initial efforts to organize the items and attendant issues. Some of the major items addressed and discussed in the workshop are listed below:

- Scientific Measures:
  - Baseline water quality and sediments (temporal)
  - Assimilation, analyses of information, and wide dissemination of data
  - Drinking water intake quality
  - Algal and Macroinvertebrate communities

- Composite Indicators of Sustainability:
  - Habitat data – quantity/quality and change over time
  - Designated use attainment
  - Acres of floodplain wetlands
  - Amount of shoreline development
  - People development (demographic shifts?)
  - Recreational pressures
  - Numbers of 404 permits, NPDES permits, and 401 certifications

- Monitoring Needs (related to "What knowledge gaps should be addressed to determine sustainability?")
  - Mussel monitoring
  - Watershed/trib data
  - Consistency with methodology and monitoring
  - Monitoring of larval fish/fish communities – ORFIn
  - Monitor shallow nearshore wetlands/embayments (acres)
  - Riparian vegetation monitoring
  - Genetic monitoring

[2] Land purchases, conservation easements, public/private management agreements, revisions to Conservation Reserve and related programs to maximize areas available for changes in floodplain land use and related habitat restoration efforts.

13.9.4 Riparian Sustainability Workshop

While workshop guidelines were similar to those used for the aquatic exercise, the riparian guidelines reflected some changes resulting from feedback from the original session. Most notably, the discussion questions expanded from the original 3 to the 5 topics summarized here:

1) What do we want the resource to look like?"
2) What must we have to increase riparian sustainability?
3) What specifically needs to be done in riparian habitats in urban areas?
4) What must be measured or monitored to determine sustainability (i.e., indicators)?
5) What actions should be taken or tools used to increase riparian sustainability?

What do we want the resource to look like?

Nearly 40 responses were made to this question, although some responses were similar or overlapping. Initially, all inputs were categorized as relating either to functions of riparian areas or to management opportunities/strategies to protect or improve riparian areas.

The three riparian functions and examples of group responses related to these functions are:

1) Providing diverse habitats – e.g., maintain and create islands, no exotics, revegetate floodplains with native species, diversify wildlife habitat
2) Promoting biogeochemical processes and nutrient cycling – e.g., functioning wetlands, 100+ meter buffer strips to intercept pollution
3) Providing hydrological connections and sediment cycling –e.g., take out or move back levees, mimic natural flows, keep existing islands stable.

Several of the group's responses potentially pertained to all three riparian functions and emphasize the complex, interrelated nature of riparian components. Such responses included restoration of identified degraded sites, floodplain function in whole system context, and presence of floodplain within each pool.

Responses categorized as "management" provided general guidelines for moving Ohio River riparian/floodplain resources in a more sustainable direction. Examples of such responses included allowing minimal floodplain development, acquiring more public lands and refuges, promoting conservation programs on agricultural lands, and creating partnerships and other institutional relationships to improve sustainability.

Combining the group's responses, the following was developed in answer to the question of what the group wants the riparian resource to optimally look like:

> Riparian resources along the Ohio River will form an integrated natural system that attains key functions related to habitat diversity, biogeochemical processes and nutrient cycling, and hydrological connectivity and sediment dynamics.

Such an integrated riparian system would be characterized by functional buffer strips, healthy wetlands, vegetation dominated by diverse native species, and the

enhancement and stabilization of islands. To attain this goal would require limits on floodplain development, more land in public ownership and conservation easements, linkages among fragmented habitats, and more natural flood regimes.

What are the critical needs that must be met to improve riparian sustainability?

Responses to this question included ideas to enhance riparian functions (e.g., increase forest cover) and management strategies (e.g., limit human encroachment through zoning). However, the group acknowledged the necessities of sufficient funding and cohesive institutional management and oversight. These are key elements of an AM program.

What specifically needs to be done in riparian habitats in urban areas?

The responses to this question included physical removal of manmade structures, increased public awareness, and more public ownership and management of urban riparian resources. A strong interest in riverfront projects (parks, multi-purpose facilities, entertainment complexes, etc.) was expressed. Most urban areas either have such projects already or they are in progress. Lack of public understanding and limited education on the benefits of riparian areas hamper improvements to urban riparian areas, but recent public facilities along the riverfront afford opportunities for education and heightened public awareness.

There was a consensus that increased sustainability of urban riparian resources will require careful balancing between land use and recreation use, on the one hand, and maintenance of riparian functions, on the other.

What must be measured or monitored to determine sustainability?

Responses to this questions included acreages of public lands, wetlands, etc., vegetation assessments (e.g., canopy cover, diameter breast height for trees), numbers of certain species, (e.g., nesting birds or amphibians) and various indices of biological assessment (IBIs). A potential tool to evaluate riparian conditions might be developed that is analogous to the Qualitative Habitat Evaluation Index (QHEI) developed for streams. Analyses of trends, riparian stability, and functions were also mentioned as measures of sustainability. Such trend analyses should continue into the future with historic data for key indicators, when available.

What actions should be taken or tools used to increase riparian sustainability?

Responses ranged from implementing specific actions (e.g., developing pool-by-pool masterplans and restoring islands) to actions aimed at establishing working relationships toward common goals (e.g., identification of stakeholders, public commitment) and procuring adequate funding.

Sustainability group members agree that communication is key to attaining goals for Ohio River riparian areas. Not only must public awareness of the importance of riparian areas be heightened, but communications with regulatory agencies and institutions must be strengthened in regard to principles of sustainability, conservation BMPs, and the Corps'

EOPs. An annual or biannual symposium on Ohio River sustainability and AM was suggested as a catalyst/tool to meet communication needs.

13.10 PLANNING FOR ADAPTIVE MANAGEMENT OF THE OHIO RIVER SYSTEM

Developing and implementing an AM program for the Ohio River system could occur over time through the efforts of many stakeholders, but would be unlikely to occur in a focused way unless several key elements formed a framework for action. Those elements include:

- authorization of an agency or organization to initiate an AM program, provide continuity, and ultimately assume responsibility for the program's implementation
- formation of a broadly representative stakeholder group, including members that would identify and conduct monitoring and other tasks and would be capable of recommending management adaptations in response to monitoring outcomes and other data, and
- funding to institute and sustain the program over the long term.

As mentioned previously, the IWG from ORMSS could be an important asset in organizing an AM stakeholders' group which could also include participants from the aquatic and riparian sustainability workshops. Further, a special symposium at forums such as at the ORBCRE could serve as a springboard for the effort.

13.11 CONCLUSIONS

This chapter emphasizes the vital importance of an AM program to continued operation of the Ohio River Navigation System in an environmentally sustainable manner. Further, an AM program and associated monitoring efforts are essential to successful ecosystem restoration of the Ohio River and its watershed. An AM program not only could confirm impacts of restoration efforts, document what works and monitor progress, but also could accomplish restoration objectives with the efficient allocation of available resources. Finally, integrating AM and monitoring into the everyday planning and operation of the Ohio River navigation system could contribute to the Corps continuing to grow as an innovative federal agency in partnership with other entities (private and public) that actively provides leadership and works toward environmental sustainability.

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Exhibit A
PROCEDURE AND METHODS

A.1. OVERVIEW

This chapter describes the procedure and four methods used in conducting this study. The first section summarizes an 11-step procedure, promulgated by the CEQ, for planning and conducting impact studies of cumulative effects. The four methods are addressed in the next four sections of this chapter. The methods that were developed and used include a continuous scoping process; matrices that relate the potential impacts of reasonably foreseeable future actions (RFFAs) to 12 valued environmental components (VECs) and their subcomponents; and an analysis approach for determining the past, present, and future ES conditions of the VECs and subcomponents. The fourth method relates to delineating environmental sustainability (ES) needs; it includes the use of a substantive area expert group to identify ES needs for specific VECs; further, addressing the needs can include mitigation for previous effects (ecological restoration), mitigation for future effects related to RFFAs, monitoring, and an adaptive management strategy integrated across pertinent VECs. Work related to this method has not been initiated; however, due to the fact that completion of this work is beyond the scope of this study, the included information should be viewed as only providing an initial conceptual framework for these efforts. The first method (continuous scoping) relates to all 11 steps in the CEQ procedure, while the RFFA matrices relate to steps 4, 8, and 9. The analyses of ES encompass information and considerations from steps 5 through 9. Lessons learned from the application of the first three methods are described in their respective sections. The method for ES needs relates to steps 10 and 11.

A.2 CEQ PROCEDURE

The CEA study within the ORMSS has been conducted based upon an 11-step methodology promulgated by the Council on Environmental Quality (1997). Steps 1 to 4 relate to scoping, Steps 5 to 7 to describing the affected environment, and, Steps 8 to 11 to determining the environmental consequences. The specific steps and how they were addressed are as follows:

- Step 1 – Identify the significant cumulative effects issues associated with the proposed action and define the assessment goals. This step was based upon the identification of the typical impacts associated with the construction and operation of navigation system locks and dams, and their repair and rehabilitation and periodic maintenance activities. Public scoping meetings were held along with several meetings of a 40-person Interagency Working Group (IWG). The membership of the IWG consisted of representatives from several federal and state agencies responsible for environmental and natural resources management, and three non-governmental organizations. The IWG has participated throughout the CEA study. The initial scoping in Step 1 provided the basis for the identification of

12 VECs of concern. The VECs included aquatic ecological resources (water and sediment quality, mussels, and fish), riparian and floodplain ecological resources (floodplain hydrology, terrestrial habitat, wetlands, islands, and soils and geology), threatened and endangered species (fish, mussels, mammals, birds, and plants), air quality, recreational uses of the River, noise, aesthetics, human health and safety, cultural resources, transportation and traffic, land use, and socioeconomic resources (including environmental justice).

- Step 2 – Establish the geographic scope for the analysis. The scope for the majority of the identified cumulative effects issues and related VECs consisted of the mainstem of the Ohio River along with its 500-year floodplain. Due to data availability on actions, resources, and impacts, the geographic scope often focused on the mainstem and the contiguous counties in the six states along the mainstem.

- Step 3 – Establish the time frame for the analysis. The selected time frame was typically from 1920 to 2060 for most VECs. The earlier date coincides with the initiation of locks and wicket dams on the Ohio River mainstem. The latter date reflects the economic study period for the system investment plan (SIP). One exception for this time frame was the inclusion of information on much earlier cultural properties for the cultural resources VEC.

- Step 4 – Identify other actions affecting the resources, ecosystems, and human communities of concern. As noted in the cumulative effects definition in Chapter 1, "other actions" include past, present, and reasonably foreseeable future actions (RFFAs). To facilitate these identifications and their potential effects, a series of 22 RFFA matrices were developed. The 22 matrices encompassed the 12 VECs and their subcomponents as delineated in Step 1. The RFFAs, which also included similar past and present actions, were defined as:

  Actions identified by analysis of formal plans and proposals by public and private entities that have primary (direct) or secondary (indirect) impacts on VECs associated with the Ohio River. RFFAs also include potential actions that are beyond mere speculation when incorporated in plans or documents by credible private or public entities. RFFAs may also include events forecasted by trends, probable occurrences, policies, regulations, or other credible data that may have bearing on the VECs.

  A total of 87 types of RFFAs were identified and considered in the analyses; the types were divided into six categories: navigation investment actions, other Corps actions, "but for" actions (actions that would not occur "but for" the existence of the navigation system), actions by others, natural disasters, and regulatory environment. Each listed RFFA was characterized in terms of its anticipated time period of occurrence, probability of occurrence, and location on the River. The anticipated effects of each RFFA on each VEC or subcomponent were described in "smart cells" using Microsoft® Excel spreadsheets. Finally, the importance (high, medium, or low) of each RFFA relative to cumulative effects on each VEC or subcomponent was also described in "smart cells"

- Step 5 – Characterize the resources, ecosystems, and human communities identified in scoping in terms of their response to change and capacity to withstand stresses.

This step was based upon an analysis of environmental sustainability (AES) for the pertinent VECs or subcomponents. The AES approach was comprised of four parts: (1) identification of "common effects" on the VEC or subcomponent thereof from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix (Step 4 above); (2) selection of indicators of ES for the VEC or subcomponent thereof, and their tiered grouping, as appropriate; (3) description of the "connections" between the common effects (and related High and Medium importance RFFAs) and the indicator groups; and (4) assignment of a "bottom line" category to the ES of the VEC or subcomponent, based on considering the past, present and future conditions. The ES categories included "not sustainable", "marginally sustainable", and "sustainable". Specific ES definitions were developed for each VEC or subcomponent (they will be illustrated below for water quality/sediment quality).

- Steps 6 and 7 – Characterize the stresses affecting these resources, ecosystems, and human communities and their relation to regulatory thresholds; and define a baseline condition for the resources, ecosystems, and human communities. These two steps were addressed jointly for each VEC or subcomponent. The approach consisted of identifying historical and current laws, regulations, ordinances, and programs that contain regulatory thresholds and/or policies related to the VEC or subcomponent. Then, historical reference point and trends information, along with current conditions, were summarized for the indicators of ES for the VEC or subcomponent. Numerous information sources were reviewed for Steps 6 and 7. Further, the institutional information and environmental conditions and compliance with regulatory thresholds served as the basis for the categorization of the past and present ES for the VEC or subcomponent.

- Step 8 – Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities. This step was largely accomplished through the development of the RFFA matrices as described in Step 4. Further, peer-reviewed literature, various governmental studies and reports, and impact-study related and resource-management related books were used to more thoroughly document numerous relationships. Attention was also given to various relationships between VECs and subcomponents (e.g., what are the implications of changes in water quality on the populations of mussels in the River?).

- Step 9 – Determine the magnitude and significance of cumulative effects. Due to limited data on specific impacts from various actions, and to the system-wide focus of the CEA study, it has not been possible to quantitatively determine the magnitude of the cumulative effects on the VECs and subcomponents. Rather, a qualitative determination was made based on the AES approach described in Step 5. The significance of the cumulative effects was ascertained via compliance or noncompliance with regulatory thresholds, and the consideration of the connections between common effects and indicators of ES. The assigned categories of ES for the past, present, and future represent the composite significance determination for the cumulative effects on each VEC or subcomponent.

- Step 10 – Modify or add alternatives to avoid, minimize, or mitigate significant cumulative effects. This step has been addressed via the identification of generic

mitigation measures for many of the analyzed actions, with particular attention being given to such measures for navigation investment actions by the Corps. In addition, various regulatory programs that have facilitated, or are expected to emphasize, generic mitigation measures for numerous actions have also been identified and incorporated in the analysis. Further, the fourth methods described in this chapter delineates a process used to identify various mitigation and other ES needs for aquatic ecological and riparian/floodplain ecological resources.

- Step 11 – Monitor the cumulative effects of the selected alternative and adapt management. This step has been addressed in a systematic manner for each VEC and subcomponent. The key criteria that are being used to "trigger" Step 11 are the past, present, and future ES categories for the VECs and subcomponents. If the VEC or subcomponent is currently "sustainable", and this is expected to continue into the future, only targeted additional monitoring over that currently being done is recommended, and no specific adaptive management strategy will be developed. For VECs or subcomponents that are currently categorized as "not sustainable", or "marginally sustainable", specific collaborate monitoring will be recommended along with an appropriate adaptive management strategy.

An early activity in this study involved the development of detailed work plans for each of the 12 VECs, including their respective subcomponents. The 11 steps of the CEQ procedure served as the conceptual basis for each work plan. The generic topics addressed in each work plan included:

- Definition of the VEC and its subcomponents
- Information sources related to the VEC and its subcomponents
- Overview of work plan (related to the CEQ's 11-step procedure)
- Phase 1: Identify "scope" of the VEC study
  - -- CEQ Steps 1 and 4. Identify the typical impact issues related to direct actions by the Corps, and identify other actions that also impact the same VEC and its subcomponents
  - -- CEQ Step 2. Identify the geographic boundaries
  - -- CEQ Step 3. Select the time frame
  - -- Select indicators for the VEC and its subcomponents
  - -- CEQ Step 8. Identify cause and effect relationships between past, present, and RFFAs and their adverse effects on the VEC and its subcomponents
  - -- Identify management goals for the VEC and its subcomponents and who is responsible
- Phase 2: Describe historical baseline and current conditions

- -- CEQ Step 7. Develop anecdotal and institutional information on the historical baseline

- -- CEQ Steps 5 and 6. Characterize the potentially affected VEC and its subcomponents in terms of their response to change and capacity to withstand adverse impacts, and characterize current (existing) stresses and their relationship to regulatory thresholds

- -- Consider the identification of special stressed zones or protection zones within the geographic boundaries

- -- Delineate criteria to consider in establishing the significance of particular cumulative effects

- Phase 3: Determine magnitude and significance of cumulative effects on the VEC and its subcomponents

  - -- CEQ Step 9. Determine the magnitude and significance of cumulative effects on selected indicators of the VEC and its components (included consideration of "best current practice" methods for qualitatively or quantitatively expressing the cumulative effects)

  - -- List the significant cumulative effects and describe the bases for their classification

- Phase 4: Develop mitigation/monitoring programs (as appropriate)

  - -- CEQ Step 10. Modify or add alternatives to avoid, minimize, or mitigate significant cumulative adverse effects on selected indicators of the VEC and its subcomponents

  - -- CEQ Step 11. Monitor the significant cumulative effects on the VEC and its subcomponents, and adapt management as appropriate

- Phase 5: Prepare specific outline and chapter on the process, and findings for the VEC and its subcomponents

- Appendices of policy and related information (as appropriate) from the Corps' Planning Guidance Notebook (ER 1105-2-100).

The emphasis in the assemblage of pertinent information was on the preparation of chapters that coincided with individual or combined VECs, or their subcomponents. The work plans provided a framework for both the assemblage and analysis of the pertinent information. The typical topical contents of these substantive chapters included:

- Definition of VEC and its Subcomponents

- Objectives and Scope of the VEC Study

- Issues from Scoping
- Indicators of Environmental Sustainability
- Laws, Regulations, Ordinances, and Programs
- Past to Current Baseline Conditions for the VEC and its Subcomponents
- Special Information Related to the Ohio River
- Interactions with Other VECs
- Relevant Actions Affecting the VEC and its Subcomponents
- Cumulative Effects and Environmental Sustainability
- Summary and Conclusions
- References

As the CEA study progressed, it was soon realized that research studies, surveys, or data gathering efforts would be necessary. Following is a list of these activities conducted to support this CEA study:

- Survey of lipid and fatty acid composition in paddlefish, white bass, and sauger collected from six navigation pools (Hannibal, Belleville, Greenup, Meldahl, Cannelton, and Smithland) -- the results are noted in Chapter 6. Reference -- Wells, M. J., "Ohio River Mainstem Systems Study - Fatty Acid Investigation", draft, September 30, 2003, Tennessee Technological University, Cookeville, Tennessee.

- Study of various engineering and hydraulic factors related to Ohio River locks and dams, along with fish swimming velocities of 44 target species, to ascertain upstream fish passage opportunities at the mainstem dams -- the results are summarized in Chapter 6. Reference -- Knights, B. C., J. H. Wlosinski, J. A. Kalas, and S. W. Bailey, "Upstream Fish Passage Opportunities at Ohio River Mainstem Dams", 2003, U. S. Geological Survey, Upper Midwest Environmental Sciences Center, La Cross, Wisconsin.

- Study of winter habitat types used by fishes in the Smithland and Belleville navigation pools, and comparison of the results between the downstream and upstream pools -- the results are summarized in Chapter 6. Reference -- Garvey, J. E., S. Welsh and K. J. Hartman, "Winter Habitat Use by Fishes in Smithland Pool and Belleville Pool, Ohio River", 2003, Prepared by the Fisheries and Illinois Aquaculture Center, USGS, and WV Cooperative Fish and Wildlife Research Unit, Southern Illinois University, Carbondale, Illinois.

- Survey of glochidial infestation on Ohio River fish species -- the results are noted in Chapter 6. Reference -- O'Bara, C. J., "Presence of Glochidial Infestation on Ohio River Species", draft, March, 2004, West Virginia Division of Natural Resources, Parkersburg, West Virginia.

- Survey of fish community structures with lock chambers in relation to tailwater fish communities, and short-term movement patterns of targeted species at the Winfield locks and dam on the Kanawha River -- the results are noted in Chapter 6. Reference -- O'Bara, C. J., "Fish Passage: Direct Observations", draft, March, 2004, West Virginia Division of Natural Resources, Parkersburg, West Virginia.

- Study of fish movement in the middle Ohio River region based on fish tagging and tag return data -- the results are summarized in Chapter 6. Reference -- O'Bara, C. J., "Fish Tagging and Recovery", draft, March, 2004, West Virginia Division of Natural Resources, Parkersburg, West Virginia.

- Description and results of creel surveys (recreational angling) conducted in 2002 in the tailwaters of upper River locks and dams -- the results are summarized in Chapter 4. Reference -- O'Bara, C. J., "Recreational Fishery Survey", draft, March, 2004, West Virginia Division of Natural Resources, Parkersburg, West Virginia.

- Composite results of fish research -- the findings are summarized in Chapter 6. Reference -- O'Bara, C. J., "Fish Passage Issues Associated with Ohio River High Lift Dams", draft, April, 2004, West Virginia Division of Natural Resources, Parkersburg, West Virginia.

- Compilation of basic literature and historical data on mussel species in the navigation pools of the Ohio River mainstem -- the findings are summarized in Chapter 5 -- Reference -- Watters, G. T., T. Cavender, C. Myers, M. Kibbey, V. Gordon, B. Pittinger and T. Pohlman, "Fish Passage Study, Product 3: Distribution of Mussels and Fish within the Ohio River (including Ohio River Mussel Database CD)", 2003, Ohio State University, Columbus, Ohio.

- Review and analysis of the Corps ' statutory authorities, policies, regulations and guidance for mitigation of historical environmental damages from Corps projects and actions by others, and for mitigation of proposed Corps projects, plans, and/or programs -- the results are summarized in this chapter. Reference -- Canter, L. W., "Identification and Analyses of U. S. Army Corps of Engineers Policies and Procedures Related to Retrospective Mitigation (Ecosystem Restoration) and Prospective Mitigation", September, 2003, Horseshoe Bay, Texas.

- Hydrogeomorphological survey of islands in the Ohio River mainstem -- the results are noted in Chapter 7, Reference -- Spoor, M., Huntington District, U. S. Army Corps of Engineers.

- Collection of data on bottom substrates and bathymetry for navigation pools in the middle to upper Ohio River mainstem -- the results will be used in NAVPAT

modeling, and the findings will be incorporated in Chapter 6. Reference -- Siemsen, T., Louisville District, U. S. Army Corps of Engineers.

- Several databases have been developed from these studies; they include a spatial database for historic mussel and fish distribution, fish tagging studies, and angler use surveys. The NAVPAT field data could also be placed in a database. Each of these databases are intended to be made available in a user-friendly CD.

- Finally, although not a part of this CEA study, the Corps is preparing a Section 7 biological assessment related to navigation system operational practices and effects on threatened or endangered plant and animal species within or nearby the Ohio River mainstem.

A.3 CONTINUOUS SCOPING PROCESS

The use of a targeted scoping process is critical to the successful planning and completion of time-efficient and cost-effective CEA studies for programmatic-level plans. Accordingly, the components of the scoping process for the CEA study and associated PEIS for the Ohio River navigation SIP are described herein. Four subsections are included. Fundamental information on the principles and practices related to the scoping process in the first subsection. The second subsection highlights six components of the utilized scoping process. The third subsection illustrates how information from the process was utilized in planning and conducting the CEA study. Finally, the fourth subsection enumerates the conclusions and lessons learned regarding cumulative effects scoping for this SIP/PEIS.

A.3.1 Background on Scoping

Scoping refers to an early and open process for determining the scope of the impact study and the significant issues to be addressed in an EIS or PEIS. This process was incorporated in the NEPA regulations promulgated by the CEQ in 1978 (Council on Environmental Quality, 1978). “Early” suggests that the process will occur during the initial stages of planning a PEIS, although scoping can continue throughout a study, particularly for programmatic-level studies such as this navigation system study that incorporates increased emphasis on themes such as CEA and environmental sustainability (U.S. Army Corps of Engineers, 2002 and 2003). “Open” denotes that the process provides the opportunity for participation by affected federal agencies, state and local governments, Indian tribes, environmental nongovernmental organizations (ENGOs), development entities, and various other publics (stakeholder groups and individuals).

The scope of the study is related to the range of actions, alternatives, and impacts to be addressed in the PEIS (Council on Environmental Quality, 1978). Other than unconnected single actions, the range of actions can include “connected actions” to the original proposal, and “cumulative actions” and “similar actions” which can affect common environmental features. The range of alternatives are to include the “no action” alternative (this could be a continuation of current practices or a no project option), other reasonable courses of action to meet the identified needs, and the proposed action with add-on mitigation measures not included in the original concept and design. The range of impacts should include the direct and indirect impacts of the proposed action and

alternatives, as well as the cumulative impacts of past, present, and reasonably foreseeable future actions on common resources, ecosystems, and human communities.

Generic objectives for the scoping process include (Council on Environmental Quality, 1981): (1) to identify the affected public and agency concerns; (2) to facilitate an efficient PEIS preparation process, through assembling the cooperating and pertinent agencies, assigning writing tasks, ascertaining all the related permits and reviews that must be scheduled concurrently, and setting time or page limits; (3) to define the issues and alternatives that will be examined in detail in the PEIS while simultaneously devoting less attention and time to issues which cause no major concern; and (4) to save time in the overall NEPA process by helping to ensure that the draft PEIS adequately addresses relevant issues, reducing the possibility that new comments will cause a statement to be rewritten or supplemented. A thorough scoping process provides the necessary basis for allocation of time and funding to address truly important resource issues. These generic objectives are being accomplished via the multi-component scoping process being used in this CEA study and the related SIP/PEIS.

An important principle related to the scoping process is that it should be uniquely designed for each impact study. The process itself can incorporate multiple features such as conducting a series of scoping meetings, telephonic and/or e-mail surveys of the perspectives of various agency and public stakeholders regarding the necessary scope, soliciting written comments from various stakeholders regarding the scope and significant issues to be addressed, and completing research studies and literature-based policy/scientific reports on potentially affected resources, ecosystems, habitats, and protected species. Each of these features has been incorporated in the continuing scoping process for this CEA study on the navigation SIP/PEIS.

Another approach that can be used in the scoping process is for the lead agency (i.e., the Corps) to identify and formally establish one or more cooperating agencies relative to preparing the SIP/PEIS. Cooperating agencies may include other federal agencies that have “jurisdiction by law” or “special expertise” relative to the potential impact issues to be addressed. Duties of the lead agency in this matter include (Council on Environmental Quality, 1978): (1) requesting the participation of each cooperating agency at the earliest possible time; (2) using the environmental analyses and proposals of cooperating agencies with jurisdiction by law or special expertise, to the maximum extent possible consistent with its responsibility as lead agency; and (3) meeting with cooperating agencies at their request. The duties of cooperating agencies include (Council on Environmental Quality, 1978): (1) participating in the scoping process; (2) assuming on request of the lead agency responsibility for developing information and preparing environmental analyses, including portions of the PEIS concerning which the cooperating agency has special expertise; (3) making available staff support at the lead agency’s request to enhance the latter’s interdisciplinary capability; and (4) normally using its own funds. However, the lead agency shall, to the extent monetary resources are available, fund those major activities or analyses it requests from cooperating agencies.

The Corps considered inviting one to several cooperating agencies for the environmental studies conducted under the ORMSS; however, an alternate strategy that involved the establishment of an Interagency Working Group (IWG) was utilized. The IWG includes several members from federal agencies that could have been invited to be

cooperating agencies. The specific involvements of the IWG in this case study are described in the next two subsections.

Specific scoping-related duties of the lead agency, that the Corps has fulfilled, include (Council on Environmental Quality, 1978):

- Invite the participation of affected federal, state, and local agencies, any affected Indian tribe, the proponent of the action, and other interested persons (including those who might not be in accord with the action on environmental grounds).

- Determine the scope and the significant issues to be analyzed in depth in the PEIS.

- Identify and eliminate from detailed study the issues which are not significant or which have been covered by prior environmental review, narrowing the discussion of these issues in the PEIS to a brief presentation of why they will not have a significant effect on the human environment or providing a reference to their coverage elsewhere.

- Indicate any public EAs and other EISs that are being, or will be, prepared that are related to but are not part of the scope of the PEIS under consideration.

- Identify other environmental review and consultation requirements so the lead agency may prepare other required analyses and studies concurrently with, and integrated with, the PEIS.

- Indicate the relationship between the timing of the preparation of environmental analyses and the agency's tentative planning and decision making schedule.

The most widely used approach in the scoping process involves public and agency-specific meetings with interested and/or pertinent stakeholders. Multiple benefits can accrue from such meetings and the related information exchange. For example, some of the best effects of the scoping process stem from the fact that all stakeholders have the opportunity to meet one another and to listen to the concerns of the others. If there is any possibility that an early resolution of underlying conflicts may be achieved, this can be enhanced by the development of personal and working relationships among the stakeholders. Further, stakeholders typically appreciate the opportunity of participating in the planning and review process (Council on Environmental Quality, 1981). The key person in various types of face-to-face meetings is the moderator (or impact study team leader) from the lead agency. The person should be focused on both communicating information about the study and soliciting related information and viewpoints from the participants.

Another feature of the scoping process is that the lead agency must consider and evaluate various inputs regarding the study scope and significant issues, and then make determinations of what will be addressed in the study and what will be eliminated or set aside for future consideration. The process of selection, elimination, or set-aside should be carefully documented, perhaps within a "scoping report" that could be included as an Exhibit in the Cumulative Effects Report or the Programmatic Environmental Impact Statement. The more extensive scoping report could be used to develop a summary of the

scoping meetings that could be provided, via traditional mail or e-mail, to all of the participants. This documentation and dissemination was incorporated in the process for this case study, with the resultant reports included in Exhibit A.

While the scoping process is often described in a step-wise manner, in reality, scoping is an iterative process. Throughout all phases of a study, previously unidentified concerns are discovered or policies/guidance are changed. It is essential that study teams recognize these events and factor them back through the process to ensure that the final document reflects the most up-to-date information. This was done in this case.

Finally, many practitioners consider the scoping process to be the most critical phase in the preparation of a PEIS. Examples of the potential benefits of a successful process include the possibility that real problems are identified early and properly studied; that issues that are of no concern do not consume time and effort; that major potential conflicts can be addressed up-front and potentially resolved; that the draft PEIS is balanced and thorough; and that the delays occasioned by re-doing an inadequate draft are avoided (Council on Environmental Quality, 1978).

A.3.2 Components of the Scoping Process

The scoping process for the CEA and the SIP/PEIS for the Ohio River navigation study was characterized by multiple components, with several extending from the early planning stage to the completion of the SIP/PEIS. **Table A-1** provides a brief synopsis of the six components and their key functions in relation to the entire scoping process. Each component is described in the following portions of this subsection.

TABLE A-1
Components of the Scoping Process

Component	Key Functions
Central Planning Team (CPT)	Provided leadership to the entire scoping process; including educational features related to CEA; interactions with the OB and IWG; development of VECs, RFFAs, methods, and AES; and analyses of received information.
Steering Committee --- Oversight Board (OB)	Provided policy advice and overall approvals for scheduling and budgetary matters for the entire ORMSS.
Interagency Working Group --- (IWG)	Provided scientific and/or policy advice to the CPT; aided in identifying research needs; participated in the completion of RFFA matrices, the identification of indicators for AES, and the delineation of ES needs; and reviewed various study documents.
Scoping Meetings --- Agencies and General Public	Provided input on the scope of the CEA study and related SIP/PEIS, including the identification of cumulative effects concerns and contributory actions to these concerns.
Questionnaires	Provided input on past actions and effects on aquatic and riparian ecological resources, the relative importance of the 12 VECs, and future concerns and management approaches.
Informational Website	Contained information on the ORMSS, public meetings, and the results of the scoping meetings; used by individuals to request further information on the issues of concern.
Notes: CEA = cumulative effects assessment, VECs = valued environmental components RFFAs = reasonably foreseeable future actions, AES = analysis of environmental sustainability,	

A.3.2.1 Central Planning Team

The Central Planning Team (CPT) was comprised of seven members, including three persons from the Corps and four persons from an environmental consulting firm. The disciplinary backgrounds include three biologists, one environmental engineer, one environmental scientist, one landscape architect, and one political scientist/planner. Regarding their experience with impact studies, one CPT member has over 30 years experience, three have from 15 to 25 years experience, and three have about 5 years experience each.

The CPT met every 2 to 3 months for the purposes of determining the timing and budgetary status of work-in-progress, conducting joint planning for specific future work elements and the overall connections between the CEA study and the SIP/PEIS, and jointly reviewing draft chapters, sections within chapters, and appendices. The need to develop a method or process for completing a task or for transitioning from one task to another was frequently identified, and such tools or methods were proposed, developed, tested, and refined during the meetings. These periodic meetings have proven to be invaluable due to the broad nature of the SIP/PEIS, and the use of CEA as a means of integrating the effects of multiple actions on environmental features within the study area.

The CPT has provided leadership related to other components of the scoping process, as well as the leadership for continuing efforts. More specifically, the CPT has:

- Developed an overall CEA and SIP/PEIS study plan based upon an 11-step CEA procedure described by the CEQ (Council on Environmental Quality, 1997) and the requirements for PEISs in the NEPA regulations (Council on Environmental Quality, 1978).

- Conducted several information gathering activities related to the history of mainstem developments and aquatic and riparian resources of the Ohio River; such activities included Internet surveys and traditional literature searches, telephonic and e-mail requests for information, reviews of numerous Corps reports related to the environmental effects of locks and dams and lock expansions, and reviews of research reports and surveys of natural and environmental resources prepared by others.

- Identified 12 Valued Environmental Components (VECs) within the study area that were subject to cumulative effects, and prepared work plans for each VEC based upon the above-noted 11-step CEA procedure.

- Planned the agendas for periodic meetings with the IWG, and provided study updates and educational components for these meetings.

- Planned and conducted 12 scoping meetings at 6 locations along the Ohio River mainstem, and prepared a summary report (see Exhibit A).

- Developed a questionnaire for solicitation of input on the overall study and the relative importance of the 12 VECs. The questionnaire was used in the scoping meetings and made available on an ORMSS website. Further, the CPT prepared a summary of the questionnaire results (see Exhibit A).

- Developed and periodically updated an overall ORMSS website for the purpose of providing summary information on the features of the study and related presentations.

- Prepared draft chapters, sections, and appendices for the CEA study that have been reviewed by the IWG. Examples of such products that have been distributed include the summary report of public scoping meeting, an Exhibit on the development and completion of RFFA matrices, and chapters on the VECs or their subcomponents.

- Conducted "situational awareness" reviews of the CEQ's handbook on conducting CEAs (Council on Environmental Quality, 1997), a related large-scale navigation study on the Upper Mississippi River System (including a review of that study by the National Academy of Science and subsequent guidance from Corps Headquarters), and the U.S. Army Chief of Engineers' (Corps) Environmental Operating Principles. These reviews provided a useful context for this case study.

A.3.2.2 Steering Committee

A steering committee can provide valuable inputs during the conduct of programmatic impact studies. For the ORMSS, the steering committee was the Oversight Board (OB), which is a 14-person group comprised of Corps management-level professionals from the pertinent geographical Division and three involved Districts. The OB meets quarterly and conducts monthly teleconferences. It provides leadership direction relative to the overall ORMSS; such direction includes scheduling, budgetary approvals and adjustments, reviews of work-in-progress, and periodic policy decisions relative to topical issues and related intra- and inter-agency coordination and collaboration. Two of the Corps members of the CPT routinely interact with the OB.

A.3.2.3 Interagency Working Group

The IWG consists of approximately 40 members representing federal and state agencies with responsibilities for environmental management, as well as several ENGOs. Six members were from the U.S. Fish and Wildlife Service, with one serving as the coordinator for the USFWS group; two were from the U.S. Geological Survey; and one was from the U.S. Environmental Protection Agency. In addition, the Ohio River Valley Sanitation Commission (ORSANCO), a federally chartered compact among several states in the Ohio River drainage, had two representatives on the group. Members from ENGOs include one person from the Sierra Club, one from the Ohio River Foundation, and two from The Nature Conservancy. The remaining members are from natural resources or environmental management agencies in the six states bordering the Ohio River. The IWG had two to three meetings annually with the CPT. These one-day joint meetings included information dissemination and updates related to the status of the CEA study, status reports on specific research projects, and working sessions on integrative topics such as impact

matrices for RFFAs, and indicators and a process for analyses of environmental sustainability (AES).

More specifically, the IWG has fulfilled the following purposes:

- Aided in identifying key issues and cumulative effects that should be addressed in the CEA study.

- Assisted the CPT in delineating and prioritizing key research needs relative to environmental issues and natural resources. Examples of completed research include fish passage studies at selected locks, determination of winter habitat requirements for selected fish species, and surveys of freshwater mussel populations at various river locations. In addition, the IWG has reviewed the completed research reports.

- Participated in the completion of RFFA matrices for VECs and their subcomponents related to aquatic ecological resources, floodplain/riparian ecological resources, and threatened/endangered/protected species.

- Reviewed work plans for addressing cumulative effects on the 12 VECs and their subcomponents; in addition, reviewed the identified methods and procedures relative to "best practice tools" for the specific issues and cumulative effects to be addressed. It should be noted that "best practice tools" infer both scientific validity and cost-effectiveness relative to their application.

- Conducted systematic reviews of draft chapters and appendices for the CEA study report and the SIP/PEIS.

- Provided periodic and continuing scientific information on emerging issues; examples include the incorporation of the environmental sustainability analyses and the need to consider nonstructural measures for navigation traffic management, along with proactive repair and rehabilitation of existing locks and dams, and lock extensions.

- Participated in the planning and implementation of a coordinated and collaborative long-term strategy for environmental monitoring and adaptive environmental management for the aquatic and floodplain/riparian ecological resources within and along the Ohio River mainstem. In fact, the IWG could become part of a long-term decisionmaking structure and process related to enhancing the environmental sustainability of key resources.

In summary regarding the OB and IWG, both provide the CPT with valuable scientific information and advice. Further, mutual education and continuing networking is occurring among the OB and CPT, and the IWG and CPT. The "buy-in" of various governmental agencies and ENGOs to the study process was achieved via a healthy dialogue. Negative perceptions related to the role of committees are typically associated with the logistics and costs regarding meetings, the roles and limits of such committees in decisionmaking processes, and the creation of unmet expectations for all involved persons. However, these negative perceptions were greatly exceeded by the benefits noted above.

As a result, the two committees in this study facilitated more time-efficient and cost-effective impact studies related to the ORMSS.

A.3.2.4 Scoping Meetings

Twelve public scoping meetings were held during the summer of 2001. Two meetings each were held in smaller cities in the six contiguous states to the Ohio River (Metropolis, Illinois; Evansville, Indiana; Parkersburg, West Virginia; Monaca, Pennsylvania; Covington, Kentucky; and Portsmouth, Ohio). At each location, an afternoon meeting was held with representatives of governmental agencies, and an evening session was held for the general public. Each of the meetings was announced via a notice in the Federal Register, press releases to local newspapers, mailings to all addresses on the ORMSS mailing list, and legal ads in major regional newspapers. More than 50% of the attendees at the afternoon sessions were from federal and state resource or regulatory agencies, with the remainder from public agencies and some business groups. Approximately 50% of the evening attendees were interested citizens, with the other 50% being from businesses, the navigation industry, environmental groups, the media, and governmental agencies. Some elected officials attended either afternoon or evening sessions.

A brochure entitled "Ohio River Mainstem Systems Study – Cumulative Effects Assessment" was distributed to the attendees at the scoping meetings, and also to persons requesting information via telephonic, written, or e-mail contacts. The brochure included brief descriptions of the navigation system issues, the goals of the CEA study, the 12 VECs, the role of public involvement and participation in the study, and the overall ORMSS program (see Exhibit A).

The format of each of the 12 meetings included a brief (5 minutes) presentation on the key elements of the ORMSS, a review (10 minutes) of several navigation system needs and the key components of the ORNIM, a brief synopsis (5 minutes) on the features of a SIP/PEIS and the relationship of the CEA study to the SIP/PEIS, and a focused educational tutorial (15 minutes) on the principles and steps associated with conducting a CEA study. These presentations were followed by a moderated question-and-answer session that typically listed for about one hour.

A composite "Scoping Comments Matrix" was compiled to summarize all of the received comments and issues identified from the meetings. The comments were grouped into 26 categories as illustrated in **Table A-2** (in many cases the same comment was made multiple times, and this was so noted in the matrix). The Scoping Comments Matrix is in Exhibit A. Its structure consisted of the left column comprised of the 26 categories in Table 2, with as many rows as needed for the individual comments and issues associated with each category. Twelve columns in the matrix related to the 12 VECs, with three additional columns associated with an authorized but unfunded Ecosystem Restoration Program (ERP), the overall ORMSS, and general concerns. Each comment row was connected, as appropriate, to the relevant columns. The final column in the matrix was entitled "Action", and a brief statement was included as to the disposition of each comment relative to the CEA study. The following "actions" were typically noted:

- Comment noted (no further action needed at this time)

- Currently being addressed
- Will be addressed (later in the CEA study)
- Will be addressed for a specific VEC (later in the CEA study)
- Addressed in the (scoping) meeting
- Comment will be forwarded to the ERP team

To provide feedback to the participants on the results of the scoping meetings, a brief summary report, along with the Scoping Comments Matrix, was provided to each person, either by e-mail or traditional mail (see Exhibit B). These same items were also included in the ORMSS website.

TABLE A-2
Topical Categorization of Comments and Issues from Scoping Meetings

Ohio River Mainstem Systems Study (ORMSS)
Cumulative effects assessment (CEA)
Baseline conditions
Barge operations
Navigation infrastructure
Water quality
Groundwater
Sedimentation
Dredging
Bank/shoreline instability
Pool elevations
Land use
Recreation/fishing
Fish and wildlife
Threatened and endangered species
Exotic/invasive species
Ohio River islands
Cultural resources
Trash (solid waste)
Aesthetics
Private property
Energy
Environmental regulations
Intermodal transportation facilities
Ecosystem Restoration Program (ERP)

Several lessons were learned regarding scoping meeting successes and areas needing improvement. Successes were a result of: (1) the thorough planning for the meetings by the CPT; (2) the technical preparation for the meetings; (3) the educational focus of the organized presentations at the meetings; (4) the exchange of information which occurred during the question-and-answer sessions; (5) the knowledge, experience, and communication skills of the moderator for the meetings; and (6) the timely feedback of summary information to the participants. The areas needing improvement for future public meetings on the SIP/PEIS relate to meeting announcements and locations. Specifically, a comprehensive approach is needed to identify organizations and pertinent mailing lists for inviting potentially interested groups and persons to the meetings. Second, all involved persons from the lead agency (beyond those on the CPT) need to be briefed so that they will clearly understand the purposes of the meetings and communicate this information, as appropriate, to the media and in response to verbal or written questions. Another need is to develop a mechanism (possibly through the agency's Public Affairs Office) to thoroughly review recent information from newspapers, radio, and television announcements, particularly for erroneous information that may have been disseminated, and convey that information to the moderator prior to the meeting. It is essential that any misleading perceptions be corrected at the beginning of the scoping meeting in order to keep to the primary topic. Finally, it would be desirable to have a member of the CPT actually visit all potential meeting locations prior to their selection; this would enable the independent verification of room size and available equipment and administrative support.

A.3.2.5 Questionnaire

The questionnaire used in the public scoping meetings and to fulfill information requests is shown in **Table A-3**. The 8 questions are structured to focus on several of the 11 steps in the CEQ's CEA procedure (Council on Environmental Quality, 1997). The 11 steps are identified in the next section; with the questions related to them in the following manner: Question 1 – Steps 4, 5, and 7; Question 2 – Steps 4 and 6; Question 3 – Steps 4 and 11; Question 4 – Steps 1, 5, 6, 7, 8, and 9; Question 5 – Steps 1 and 9; Question 6 – Step 4; Question 7 – Steps 10 and 11; and Question 8 – all 11 steps.

TABLE A-3
Questions in the Scoping Questionnaire

1. What do you think is the most important change associated with the Ohio River over the past 20 to 25 years; and do you consider this change to be beneficial or detrimental?

2. What do you like best about the current conditions for the Ohio River; and what do you like the least?

3. What change would you most like to see for the Ohio River over the next 50 to 60 years; and what change would you least like to see over the same time period?

4. Please assign an importance number to the following Environmental Resources identified for the Cumulative Effects Assessment (CEA) study of the Ohio River. Write a "3" in parentheses for those Environmental Resources you think have the highest importance, 2 for those with moderate importance, and 1 for those with the lowest importance:

( ) Aquatic ecological resources (includes biological resources such as fish, mussels, waterbirds, etc.; and water quality and sediments)

( ) Air quality

( ) Riparian/floodplain ecological resources (includes terrestrial habitats, islands, wetlands, soils and geology, and floodplain hydrology)

( ) Threatened, endangered, and other protected species

( ) Aesthetic resources (includes visual quality and scenic resources

( ) Noise

( ) Human health and safety (includes hazardous waste sites and chemical spills)

( ) Land use (includes changes from projected developments)

( ) Transportation and traffic (includes changes in shipping modes and commodities shipped)

( ) Socioeconomic resources (includes population changes and environmental justice)

( ) Cultural resources (includes historical and archeological resources)

( ) Recreation (includes river-based activities)

5. For those Environmental Resources you think are most important; please identify your reasons why.

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6. For those Environmental Resources you think are most important list the past and current actions (by any governmental entities or the private sector) which have contributed to cumulative effects concerns for the respective Environmental Resources.

7. What strategies should be considered to more effectively manage future cumulative effects concerns for the Environmental Resources you think are most important?

8. List any other comments you have regarding cumulative effects and the CEA study within the ORMSS being planned by the U.S. Army Corps of Engineers.

The written comments on Questions 1 through 3 and 5 through 8 were particularly helpful in identifying cumulative effects and related concerns. Question 4 involved rating the importance of the 12 VECs and their subcomponents. Based upon the responses, two importance groupings for the VECs were identified as shown in **Table A-4**.

A.3.2.6 ORMSS Website

An Internet website for the ORMSS was maintained and periodically updated by the Louisville District of the Corps. The website address is www.lrl.usace.army.mil.ormss/ As of August, 2003, it contained a fact sheet on the ORMSS, 13 frequently asked questions related to the navigation economics study and the ORNIM, an announcement of the CEA public scoping meetings, and a summary of the meetings and received comments. In addition, the 8-question CEA questionnaire is also included.

TABLE A-4
Importance Groupings and Disposition for the 12 VECs

Importance Grouping	VECs and Associated Subcomponents	
Higher	• Aquatic ecological resources -- separate and detailed chapters prepared for the fish, mussels, and water quality/sediment quality subcomponents • Riparian/floodplain ecological resources (includes terrestrial habitats, islands, wetlands, soils and geology, and floodplain hydrology) – detailed chapter prepared • Threatened, endangered, and other protected species – addressed in the fish, mussels, and riparian/floodplain chapters • Human health and safety (includes hazardous waste sites and chemical spills) – detailed chapter prepared • Recreation (includes river-based activities) – detailed chapter prepared • Transportation and traffic (includes changes in shipping modes and commodities shipped) – detailed chapter prepared	
Lower	Individual chapters prepared for: • Socioeconomic resources (includes population changes and environmental justice) • Air quality • Cultural resources (includes historical and archeological resources)	Other: • Land use (includes changes from projected developments) – exhibit prepared • Noise – addressed in the human health and safety chapter • Aesthetic resources (includes visual quality and scenic resources) – included in recreation chapter

A.3.3 Integration of Scoping Process Information

Information from the various components of the scoping process has been integrated throughout the planning and conduction of the CEA study. The study itself is based upon the 11-step procedure promulgated by the CEQ, and as described earlier (Council on Environmental Quality, 1997). The scoping process itself was used in relation to all 11 steps. The integration of scoping process information within the 11 steps is described below. The CPT has provided the leadership for the approach for each step.

- Step 1 – Identify the significant cumulative effects issues associated with the proposed action and define the assessment goals. Public scoping meetings, along with the joint meetings with the IWG, and work by the CPT, provided the basis for the identification and prioritization of the 12 VECs of concern (see Table 4).

- Step 2 – Establish the geographic scope for the analysis. The approach for establishing the geographic boundaries for individual VECs was discussed with the IWG and OB. Further, it was recognized that it is very important to maintain a

degree of flexibility in establishing geographic boundaries. No single type of boundary definition (e.g., political, watershed, etc.) works well for every resource, ecosystem, and human community. Therefore, the delineation of general boundaries must be allowed to be adjusted somewhat to fit the nature of a particular VEC.

- Step 3 – Establish the time frame for the analysis. Again, the approach for establishing the temporal boundaries was discussed with the IWG and OB. Just as with establishing geographic boundaries, general temporal boundaries must be amenable to adjustments. Factors such as availability and quality of historical data may limit quantitative analyses, and use of anecdotal information may become a necessity for certain VECs.

- Step 4 – Identify other actions affecting the resources, ecosystems, and human communities of concern. As noted in the cumulative effects definition above, "other actions" include past, present, and reasonably foreseeable future actions (RFFAs). Information for many of the types of RFFAs was derived from the IWG, the scoping meetings, the questionnaire, and usage of the ORMSS website. As noted earlier, the anticipated effects of each RFFA on each VEC or subcomponent were described in "smart cells" using Microsoft® Excel spreadsheets. Finally, the importance (high, medium, or low) of each RFFA relative to cumulative effects on each VEC or subcomponent was also described in "smart cells". The IWG participated with the CPT in the completion of several of 22 RFFA matrices.

- Step 5 – Characterize the resources, ecosystems, and human communities identified in scoping in terms of their response to change and capacity to withstand stresses. This step was based upon an analysis of environmental sustainability (AES) for the pertinent VECs or subcomponents. The AES is the third method described herein. The IWG participated with the CPT in the development of this approach.

- Steps 6 and 7 – Characterize the stresses affecting these resources, ecosystems, and human communities and their relation to regulatory thresholds; and define a baseline condition for the resources, ecosystems, and human communities. Information received from the IWG, scoping meetings, and the questionnaire, relative to institutional requirements, historical and current conditions, and appropriate regulatory thresholds and/or policies, was used in the completion of Steps 6 and 7.

- Step 8 – Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities. This step was largely accomplished with the IWG via the development of the RFFA matrices. Topics related to Step 8 were discussed in several IWG meetings, and these inputs, along with the RFFA matrices, were used in delineating the cause-and-effect relationships.

- Step 9 – Determine the magnitude and significance of cumulative effects. Again, the IWG participated in this step via discussions on the findings from several research studies as noted above, as well as "best professional practices" for both magnitude determinations and significance assessments. For the ORMSS,

significance relates to major changes (either positive or negative) in the long-term sustainability of a given resource type.

- Step 10 – Modify or add alternatives to avoid, minimize, or mitigate significant cumulative effects. The IWG participated with the CPT in identifying ES needs, including mitigation for the aquatic and some riparian/floodplain ecological resources. The emphasis was on what is needed from a resource perspective, not on what agency has the authority or funding for mitigation. The ES needs approach is the fourth method described herein. For the ORMSS, a primary reason for deferring mitigation until late in the CEA process was the concept that mitigation planning should not begin until the impacts have been determined.

- Step 11 – Monitor the cumulative effects of the selected alternative and adapt management. The key criteria being used to "trigger" Step 11 are the past, present, and future ES categories for the VECs and subcomponents. Through reviews of draft VEC chapters, the IWG has participated with the CPT, along with the OB, in further scoping and decision-making related to this step.

A.3.4 Conclusions and Lessons Learned

A multi-component process for scoping was used in conjunction with this study of the cumulative effects of 19 lock and dams, and numerous other actions, on 12 VECs identified for the 981-mile length of the mainstem of the Ohio River. One unstated thesis herein was that scoping does not refer solely to a single event or meeting; rather, it is a process that can include several mutually supportive and beneficial components. Further, and as demonstrated herein for this CEA study that is preparatory to a navigation SIP/PEIS for the Ohio River mainstem, the features of scoping can be beneficially extended throughout the planning and conduction of a CEA study (i.e., scoping is an on-going and iterative process).

The scoping process design includes specific duties and/or purposes associated with six integrated components; namely, the CPT, two committees (the OB and IWG), 12 scoping meetings, a questionnaire, and the ORMSS website. The CPT, as the representative of the lead agency, provided the leadership in planning and implementing the CEA study. Valuable policy input has been received from the OB and scientific information from the IWG; and the IWG has been actively engaged in providing technical advice and reviews of prepared documents. The scoping meetings, questionnaire results, and website have facilitated information dissemination and generated input on cumulative effects issues and contributory actions. The integration of information from each of the components of the scoping process is illustrated via a step-by-step discussion of how the 11 steps in the CEQ's procedure have been applied in the CEA study.

Based upon the information presented herein, the following conclusions and lessons learned can be articulated:

- As illustrated by this example, scoping should be viewed as an important continuing, iterative process that can facilitate the integration of CEA within a large-scale SIP/PEIS. This "continuing process" is particularly important when dealing with largely unprecedented impact studies at the programmatic level.

- Due to the relative newness of CEA within impact studies, particularly at the programmatic level, it is important that an educational component related to cumulative effects be incorporated in all components of the scoping process.

- An interagency and multiple stakeholder working group, such as the IWG, can provide invaluable input relative to scoping and various levels of participation in a CEA study.

- A multi-component scoping process can provide a more robust input to planning and conducting a CEA study than a process comprised only of one to several scoping meetings.

- The 11-step CEA procedure developed by the CEQ provided a useful framework for conducting a comprehensive study of the cumulative effects of past, present, and reasonably foreseeable future actions on key resources, ecosystems, and human communities along and within the mainstem of the Ohio River; further, it provided a useful framework for designing a unique scoping process for a CEA study.

- The designed scoping process needs to include sufficient flexibility so as to facilitate adjustments over the period of time required for a SIP/PEIS to be prepared.

A.4 RFFA MATRICES

A method involving matrices for connecting RFFAs with anticipated effects on VECs and their components was developed for this study. This method is described herein, beginning with a subsection related to the challenges associated with identifying and analyzing RFFAs. The major subsection relates to the process for developing, completing and using 22 RFFA matrices. The last two subsections, respectively, delineate lessons learned about the completion of the matrices, and about the various uses of the results in the overall CEA study.

A.4.1 Background on RFFAs

The RFFA wording in the cumulative effects (impacts) definition included in Chapter 1 suggests that there should be some level of certainty related to the action, and that it should not be simply speculative or hypothetical. Further, RFFAs may be promulgated by Federal and non-Federal agencies, and by the private sector. In addition, such RFFAs could occur as a part of general population growth and economic development. Finally, another important implication of the above definition is that the RFFAs must impact the same resources, ecosystems, and human communities that are being impacted by the proposed action, in this case, the navigation system investment plan (Council on Environmental Quality, 1997).

Many pragmatic questions have arisen regarding how to incorporate RFFAs into cumulative effects studies. Examples of such questions and relevant responses for this study include:

(1) Should contacts regarding RFFAs be made with governmental agencies beyond the "proponent agency" (i.e., the Corps in this case)? Should private sector developers also be contacted? The answer is "yes" to both questions. The emphasis should be on those RFFAs within the cumulative effects study area as well as those relevant to resources, ecosystems, and human communities affected by the proposed action. The study area for the Ohio River mainstem includes the river itself and the 500-year floodplain and contiguous counties.

(2) How can pertinent RFFAs be identified when agency/developer contact persons indicate they are "not sure that an action will be taken" or they do not identify possible future actions despite their existence? The study team must ask questions related to the timing associated with the planning of a future project (action). Further, information on RFFAs was assembled via 12 public scoping meetings, collaboration with the IWG, individual contacts with multiple public and private entities, and review of information from procured reports and the Internet.

(3) How can the likelihood of occurrence of an RFFA be established? Categories such as high, medium, and low likelihood were used herein, with such likelihoods being assigned for each RFFA based on multiple sources of information as noted in (2).

(4) How can a quantitative approach be used when detailed information about RFFAs is generally lacking? A quantitative approach was not possible for all RFFAs due to the high cost of information procurement at the programmatic level, thus qualitative descriptions and analyses were typically used. However, when quantitative information was readily available, it was used.

(5) How can RFFAs be reasonably identified in large geographical areas typically associated with programmatic impact studies? A variety of information sources such as those noted in (2) above were used, along with historical trends data, various land use planning and economic development reports, contacts with local and regional experts, and analyses of future regulatory programs.

(6) Should future governmental programs, regulations, or standards related to environmental quality and natural resources be considered as RFFAs? Definitely yes. Consideration of these types of RFFAs can be beneficial relative to protecting key resources, ecosystems, and human communities, and incorporating ES features in management efforts.

(7) Are cumulative effects (impacts) simply the sum of the direct and indirect effects (impacts) of a proposed action? Regarding this question, the CEQ regulations contain the following definitions (Council on Environmental Quality, 1978):

Direct effects are caused by the action and occur at the same time and place. Indirect effects are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.

A key point from these definitions is that RFFAs that are not related to the proposed action (the navigation system investment plan) can occur in the same geographical area of the proposed action. Cumulative effects analysis requires the consideration of "total effects" (direct and indirect) from the proposed action along with effects from other past, present, and future RFFAs not related to the proposed action. This "total effects" perspective was used in this study. Therefore, cumulative effects can be the sum of similar impacts from multiple actions, or the product, synergistically, of seemingly unrelated impacts from a variety of actions. In addition, cumulative effects may be countervailing in that a particular type of action would offset the effects of another type of action. Accordingly, cumulative effects arise from actions that may be connected only by their common impacts on similar resources, ecosystems, or human communities.

The identification and analysis of RFFAs presents several challenges in a CEA study. For example, and as noted above, the actual or potential proponents of such future actions may be reluctant to disclose information that could ultimately appear in a PEIS. Early disclosure of such information could lead to controversy about an action that is not completely designed or evaluated. It could also cause speculative changes in land values and thus increase the project costs, or it could jeopardize permit procurement activities that might be in progress. Further, it should be recognized that disclosure reluctance can be due to the fact that final decisions have not yet been made by agency or private sector decision-makers on pursuing a specific action.

A second challenge is that even when RFFAs can be identified, it is unlikely that detailed design and operational information will be available, thus hindering site-specific analysis of cumulative effects, particularly where quantitative emphases would be valuable. The implication is that the effects of each RFFA must be qualitatively identified based on accumulated knowledge of typical "impact footprints" for the types of actions. Furthermore, even if preliminary design information is available on a RFFA, the design details and specific location may change over the time period prior to the actual construction and operation of the project.

A third challenge is related to the multiple influences which may dictate timing, location, and design and mitigation features of a specific future action. For example, future economic influences may be both a key and relatively uncertain influence. Changing environmental regulations can also influence numerous specific design and mitigation features of an action. Such changes can be more stringent or less demanding relative to current regulatory conditions. Finally, decisions on certain actions may be affected by decisions on connected or related actions, thus combinations of RFFAs may need to be considered in the analysis of cumulative effects.

A final challenge is to address the range of "definitions" of RFFAs as found in approximately 40 NEPA-related court case decisions in the United States (Rumrill and Canter, 1997). To illustrate, one to several court cases can be identified for each of the following range of "definitions" of RFFAs:

- Only formal proposals are required to be considered as RFFAs

- Informal proposals beyond speculation are to be considered as RFFAs

- Remote or speculative informal proposals are not required to be considered as RFFAs

- Future actions that are a direct consequence of the current action, and where consideration could alter the nature of the project or its effects, are to be considered as RFFAs

- Geographic connections require actions to be evaluated together

- Geographic connections do not require actions to be evaluated together

- Common natural resources threats or environmental effect connections require actions to be evaluated together

- Planning document related actions supporting defined goals are connected and are to be considered as RFFAs

This range of definitions was considered in the development of the RFFA matrix approach for the CEA study for the mainstem of the Ohio River.

A.4.2 RFFA Matrices – Development, Completion and Usage

This subsection highlights the development and structure of the matrices, the team approach for completion and review of the matrices, and a brief summary of the findings from the completed matrices. The RFFA matrix approach was developed by the CPT.

A.4.2.1 Development Process for the Basic Matrices

A fundamental principle related to planning a CEA study is to focus on the potentially affected resources, ecosystems, and human communities (Rs, Es, and HCs). In a project-level study the focus is typically on the effects of that project on specific Rs, Es, and HCs. When cumulative effects are considered, each R, E, and HC potentially affected by the proposed action must be examined from the perspective of all past, present, and RFFAs that have or might contribute to each effect. Therefore, an early activity in this CEA study was to identify relevant Rs, Es, and HCs. This was accomplished via the continuous scoping process described in the previous section. Twelve Rs, Es, and HCs were identified as VECs, a term used in Canadian cumulative effects studies. Three of the 12 original VECs included subcomponents.

The original perception of the CPT was that one “overall matrix” could be developed for the ORMSS cumulative effects study. The overall matrix would have included all the identified RFFAs and the VECs and their subcomponents together. However, due to expediency relative to matrix completion, it was recognized that individual matrices would be needed for the 12 VECs. For the three VECs with multiple components (Aquatic Ecological Resources, Riparian/Floodplain Ecological Resources, and Threatened/Endangered /Protected Species), additional matrix columns were envisioned. However, it was soon recognized that matrices focused on single subcomponents within VECs, or single VECs themselves, would be more useable. As a result, 22 matrices were used; the listing is in the left column of **Table A-5**.

TABLE A- 5
Summary of Process Features Related to Completion of the RFFA Matrices

VEC	Preparation of Matrix	Review and Summarization of Matrix
AER – Water Quality/Sediment Quality	CPTC	CPT
AER – Fish	ERTC	CPT
AER – Mussels	IWGC (Note 1)	CPT
Air Quality	CPTC	CPT
RFER – Terrestrial Habitat	IWGC	CPT
RFER – Islands	IWGC	CPT
RFER – Wetlands	IWGC	CPT
RFER – Soils and Geology	IWGC	CPT
RFER – Floodplain Hydrology	IWGC	CPT
T/E/P Species – Fish	IWGC	CPT
T/E/P Species – Mussels	IWGC	CPT
T/E/P Species – Mammals	IWGC	CPT
T/E/P Species – Birds	IWGC	CPT
T/E/P Species - Plants	IWGC	CPT
Aesthetic Resources	CPTC	CPT
Noise	CPTC	CPT
Human Health and Safety	CPTC	CPT
Land Use	CPTC	CPT
Transportation and Traffic	CPTC	CPT
Socioeconomic Resources	CPTC	CPT
Cultural Resources	CPTC	CPT
Recreation	CPTC	CPT

Notes: CPTC = central planning team committee (3-4 members)
CPT = central planning team
IWGC = interagency working group committee (3-4 members)
Note 1 = it was assumed that T/E/P Species-Mussels RFFA Matrix is applicable to AER-Mussels
AER = aquatic ecological resources
RFER = riparian/floodplain ecological resources
T/E/P Species = threatened/endangered/protected species

A.4.2.2 Structure of the RFFA Cumulative Effects Matrices

The definition for RFFAs was included in the Step 4 description in the CEQ Procedure section of this chapter. **Table A-6** displays the RFFA cumulative effects matrix which was used for the water and sediment quality VEC. The 87 RFFAs were divided into six categories: (1) navigation investment actions; (2) other Corps actions; (3) "but for" actions; (4) actions by others (could occur regardless of the Ohio River navigation system); (5) natural disasters; and (6) regulatory environment. "But for" actions refer to those actions by others which would not occur except for the existence and maintenance of the Ohio River navigation system. Natural disasters are included since floods, droughts, severe storms, and/or earthquakes can have major influences on many of the VECs and subcomponents. Definitions for each of the listed types of RFFAs are available in Exhibit B. Under the ORMSS, only "navigation investments actions" are being evaluated programmatically for federal action.

The second column in **Table A-6** relates to sources of information that were the basis for the listed RFFA. Sources included plans, permits, census data, other EAs (environmental assessments) and EISs, surveys, map and/or navigation chart (Navchart) analyses, trends analysis data (TAD), and professional opinion. A summary of the utilized sources is available in Exhibit B.

The next three columns in **Table A-6** highlight relative characteristics of the listed RFFAs. The following definitions relate to the "codes" which were used for each of the characteristics (the codes are defined at the bottom of **Table A-6**).

(1) Time Period-short, medium and long-term. Short-term is the initial 10-year period from the point of completion of the CEA study (2005) and is based upon the probability of occurrence, availability of information, status of funding, and other factors. The medium time frame is from 10 to 25 years beyond 2005. The long-term period is 25 to 55 years. The date of 55 years is based on the economic analysis period for the navigation investment plan (to 2060).

(2) Occurrence Probability- high, medium, and low. High denotes substantial information exists and funding is already in place (already "on the books"). Medium denotes some information is available, and some funding possibilities exist. Low denotes minimal information and no identified funding or proponent.

(3) Location on River- Three reaches of the River were routinely used (upper, middle, or lower); the upper reach was from Pittsburgh to approximately Huntington, West Virginia; the middle reach was from Huntington, to Louisville, Kentucky; and the lower reach was from Louisville to Cairo.

The final three columns relate to the effects on the VEC or sub-component thereof, and the overall importance of the RFFAs regarding cumulative effects. The key display information in the two VEC-related columns was associated with whether the RFFA exhibits negative or positive effects. Descriptive rationale for this determination was entered in "smart cells" as follows. The RFFA matrices were provided to each committee as Microsoft® Excel spreadsheets. The "insert comment" function was used to access a detailed definition of each RFFA. Committee members were able to read each definition by moving their cursor over the RFFA cell. The committee was also encouraged to insert

comments to expand upon coded entries. This proved most useful when the team was describing the effects on the VEC or subcomponent, and rating the relative importance of the RFFA's impact. In so doing, the issues or values most important in the formulation of their entries were identified. Although use of the comments function was optional, committees often provided comments for all of their high and medium importance entries. Detailed information on the "smart cell" contents for all matrices is available elsewhere (U.S. Army Corps of Engineers, 2003).

TABLE A-6
RFFA Cumulative Effects Matrix for Water and Sediment Quality

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Navigation Investment Actions							
Lock Extensions/New Locks/Replacement or Rehabilitation	Corps planning (districts); ORNIM study outputs						
L&D operation and maintenance	Corps O&M records, J.T. Myers & Greenup Locks Improvements EIS						
Non-structural navigation improvements	Examples from: Upper Mississippi - Illinois Waterway report, national park studies.						
Dam replacement and rehabilitation	(Category added by review team)						
Other Corps Actions							
Channel dredging/dredged material disposal	Corps (districts), J.T. Myers & Greenup Locks Improvements EIS						
Navigation aids - Construction and O&M	Corps historic records, trends related to GPS, 1980 Corps O&M EIS						
Flood damage reduction projects							
levees/floodwalls	EAs and EISs from individual communities, Corps O&M records, ERP projects list						
dry dams, other projects off mainstem	EISs in Corps planning offices (districts), projects planned on tributaries						
channel modifications	Point Pleasant project, projects planned on tributaries						
nonstructural measures (e.g. relocation)	FEMA, flood relocation reports, Corps planning, Mill Creek project						
Emergency streambank stabilization (Sec. 14)	Corps planning & operations (districts)						
Modification of Corps structures for environmental improvements (Sec. 1135)	Corps planning & operations (districts)						
Environmental restoration of aquatic ecosystems (Sec. 206)	Corps planning & environmental offices (districts), EA for ERP						
Recreation facilities - Construction and O&M	Corps recreation planning, and operations (districts), navigation charts						
ERP Projects - 5 categories	EAs for ERP divided by habitat type						

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Port development (Sec. 107) and maintenance dredging	Corps planning, operations & historic records, state port authorities, state plans						
Pool maintenance	(Category added by review team)						
"But for" Actions							
Commercial Navigation							
barge queuing	Corps traffic forecasts/planning/ operations Queuing data from EMD, J.T. Myers & Greenup Locks Improvements EIS						
fleeting areas/barge storage	Navigation charts, Sec.404 permits, US Coast Guard						
terminals	Navigation charts, Sec.401 & 404 permits, Mangi questionnaire						
multi-modal sites	Navigation charts, riverfront development plans, Mangi questionnaire, state transportation improvement plans						
increased traffic	Corps traffic forecasts by Huntington economics group						
dispersed barge traffic	US Coast Guard watercraft safety records, existing and proposed recreational users' surveys, barge operators' associations						
barge/tow tech/"green" design	equipment manufacturers, barge operators' associations, examples from other countries						
accidents/spills	ORSANCO database, USEPA, emergency response groups						
Coast Guard Nav. Aids - Construction, O&M	US Coast Guard, navigation charts						
Instream sand and gravel mining	State mineral extraction agencies, 1981 Corps EIS, Corps economics group (Huntington)						
Floodplain sand and gravel mining	State mineral extraction agencies, navigation charts, aerial photos						
Limestone aggregates mining	State mineral extraction agencies, navigation charts, aerial photos, National Mining Association						
Coal utilities	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders						
Other coal industries	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders						
Hydropower on dams	FERC, ORSANCO, Corps (districts), 1988 EIS on hydroelectric power on the Upper Ohio River, state tourism departments						
Water intakes	ORSANCO, navigation charts, individual communities						

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Industrial users, excluding coal-related	ORSANCO , NPDES permits						
Recreation facilities - Construction and O&M	State tourism offices, DNRs, SCORPs, Land & Water Conservation Fund						
Traffic effects due to new locks	Added by Aquatic VEC subgroup						
Actions by Others							
Public lands acquisition and management	Nature Conservancy, Audubon, L&WCF, Forest Plans, DNR strategic plans						
Floodplain development							
residential	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,						
commercial	(same as above)						
industrial	(same as above)						
Private recreational sites: campgrounds, docks, and seasonal trailer parks	(Category added by review team)						
Crossings							
bridges	State transportation plans, KY bridges and Corridor D (WV) web sites, EISs,						
utility	navigation charts, US Coast Guard, FERC, Sec.404 permits						
industrial	navigation charts, US Coast Guard, FERC, Sec.404 permits						
Riverbed crossings	navigation charts, Corps planning (district)						
Marina development & operation	navigation charts, historic trends, LANDSAT, Sec.404 & NPDES permits						
Water -based recreation							
boating	State boat registration agencies, recreation surveys						
fishing	State resource agencies, recreation and creel surveys						
PWCs	State boat registration agencies, recreation surveys						
hunting	State resource agencies, recreation surveys						
wildlife watching	State resource agencies, NAWMP, recreation surveys, environmental groups						
sight-seeing	State tourism offices,						

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Silviculture	NRCS, state resource agencies, woodland management associations						
Agriculture	NRCS, state agricultural agencies, aerial photos						
WWTP discharges							
municipal	ORSANCO, navigation charts, NPDES permits, state regulatory agencies						
industrial	ORSANCO, navigation charts, NPDES permits, state regulatory agencies						
onsite systems	County & state health dept., sewer system maps, census data						
Stormwater discharges	Stormwater utilities, Phase 1 & 2 communities, exempt communities (CSOs)						
Brownfields redevelopment	Riverfront dev. plans, port authorities, federal and state brownfields redevelopment funding authorities						
Trail/bikeway development	Regional planning organizations, Rivers & Trails Assistance program, state plans						
Casinos	State gaming commissions						
Hazardous waste sites	HAZMET inventory						
Natural Climatic Events							
floods	Historical data from Corps, FEMA, state climatology agencies						
droughts	Historical data from NOAA						
severe storms	Historical data from NOAA						
earthquakes	Data from USGS, state geological surveys, earthquake hazard maps						
Regulatory Environment							
Phase I & 2 NPDES program	USEPA Regulatory Agenda Updates (RAU), state agencies, CWA amendments						
TMDLs	USEPA RAU, state agencies, ORSANCO, CWA amendments						
Site remediation	USEPA RAU, amendments to RCRA, CERCLA & SARA, state laws/updates						
More stringent quality standards for environmental media	USEPA RAU, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal laws						
Pollutant source control	USEPA RAU, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal laws						
Wetland Mitigation Banking	Updates to federal guidance by Corps, USEPA, NRCS, USFWS and NOAA;						
Carbon sequestration	US Dept. of Energy						
Farmland preservation	Policy updates from NRCS, amendments to federal Farm Bills, state agencies						

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Effluent trading	Policy, regulatory updates from USEPA, amendments to CWA; ORSANCO, state water and/or pollution control agencies						
Agricultural discharges	USEPA RAU, CWA amendments, state agencies, US Dept. of Agriculture						
Pollution Prevention	USEPA RAU, amendments to PPA, federal/state voluntary program initiatives.						
Emissions trading	Policy, regulatory updates from USEPA, amendments to CAA, state, regional or local air quality management programs						
COE permitting programs	Corps (districts, division, and HQ), amendments to CWA, WRDA, other laws						
Small navigation projects	Corps (headquarters), amendments to RHA and WRDA						
Boating safety regulations	Policy, regulatory updates from USDOT and US Coast Guard, pertinent state agencies, national boating organizations						
ORSANCO monitoring program	ORSANCO, USEPA regulatory updates, amendments to CWA & SWDA, USFWS policies & regulatory updates (ESA)						
Spill response	ORSANCO, policy and/or regulatory updates to Section 301 of CWA, amendments to CWA and SDWA						
Information and FOIA	Policy and/or regulatory updates to FOIA, amendments to FOIA						
Environmental Awareness Education	USEPA policies and programs, educational components of CWA, SDWA, CAA, RCRA, ESA, state programs						
ESA (Endangered Species Act)	USFWS policy, regulatory changes, recovery plans & candidate species list, ESA amendments, OR Valley Ecosystem Team, biological assessment for ORMSS						
Environmental sustainability practices	President's Council on Sustainable Development, environmental NGOs						

[1] Reasonably Foreseeable Future Actions
[2] Plans, regulations, sampling data, maps, trend analyses, etc.
[3] Time period in which the RFFA may occur
1 = within 10 years, 2 = in 10 - 25 years, 3 = in 25 - 55 years, A = applicable for all time periods
[4] Occurrence probability or likelihood RFFA will happen
H = high, M = medium, L = low
[5] Location or setting on river where RFFA is expected to occur
U = upper (Pittsburgh - Huntington), M = middle (below Huntington - Louisville)

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
L = lower ((below Louisville - mouth), A = along entire length of river SL = specific location, e.g. locks and dams, U = urban setting, R = rural setting [6]Importance of RFFA H = high, M = medium, L = low							

Actual completion of an individual "cell" in a matrix was based upon a series of considerations. To illustrate, **Table A-7** lists questions and example responses related to the effects of barge queuing (an RFFA) on water quality (a subcomponent of the aquatic ecological resources VEC). The first three questions are related to the characteristics of the RFFA, while the last six questions are associated with the characteristics of the anticipated effects. It is recognized that the development of thorough, written answers to each of the nine questions for each RFFA for each matrix would be overwhelming. To illustrate, with 87 identified RFFAs, 22 matrices (VECs or subcomponents), and 9 questions each, a total of 17,226 questions would need answers! Accordingly, the nine questions were considered as a potential generic checklist of things to think about for water quality, with specific responses grouped in a shorthand manner to provide documentation.

The final column in **Table A-6** is entitled "Importance". In this case, the committee assigned an "importance rating" to all RFFAs identified as having effects. The rating code was H (high importance), M (medium importance), or L (low importance). Again, notes were added to the respective "smart cells" in the Importance column to denote the rationale used. Some things that were considered included: (1) the relative contribution of the RFFA to the cumulative effects; (2) the spatial and temporal extent of the anticipated effects; (3) the level of knowledge regarding the affected VEC or subcomponent, and the effects themselves, and (4) the possibilities for cost-effectively mitigating the negative effects.

TABLE A-7
Questions for Consideration in Completing the Cells in a Matrix
(An example related to barge queuing, an RFFA, and water quality, a subcomponent of the aquatic ecological resources VEC)

- **Questions Related to the Characteristics of the RFFA**

  (1) Time Period – How frequently will the RFFA (barge queuing) take place? Repeatedly occurring under current conditions with frequency directly related to traffic congestion and lock closures for repairs.

  (2) Occurrence Probability – What is the probability of occurrence of the RFFA (barge queuing)? High, under current conditions.

  (3) Location on River – What is the anticipated location of the RFFA (barge queuing) along the river? Wherever barge congestion occurs at locks.

- **Questions Related to the Effects of the RFFA**

  (1) What are the anticipated effects of the RFFA (barge queuing) on the VEC or subcomponent of the VEC (water quality)? Increased localized velocities create

turbulence causing bottom scouring, resuspension of sediments, release of contaminants into the water column, volatilization of some contaminants, reduction in thermal stratification; also, a temporary increase in oxygen due to aeration by barges can occur, followed by a decrease in oxygen related to increased turbidity.

(2) What is the anticipated "area of occurrence" of the effects? Vicinity of locks.

(3) What is the duration of the RFFA (barge queuing) and the related effects? Relatively short (hours or days).

(4) What is the recoverability or reversibility of the effects on the VEC or subcomponent of the VEC (water quality)? Relatively quick recovery of conditions in the water column will occur, but longer-term impacts are related to release of contaminated sediments and bottom deposition.

(5) What regulatory standards or policies apply to the effects, and will they be violated? Effects are not likely to cause exceedances of instream water quality standards for dissolved oxygen or turbidity.

(6) What are the anticipated effects of the RFFA on other VECs or components thereof? Includes reduced algae productivity resulting from decreased light penetration, redeposition of suspended sediments on habitat of mussels and other benthic organisms and bottom-feeding fishes, and shoreline erosion with attendant increases in bedload of sediments and loss of trees and other vegetation affecting nutrient levels and further exacerbating shoreline instability.

A.4.2.3 Team Approach for Completion and Review of Matrices

Completion of the 22 matrices listed in Table 5 was a joint endeavor between the study's IWG and CPT. Committees comprised of IWG members and, in some instances, CPT members, prepared 11 matrices; the CPT prepared the remaining 11 matrices. Following the completion of the draft versions of the matrices, they were each reviewed and summarized by the CPT. Details on the membership of each completion and review committee are available elsewhere (U.S. Army Corps of Engineers, 2003).

A.4.2.4 Summary of Completed Matrices

One common feature of all 22 matrices are the columns entitled time period, occurrence probability, and location on River. These columns relate to the features of the RFFAs; thus they have the same codes on all 22 matrices. **Table A-8**, which is a portion of the completed matrix for water and sediment quality, displays the common characteristics of several RFFAs. The following comments summarize these characteristics for all 87 RFFAs:

(1) Eighty-five RFFAs are depicted as occurring over all three time periods. Two RFFAs (carbon sequestration and environmental sustainability practices) are anticipated in the second (10-25 years) and third (25-55 years) periods.

(2) Regarding occurrence probability, 75 RFFAs are listed as high, 9 as medium, and 3 as low.

(3) Fifty-five RFFAs are designated as occurring at specific locations along the River, while 32 are expected to take place along the entire River.

One reason for the high numbers occurring over all three time periods is that the vast majority of RFFAs represent continuations, or possible expansions, of past and present actions. For example, **Table A-9** displays time periods for the actions ranging from before 1950 to beyond 2005. This logic was also basic to the high occurrence probabilities, and the patterns of distribution along the River.

Table A-10 contains tabulations of the numbers of RFFAs causing negative and positive effects on each specified VEC or subcomponent. Detailed information on the effects ratings, importance ratings, and their associated comments in "smart cells" are in the individual matrices; with this information being available elsewhere (U.S. Army Corps of Engineers, 2003).

Table A-8
RFFA Cumulative Effects Matrix for Water and Sediment Quality with Examples of Inserted Comments

RFFA[1]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Navigation Investment Actions						
Lock Extensions/New Locks/Replacement or Rehabilitation*	A	H	A	-	-	L
*Description of Category: lock extensions - involves expanding lock chambers from 600' to 1200' at seven projects from R.C. Byrd to Smithland L/D and encompasses all related construction activities, including establishing parking and maintenance areas for equipment and materials, clearing and disposal of vegetation, establishing a disposal area for excess soil and rock, and some earthwork to connect portions of the new lock chamber with the riverbank Lock replacements - involves constructing one 1200' main chamber to replace the 360' auxiliary lock chamber at Emsworth, Dashields and Montgomery L/Ds. The 600' chamber currently in place at each of these projects would remain. Includes related construction activities similar to those associated with lock extension	*Water Quality Comment: Turbidity increase due to construction activities; some flow changes may also occur during construction; localized effects. *Sediment Comment: Negative temporary impacts to sediments related to construction impacts. Also, long term impacts of 19 lock & dam projects on sediment transport throughout the river system. *Importance Comment: Low importance due to minimal occurrences over the study period; mitigation measures to be used during construction.					
L&D operation and maintenance	A	H	A	-	-	M
Lock maintenance, repair and rehabilitation - involves activities that require temporary closure of a lock chamber, including periodic upkeep, major and minor repairs of lock chambers and more long-term restoration projects	*Water Quality Comment: Water surges from operation may cause temporary localized impacts to turbidity and sediments.	*Sediment Comment: Negative temporary impacts to sediments related to construction impacts and long term impacts of 19 lock & dam projects on sediment transport throughout the river system.		Importance Comment: Medium importance due to high frequency of occurrence at multiple locations over the study period.		
Non-structural navigation improvements	A	H	A	+	+	L
Dam replacement and rehabilitation	A	H	A	-	-	L
Other Corps Actions						
Channel dredging/dredged material disposal	A	H	A	-	-	H

RFFA[1]			Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Channel dredging/dredged material disposal - refers to removal and disposal of sand and gravel deposits from the navigation channel of the Ohio River to maintain a nine-foot depth.	Water Quality Comment: Dredging can cause negative effects due to increased turbidity and possible sediment contaminant releases.	Sediment Comment: Sediment movement and contaminant releases can occur.			Importance Comment: High importance due to magnitude of effects at several possible locations.			
Flood damage reduction projects								
levees/floodwalls			A	L	A	-	?	L
dry dams, other projects off mainstem			A	L	A	-	?	M
Off mainstem projects - include structures located along tributaries that retain or detain surface runoff to alleviate downstream flooding	Water Quality Comment: Dam operations can have both beneficial and detrimental effects on water quality.	Importance Comment: Medium importance since there are numerous upstream dams on the tributaries.						
ERP Projects - 5 categories			A	M?	A	+	+	M
ERP projects (5 habitat types) - projects encompassed by the Ohio River Ecosystem Restoration Program (ERP), aimed at the restoration of significant ecosystem function, structure and dynamic processes that have been degraded. ERP partners would include federal and state resource agencies and regional environmental resource groups. The five broad habitat types involved are: 1) bottomland hardwood forests, 2) aquatic habitat, 3) islands, 4) shoreline/riparian habitat and 5) wetlands.	Water Quality Comment: Beneficial effects since aquatic and riparian projects would be expected to have improvements to water quality as an objective.	Sediment Comment: Beneficial effects: projects would be expected to have sediment quality improvement as an objective.			Importance Comment: Medium importance due to the potential for a large number of projects over the study period. Note also, potential cumulative benefits of related restoration programs.			
Port development (Sec. 107) and maintenance dredging			A	H	A	-	-	M
Port development and maintenance dredging - authorized by Section 107 of the Rivers and Harbors Act of 1960, as amended; permits the Corps to construct small river and harbor improvement projects not specifically authorized by Congress when they will result in substantial benefits to navigation.	Water Quality Comment: operations may cause temporary localized impacts to turbidity and sediments, also would have turbidity increases due to periodic maintenance dredging, localized effects.	Sediment Comment: sediment disturbances during construction and maintenance dredging; localized effects.			Importance Comment: medium impacts due to scale of port developments and ongoing activity.			
"But for" Actions								
Commercial Navigation								
fleeting areas/barge storage			A	H	A	-	-	M
Fleeting areas / barge storage - areas where harbor towboats assemble, dissemble and reassemble barge tows into different configurations, according to their delivery destinations; includes temporary instream storage of surplus barges	Water Quality Comment: operations may cause temporary localized impacts to turbidity and sediments, may also get oil products from tows, could get rust from barge storage.	Sediment Comment: Resuspension of localized sediments.	Importance Comment: Medium importance due to routine occurrence over the study period and several locations along the mainstem.					

RFFA[1]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Terminals and/or multi-modal sites	A	H	A	-	-	M
Terminals - facilities at either end of a shipping line where materials are unloaded, loaded or temporarily stored; also may serve as intermediate ports where fleeting activity occurs Multi-modal sites - port facilities involving more than one mode of transportation (e.g. rail connection at terminal).	Water Quality Comment: operations may cause temporary localized impacts to turbidity and sediments, plus localized effects from barge operations.	Sediment Comment: Local sediment disruption during construction and barge operations.	Importance Comment: Medium importance due to routine occurrence over the study period and several locations along the mainstem.			
Increased traffic	A	H	A	-	-	M
Increased traffic - refers to additional barge traffic on the Ohio River with or without future improvement to the lock and dam system.	Water Quality Comment: Turbidity increases due to barge-tow travel within the mainstem.	Sediment Comment: Sediment Resuspension	Importance Comment: Medium importance due to cumulative effect of multiple sources plus possible synergistic effect of increased concentration and reduced recovery time between impacts.			
Accidents/spills	A	H	A	-	-	M
Accidents/spills - refers to barge traffic accidents and spillage of shipping materials while in transit or storage	Water Quality Comment: Degradation of several water quality parameters, depending on sizes and types of spills/accidents.	Sediment Comment: Possible sediment contamination from released products and chemicals.	Importance Comment: Low importance due to minimal occurrences and existing countermeasure plans for control and clean-up.(LC) Suggest medium importance due to continued occurrence of major spills that kill biota &/or threaten water supplies – e.g. Winter 2000/Spring 2001 sludge spill in Big Sandy that threatened water supplies through Cincinnati. [EH]			
Instream sand and gravel mining	A	H	A	-	-	H
Instream sand and gravel mining - commercial extraction of sand and gravel from the Ohio River itself	Water Quality Comment: Turbidity increases and releases of sediment contaminants in mining areas; localized effects of possible large magnitudes.	Sediment Comment: Disruptions in sediment deposits.	Importance Comment: High importance due to magnitude of effects at several possible locations.			
Coal utilities	A	H	A	-	-	H
Coal utilities - refers primarily to power stations located along the Ohio River which burn coal to generate electricity for their customers	Water Quality Comment: Thermal pollution and possible chemical pollution from corrosion inhibitors, and suspended discharges from coal piles.	Sediment Comment: Sediment discharges could have some chemical pollutants associated therewith.	Importance Comment: High importance due to number of utility plants and quantities of point and nonpoint discharges; are subject to point and nonpoint source standards.			

TABLE A-9
Timeframe of Reasonably Foreseeable Future Actions (RFFAs)

RFFA[1]	Sources[2]	Applicable Time Period[3]
Navigation Investment Actions		
Lock Extensions/New Locks/Replacement or Rehabilitation	Corps planning (districts); ORNIM study outputs	All
L&D operation and maintenance	Corps O&M records, J.T. Myers & Greenup Locks Improvements EIS	All
Non-structural navigation improvements	Examples from: Upper Mississippi -Illinois Waterway report, national parks congestion management strategies, other countries	P3, Pr, F
Dam replacement and rehabilitation		P2, P3, Pr, F
Other Corps Actions		
Channel dredging/dredged material disposal	Corps (districts), J.T. Myers & Greenup Locks Improvements EIS	All
Navigation aids - Construction and O&M	Corps historic records, trends related to GPS, 1980 Corps O&M EIS	All
Flood damage reduction projects		
levees/floodwalls	EAs and EISs from individual communities, Corps O&M records, ERP projects list	All
dry dams, other projects off mainstem	EISs in Corps planning offices (districts), projects planned on tributaries	All
channel modifications	Point Pleasant project, projects planned on tributaries	All
nonstructural measures (e.g. relocation)	FEMA, flood relocation reports, Corps planning, Mill Creek project	All
Emergency streambank stabilization (Sec. 14)	Corps planning & operations (districts)	P3, Pr, F
Modification of Corps structures for environmental improvements (Sec. 1135)	Corps planning & operations (districts)	P3, Pr, F
Environmental restoration of aquatic ecosystems (Sec. 206)	Corps planning & environmental offices (districts), EA for ERP	Pr, F
Recreation facilities - Construction and O&M	Corps recreation planning, and operations (districts), navigation charts	All
ERP Projects - 5 categories	EAs for ERP divided by habitat type	F
Port development (Sec. 107) and maintenance dredging	Corps planning , operations & historic records, state port authorities, navigation charts, state transportation plans	P2, P3, Pr, F
Pool maintenance		All
"But for" Actions		
Commercial Navigation		
barge queuing	Corps traffic forecasts, planning & operations, queuing data from EMD, J.T. Myers & Greenup Locks Improvements EIS	All
fleeting areas/barge storage	Navigation charts, Sec.404 permits, US Coast Guard	All
terminals	Navigation charts, Sec.401 & 404 permits, Mangi questionnaire	All
multi-modal sites	Navigation charts, riverfront development plans, state transportation improvement plans	All
increased traffic	Corps traffic forecasts by Huntington economics group	All

RFFA[1]	Sources[2]	Applicable Time Period[3]
dispersed barge traffic	US Coast Guard watercraft safety records, existing and proposed recreational users' surveys, barge operators' associations	P2, P3, Pr, F
barge/tow tech/"green" design	equipment manufacturers, barge operators' associations, examples from other countries	Pr, F
accidents/spills	ORSANCO database, USEPA, emergency response groups	All
Coast Guard Nav. Aids - Construction, O&M	US Coast Guard, navigation charts	All
Instream sand and gravel mining	State mineral extraction agencies, navigation charts (?), 1981 Corps EIS, Corps economics group (Huntington)	All
Floodplain sand and gravel mining	State mineral extraction agencies, navigation charts, aerial photos	All
Limestone aggregates mining	State mineral extraction agencies, navigation charts, aerial photos, National Mining Association	All
Coal utilities	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders	All
Other coal industries	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders	All
Hydropower on dams	FERC, ORSANCO, Corps (districts), 1988 EIS on hydroelectric power on the Upper Ohio River, state tourism departments	All
Water intakes	ORSANCO, navigation charts, individual communities	All
Industrial users, excluding coal-related	ORSANCO , NPDES permits	All
Recreation facilities - Construction and O&M	State tourism offices, DNRs, SCORPs, Land & Water Conservation Fund	All
Traffic effects due to new locks	Added by Aquatic VEC subgroup	F
Actions by Others		
Public lands acquisition and management	Nature Conservancy, Audubon Society, Land & Water Conservation Fund, Pt. Pleasant Riverfront Park Feasibilty Study, Forest Management Plans, state forest plans, DNR strategic plans	P2, P3, Pr, F
Floodplain development		
residential	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	All
commercial	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	All
industrial	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	All
Private recreational sites, including campgrounds, docks, and seasonal trailer parks	Added by Riparian/Floodplain subgroup	All
Crossings		

RFFA[1]	Sources[2]	Applicable Time Period[3]
bridges	State long-term transportation plans, KY bridges and Corridor D (WV) web sites, navigation charts, EISs, River Fields (Louisville) web site	All
utility	navigation charts, US Coast Guard, FERC, Sec.404 permits	All
industrial	navigation charts, US Coast Guard, FERC, Sec.404 permits	All
Riverbed crossings	navigation charts, Corps planning (district)	All
Marina development & operation	navigation charts, historic trends, LANDSAT images, Sec.404 & NPDES permits	All
Water -based recreation		
boating	State boat registration agencies, recreation surveys	All
fishing	State resource agencies, recreation and creel surveys	All
PWCs	State boat registration agencies, recreation surveys	Pr, F
hunting	State resource agencies, recreation surveys	All
wildlife watching	State resource agencies, NAWMP, recreation surveys, environmental groups	All
sight-seeing	State tourism offices, recreation surveys	All
Silviculture	NRCS, state resource agencies, woodland management associations	All
Agriculture	NRCS, state agricultural agencies, aerial photos	All
WWTP discharges		
municipal	ORSANCO, navigation charts, NPDES permits, state regulatory agencies	All
industrial	ORSANCO, navigation charts, NPDES permits, state regulatory agencies	All
onsite systems	County & state health dept., sewer system maps, census data	P2, P3, Pr, F
Stormwater discharges	Stormwater mgmt. utilities, Phase 1 & 2 communities, exempt communities with CSOs and SSOs	All
Brownfields redevelopment	Riverfront dev. plans, port authorities, federal and state brownfields redevelopment funding authorities	Pr, F
Trail/bikeway development	Regional planning organizations, state tourism offices, Rivers, Trails & Con. Assistance program, state transportation plans	P3, Pr, F
Casinos	State gaming commissions	P3, Pr, F
Hazardous waste sites	HAZMET inventory	P3, Pr, F
Natural Climatic Events		
Floods	Historical data from Corps, FEMA, state climatology agencies	All
Droughts	Historical data from NOAA	All
Severe storms	Historical data from NOAA	All
Earthquakes	Historical data from USGS, state geological surveys, earthquake hazard maps	All
Regulatory Environment		
Phase I & 2 NPDES program	USEPA Regulatory Agenda Updates, state agencies administering program, CWA amendments	P3, Pr, F

RFFA[1]	Sources[2]	Applicable Time Period[3]
TMDLs	USEPA Regulatory Agenda Updates, state agencies, ORSANCO, CWA amendments	Pr, F
Site remediation	USEPA Regulatory Agenda Updates, amendments to RCRA, CERCLA & SARA, new or amended state laws	P3, Pr, F
More stringent quality standards for environmental media	USEPA Regulatory Agenda Updates, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal and state environmental media laws	P3, Pr, F
Pollutant source control	USEPA Regulatory Agenda Updates, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal and state environmental media laws	P2, P3, Pr, F
Wetland Mitigation Banking	Updates to federal guidance by Corps, USEPA, NRCS, USFWS and NOAA; Institute for Water Resources)	P3, Pr, F
Carbon sequestration	US Dept. of Energy	Pr, F
Farmland preservation	Policy updates from NRCS, amendments to federal Farm Bills, state agriculture or natural resource agencies	P3, Pr, F
Effluent trading	Policy and/or regulatory updates from USEPA, amendments to CWA; ORSANCO, state water and/or pollution control agencies	P3, Pr, F
Agricultural discharges	USEPA Regulatory Agenda Updates, CWA amendments, state regulatory agencies, US Dept. of Agriculture	All
Pollution Prevention	USEPA Regulatory Agenda Updates, amendments to PPA, federal and/or state initiatives for voluntary programs	P3, Pr, F
Emissions trading	Policy and/or regulatory updates from USEPA, amendments to CAA, state, regional or local air quality management programs	P3, Pr, F
COE permitting programs	Corps (3 districts, division, and headquarters), amendments to CWA, WRDA and other pertinent laws	All
Small navigation projects	Corps (headquarters), amendments to RHA and WRDA	P2, P3, Pr, F
Boating safety regulations	Policy and/or regulatory updates from the USDOT and US Coast Guard, pertinent state agencies, national boating organizations	P2, P3, Pr, F
ORSANCO monitoring program	ORSANCO, regulatory updates from USEPA, amendments to CWA and SWDA, policies and/or regulatory updates from USFWS (Endangered Species Act)	P2, P3, Pr, F
Spill response	ORSANCO, policy and/or regulatory updates to Section 301 of CWA, amendments to CWA and SDWA	P3, Pr, F
Information and FOIA	Policy and/or regulatory updates to FOIA, amendments to FOIA	P3, Pr, F
Environmental Awareness Education	USEPA policies and programs, educational components of CWA, SDWA, CAA, RCRA, ESA and natural resources laws (current or based on amendments), state programs	P3, Pr, F

RFFA[1]	Sources[2]	Applicable Time Period[3]
ESA (Endangered Species Act)	Policy and/or regulatory changes of USFWS, amendments to ESA, USFWS candidate species list, recovery plans, OR Valley Ecosystem Team, biological assessment for ORMSS	P2, P3, Pr, F
Environmental sustainability practices	President's Council on Sustainable Development, environmental NGOs	Pr, F

[1] Reasonably Foreseeable Future Actions
[2] Plans, regulations, sampling data, maps, trend analyses, etc.
[3] Time period in which the RFFA may occur:

P1	Before1950	P3	19751995	F	Beyond 2005
P2	1950-1975	Pr	1995-2005	All	Includes all time periods

Table A-10
Tabulations of RFFAs causing effects on various VECs
(or subcomponents of VECs)

VEC	Number of RFFAs		
	Negative Effects	Positive Effects	No Change
AER – Water Quality/Sediment Quality	43 (4H, 8M, 32L)	21 (2H, 7M, 13L)	22
AER – Fish (see Note 1)	54 (16H, 20M, 18L)	27 (13H, 2M, 12L)	9 (4U)
AER – Mussels (see Note 2)	51 (35H, 9M, 7L)	28 (21H, 5M, 2L)	13
Air Quality	49 (3H, 14M, 32L)	10 (2H, 2M, 6L)	28
RFER – Terrestrial Habitat	50 (37H, 13L)	18 (18H)	20
RFER – Islands	35 (26H, 9L)	17 (17H)	36
RFER – Wetlands	48 (37H, 11L)	21 (21H)	19
RFER – Soils and Geology	38 (30H, 8L)	13 (13H)	37
RFER – Floodplain Hydrology	29 (26H, 3L)	15 (15H)	44
T/E/P Species – Fish	NA	NA	NA
T/E/P Species – Mussels (see Note 2)	51 (35H, 9M, 7L)	28 (21H, 5M, 2L)	13
T/E/P Species – Mammals	33 (18H, 8M, 7L)	3 (2H, 1L)	52
T/E/P Species – Birds (see Note 3)	42 (18H, 24M)	27 (23H, 3M, 1L)	20
T/E/P Species – Plants	30 (14H, 11M, 5L)	16 (1M, 15L)	41
Aesthetic Resources	27 (3H, 23M, 1L)	33 (3H, 19M, 11L)	24
Noise	50 (8H, 14M, 28L)	12 (5M, 7L)	25
Human Health and Safety	NYR	NYR	NYR
Land Use	61 (32H, 29L)	19 (15H, 4L)	7

VEC	Number of RFFAs		
	Negative Effects	Positive Effects	No Change
Transportation and Traffic	17 (6M, 11L)	18 (1H, 7M, 10L)	52
Socioeconomic Resources	NYR	NYR	NYR
Cultural Resources	NYR	NYR	NYR
Recreation (see Note 4)	37 (10H, 19M, 8L)	31 (7H, 15M, 9L)	25

Codes: H = high importance, M = medium importance, L = low importance, U = uncertain, NA = not available at this time but will be developed later in 2003, NYR = a preliminary matrix has been prepared, however, it will be refined and reviewed later in 2003

Note 1: The totals of 54 and 27 each include one RFFA with both negative and positive effects and categorized as having a low importance.

Note 2: The totals of 51 and 28 each include five RFFAs with both negative and positive effects; the five RFFAs include three categorized as having high importance, and two as having medium importance.

Note 3: The totals of 42 and 27 each include three RFFAs having both negative and positive effects; the three include two categorized as having high importance and one as having medium importance.

Note 4: The totals of 37 and 31 each include seven RFFAs with both negative and positive effects; the seven include one categorized as having high importance, four as medium importance, and two as low importance.

Brief summary comments on the AER – Water Quality/Sediment Quality matrix will be used as an illustration. A total of 64 RFFAs were denoted as having effects, with 43 anticipated causing negative effects and 21 causing positive effects. The importance categories of the 64 RFFAs are listed in **Table A-11**. The negative effects are anticipated from construction activities that cause increased turbidity levels; from multiple activities and operational processes that may cause increased discharges of many types of pollutants; and from nonpoint sources such as runoff from urban, industrial and agricultural land uses. Beneficial effects are typically associated with RFFAs in the Regulatory Environment category; examples include the adoption of more stringent standards for environment media, pollutant source control, and the Phase 1 and 2 NPDES program. A key point relates to the multiple RFFAs (43) that are anticipated to cause negative effects on water and sediment quality. Further, there are implications of changes in water/sediment quality relative to other aquatic ecological resources such as fish, mussels, and macro-invertebrates. Summary comments on the other matrices are available in Exhibit B. As appropriate, each of the VEC-related chapters include summary information from their pertinent RFFA matrices.

A.4.3. Lessons Learned About the Completion of the RFFA Matrices

A number of lessons have been learned regarding the completion process for the 22 matrices; they include:

(1) Review of the definitions of various matrix terms is critical for each user prior to the initiation of completion work. Such definitions relate to categories of, and individual, RFFAs; and the classification codes for time period, occurrence probability, location on the River, and relative

importance. Further, frequent referrals to the definitions will be necessary as the completion work proceeds.

(2) Completion of a matrix for an individual single component VEC (e.g., air quality), or matrices for multiple subcomponents of a single VEC (e.g., terrestrial habitat, islands, wetlands, soils and geology, and floodplain hydrology within the riparian/floodplain ecological resources VEC) can be a complex task. The complexity is due to the need to address 87 RFFAs, to consider various features of each identified effect (whether positive or negative, or both; frequency; duration; area affected; other VECs affected; recoverability/reversibility; and relevant regulatory standards, criteria, or policies), and to rate the relative importance of each effect. Further, the aggregate tasks associated with the completion of 22 such matrices also add to the overall complexity.

TABLE A-11
Importance Categories for RFFAs in Relation to the Water Quality/Sediment Quality Subcomponent of the Aquatic Ecological Resources VEC

RFFA Importance Category	Negative Effects	Positive Effects
High	• Instream sand and gravel mining (BFA) • Coal utilities (BFA) • Other coal industries (BFA) • Industrial users, excluding coal-related (BFA)	• More stringent standards for environmental media (RE) • Pollutant source control (RE)
Medium	• L&D operation and maintenance (NIA) • Dry dams, other projects off mainstem (OCA) • Fleeting areas/barge storage (BFA) • Terminals (BFA) • Floodplain sand and gravel mining (BFA) • Agriculture (ABO) • WWTP discharges, industrial (ABO) • Stormwater discharges (ABO)	• Dry dams, other projects off mainstem (OCA) • ERP projects – 5 categories (OCA) • Phase 1 and 2 NPDES program (RE) • TMDLs (RE) • Effluent trading (RE) • Agricultural discharges (RE) • Environmental awareness education (RE)
Low	• Lock extensions/new locks/ replacement or rehabilitation (NIA) • Dam rehabilitation (NIA) • Channel dredging/dredged material disposal (OCA) • Navigation aids-construction and O&M (OCA) • Levees/floodwalls (OCA) • Channel modifications (OCA) • Recreation facilities-construction and O&M (OCA) • Port development (Sec.107) and maintenance dredging (OCA) • Pool maintenance (OCA) • Barge queuing (BFA) • Increased traffic (BFA) • Dispersed barge traffic (BFA)	• Non-structural navigation improvements (NIA) • Emergency streambank stabilization (OCA) • Modifications of Corps structures for environmental improvements (Sec.1135) (OCA) • Environmental restoration of aquatic ecosystems (Sec.206)(OCA) • Barge/tow tech/green design (BFA) • Hazardous waste sites (ABO) • Wetland mitigation banking (RE) • Pollution prevention (RE) • ORSANCO monitoring program (RE) • Spill response (RE) • Information and FOIA (RE)

RFFA Importance Category	Negative Effects	Positive Effects
	• Accidents/spills (BFA) • Coast Guard navigation aids-construction and O&M (BFA) • Limestone aggregates mining (BFA) • Hydropower on dams (BFA) • Recreation facilities-construction and O&M (BFA) • Floodplain development-residential (ABO) • Floodplain development-commercial (ABO) • Floodplain development-industrial (ABO) • Riverbed crossings (ABO) • Marina development and operation (ABO) • Boating (ABO) • PWCs (ABO) • Silviculture (ABO) • WWTP discharges-municipal (ABO) • Casinos (ABO) • Floods (ND) • Droughts (ND) • Farmland preservation (RE) • COE permitting programs (RE) • Small navigation projects (RE)	• ESA (Endangered Species Act) (RE) • Environmental sustainability practices (RE)
Notes: NIA = navigation investment actions OCA = other Corps actions BFA = "but for" actions ABO = actions by others ND = natural disasters RE = regulatory environment		

(3) Completion of a matrix can also be time-consuming. One reason is related to the above-noted complexity. Further, recording of "smart cell" notes related to the matrix cells is time-consuming. Finally, if a team approach is used, the discussions related to the pertinent cells can extend over considerable time periods.

(4) Several approaches can be used for matrix completion. For example, the matrices were initially completed using the following approaches: (a) an IWGC or CPTC discussed and completed a matrix; (b) a sub-set of an IWGC or CPTC either met together, or utilized a teleconference, to discuss and complete a matrix; the draft matrix was then provided to the other members of the IWGC or CPTC for review and comment; or (c) a subject matter expert from an IWGC or CPTC completed a matrix; the draft was then provided to other members of the IWGC or CPTC for review and comment. Following the initial completion of the matrices, they were subjected to an independent consistency review by the CPT. Then, the CPT prepared summaries of each matrix. One primary lesson learned from this process was that there is no single approach that is always better for an initial matrix completion. Further, to ensure inter-matrix and intra-matrix consistency, it is important to subject the completed matrices to internal and

independent review procedures in order to minimize the introduction of bias into the process.

(5) To facilitate a more efficient use of time in the completion of a matrix, it may be desirable to break the work into shorter segments. One way to do this would be to address complete categories of RFFAs during an allocated time period. Another approach for achieving time efficiency would be to assign effects ratings, as appropriate, to all RFFAs; this could be followed, at a later time, with the assignment of importance ratings for the RFFAs.

(6) A critical component of matrix completion is the recording of notes in the individualized "smart cells". These notes provide the basic logic for the column related to the effects of the RFFA on the VEC (or the subcomponent of the VEC). Such information related to the types of effects has been used in the preparation of chapters on the VECs and their related subcomponents. Further, notes are also important for the "smart cells" in the column related to the relative importance of the RFFA. This information is fundamental to describing the logic for the importance categories of high, medium, and low. The results were used in "downstream scoping" of (selecting and prioritizing) the RFFAs addressed in the VEC-related chapters. Finally, it is recognized that the effects of multiple RFFAs on the VEC (or subcomponent) may be a result of similar activities (e.g., construction phase runoff), thus similar notes could apply to multiple RFFAs.

(7) It is important that the RFFA matrices be seen as "tools" to facilitate one feature of the CEA process. However, users of the matrices should not become "slaves" thereof. For example, larger scale ecological processes and/or smaller scale concerns may not be given appropriate attention via the delineation of specific VECs and related subcomponents. However, issues "outside the box" can be addressed, with this being accomplished by supplementary notes and observations, as appropriate. This lesson is based on the premise that a "tool" should lead the users in a given direction, but their associated thinking should not be constrained.

(8) Systematic work on the completion of an RFFA matrix can facilitate creative thinking by the users. Such thinking can be prompted by discussions related to effects or importance ratings, or both. Illustrations of where creative thinking is needed include the identification of linkages between VECs or subcomponents; and the recognition of similarities between effects of different RFFAs, and the possibility for using common mitigation measures.

(9) While an RFFA matrix can be a valuable tool for analysis (breaking a complex issue into parts and examining the parts), it also needs a synthesis feature to bring the parts into an overall perspective. Accordingly, a completed matrix needs to be summarized in order to present a holistic perspective, and to make the results comparative and useable.

A.4.4 Lessons Learned About the Value and Further Uses of RFFA Matrices

The following lessons have been identified relative to the value and further uses of the RFFA matrices in this CEA study:

(1) The RFFA matrix is a valuable tool that facilitated a systematic process for considering and evaluating RFFAs in a CEA study. For example, in traditional project-level impact studies, there is a tendency to consider the effects of the project in isolation. CEA requires the consideration of the effects of multiple past, present, and future actions. RFFA matrices force the users to consider multiple future actions that may impact a given VEC or subcomponents. Further, completed RFFA matrices provide a documented basis for "scoping" RFFAs and determining which should be addressed in a more detailed manner.

(2) Information extracted from completed RFFAs can be utilized to summarize a number of key points related to a CEA study. Examples of such information include expected time periods wherein given RFFAs are expected to occur; their occurrence probabilities; the locations or settings on or along the River wherein the given RFFAs are expected to occur; the RFFAs with anticipated negative effects, positive effects, and combinations thereof; and the importance categories for the RFFAs. Further, a composite picture of the effects of a given RFFA across all VECs was drawn from an analysis of each of the 22 matrices.

(3) The RFFA matrix was used as an initial step in delineating the relative contributions of individual RFFAs to the overall cumulative effects. For example, RFFAs rated as having high importance would be expected to contribute more to the cumulative effects on a VEC than RFFAs rated as low importance. In certain cases, more detailed data gathering and analysis efforts were conducted to quantify (approximate) the relative contributions of an RFFA to the cumulative effects on a VEC.

(4) The majority of the RFFAs in the first five categories (4 in navigation investment actions, 13 in other Corps actions, 19 in "but for" actions, 26 in actions by others, and 4 in natural disasters) represent continuations of past and present actions. However, from an historical perspective, different actions were initiated in different time periods in the past. Therefore, effects information from the completed RFFA matrices were applied, as appropriate, to historical time periods and present actions, and utilized to qualitatively summarize the effects of past and current actions on the VECs.

(5) Information from the RFFA matrices can be used to examine the relationship between cumulative effects on a VEC or subcomponent thereof, and the ES of that resource, ecosystem, or human community. As utilized herein, ES refers to "a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations" (U.S. Army Corps of Engineers, 2002). The AES approach was briefly described in

conjunction with Step 5. An example for this third method is in the following section of this chapter.

(6) Necessary monitoring programs can be developed for "not sustainable" or "marginally sustainable" VECs or subcomponents determined to have significant cumulative effects. Such monitoring can be focused on the indicators and the potential contributions of RFFAs identified as being in the high and medium importance categories. Further, mitigation measures can be identified for key RFFAs, thus forming an initial basis for interagency discussions related to appropriate mitigation and adaptive management strategies for specific VECs.

(7) The following generalized steps can be used to develop RFFA matrices for any CEA study:

- Develop a RFFA definition.
- Identify RFFAs based on a diversity of approaches, including the scoping process, review of planning documents, discussions with multiple public sector agencies and private sector groups, solicitation of information from a study steering committee, and use of the Internet.
- Categorize the RFFAs as appropriate.
- Develop matrices that relate the RFFAs to potentially affected resources, ecosystems, and human communities (referred to herein as VECs and subcomponents thereof). Include appropriate RFFA codes within the matrices that delineate the time period and probability of their occurrence, and their location, effects, and relative importance.
- Complete the matrices via assignment of the codes and the inclusion of the rationale for each assignment.
- Summarize the results of the completed matrices and use them as appropriate in the CEA study documentation process.
- Develop "downstream uses" of the RFFA matrices as appropriate; examples include relating cumulative effects to environmental sustainability, identifying and planning mitigation measures and adaptive management, and implementing a focused cumulative effects monitoring program.

A.5 ANALYSIS OF ENVIRONMENTAL SUSTAINABILITY

The third method relates to a qualitative approach to integrate information on past, present, and future actions into an analysis of their effects on Environmental Sustainability (ES). This method was used for all of the VECs and their subcomponents, with the results described in the individual pertinent chapters. The findings were then used as a basis for applying the ES needs approach (the fourth method). This section includes an example of the application of the Aquatic Environmental Sustainability (AES) approach to the water quality and sediment quality VEC (see Chapter 3). The second subsection enumerates some lessons learned from the applications of the AES method.

A.5.1 Example of AES Approach

To illustrate the AES approach as described in Step 5 above, the water quality subcomponent of the aquatic ecological resources VEC will be used as an example. The first part of the AES identified four common effects of multiple High and Medium importance actions. As shown in **Table A-12**, they include 8 actions causing turbidity and sedimentation, 5 actions contributing to point source pollution, 4 actions contributing to nonpoint source pollution, and 8 actions contributing to pollution reduction. Examples of actions from each common effects category include channel dredging/dredged material disposal and instream sand and gravel mining (turbidity and sedimentation), coal and related industries and marina operation (point source pollution), stormwater discharges and agriculture (nonpoint source pollution), and more stringent quality standards for environmental media and pollutant source control (pollution reduction).

Table A-12
Actions Causing Four Common Effects on Water Quality

Effects	Actions
Turbidity and Sedimentation	• Channel dredging/dredged material disposal (H) • Instream sand and gravel mining (H) • Lock and dam maintenance and operation (M) • Port development and maintenance dredging (M) • Terminals and multimodal sites (M) • Fleeting areas/barge storage (M) • Increased traffic (M) • Marina development and operation (M)
Point Source Pollution	• Coal and other related industries (H) • Industrial river users, excluding coal-related (H) • Industrial discharges (M) • Accidents/spills (M) • Marina operation (M)
Nonpoint Source Pollution	• Stormwater discharges (M) • Agriculture (M) • Industrial development (M) • Floodplain sand and gravel mining (M)

Effects	Actions
Pollution Reduction	• More stringent quality standards for environmental media (H) • Pollutant source control (H) • ERP projects (M) • Phase 1 and 2 NPDES program (M) • TMDLs (M) • Effluent trading (M) • Control of agricultural resources (M) • Environmental awareness education (M)
(H) = high importance (M) = medium importance	

Six indicators of ES were identified and pertinent historical to current information on them has been summarized in Chapter 3. Regarding their relevance for ES, the following rationale is appropriate:

- measures of key water quality parameters

(1) dissolved oxygen – related to the total organic loading from point and nonpoint sources at specific locations along the river; can also be used as a threshold indicator since the DO standard is 5.0 to 6.5 mg/l, depending upon several conditions

(2) fecal coliforms – related to fecal matter contamination from humans or other animals, whether from point or nonpoint sources at specific locations along the river; can also be used as a threshold indicator since the standard is 2000 fecal coliforms/100 ml

(3) turbidity and total suspended solids – related to solid material which can be attributed to point and nonpoint sources at specific locations along the river; can originate from both man-made wastewater discharges and natural erosional processes; no specific numerical standards exist for the Ohio River

(4) nutrients such as nitrogen and phosphorus – related to the total nutrient loading from point and nonpoint sources at specific locations along the river; the nitrogen standard is 10 mg/l (for nitrite plus nitrate nitrogen); no standard has been adopted for phosphorus

- level of conformance with state and federal water quality standards, including attainment of permissible use designations – water quality standards are based on various use designations, with the level of conformance representing a composite indicator of a sustainable aquatic ecological resource

- TMDL implementation – the TMDL (total maximum daily load) program is for specific water quality parameters which may reflect an “overloaded” situation related to point and nonpoint sources at specific locations; implementation of the program reflects a coordinated effort to achieve appropriate water quality standards and promote a sustainable ecological resource

- effectiveness of specific point source control and nonpoint source control programs – such programs are focused on reducing pollutant discharges into the river, and thus they promote a more sustainable aquatic ecological resource

- ability to sustain diverse, healthy populations of aquatic organisms – an aquatic system which attains water quality standards while minimizing the effects of "legacy contaminated sediments" should sustain diverse populations of various organisms; further, it should attain permissible use designations

- effectiveness of spill response, monitoring programs, and related precautionary measures – these represent both direct and indirect programs which are focused on more effective management of water and sediment quality, and thus the promotion of a sustainable aquatic ecological resource

For the purposes of AES, the six indicators were grouped into three tiers as follows:

- first tier – "scientific measures of quality" -- water quality parameters (DO, fecal coliform bacteria, turbidity, total suspended solids, N and P); and conformance with water quality standards

- second tier – "positive actions related to source control" -- point source control and nonpoint source control programs; TMDL implementation; and spill response, monitoring programs, and related precautionary measures

- third tier – "composite indicators of aquatic ecosystem sustainability"; this includes two measures developed from several indicators -- attainment of permissible use designations; and sustain diverse, healthy populations of aquatic organisms

Finally, the indicators and tiers were displayed into four tables (not included herein, but found in Chapter 3), with each table coinciding with the four groups of actions with common effects. Qualitative discussions of each table were then presented. For example, turbidity and sedimentation represent historical water quality concerns in the Ohio River, even with the absence of specific standards. Control programs for municipal and industrial point sources have been implemented within the last several decades, while similar programs for nonpoint sources are largely in their first decade. Increased control programs, including operational measures, are expected in the future for channel dredging/dredged material disposal, and port and marine development and operation. Implementation of a TMDL program for turbidity could occur in localized reaches of the river. Further, spill-related programs and precautionary measures are expected to reduce accidental releases. As a result of these current and anticipated future source control efforts, for turbidity and sedimentation it is expected that permissible use designations will be more easily attained, thus increasing the sustainability of diverse populations of aquatic organisms.

Regarding point source pollution, of particular concern are industrial water users and dischargers who may introduce diverse chemicals and bacteria into the river. Existing point and nonpoint source control programs have already led to reductions in industrial discharges, thus increasing the possibilities for achieving conformance with water quality standards. Future source control programs may become more stringent, and TMDL

requirements could be implemented for specific industrial pollutants in certain river reaches. Also, spill prevention and response programs are expected to reduce accidental point source pollution. As a result of these current and possible future point source control efforts, it is anticipated that additional river reaches will attain their respective permissible use designations, and the river itself will be able to sustain more diverse populations of aquatic organisms.

Nonpoint source control programs are being currently implemented for stormwater discharges from urban areas, and for runoff waters from industrial areas. Source control programs related to floodplain sand and gravel mining, as well as agriculture, are anticipated, although the specific requirements and their possible effectiveness are largely unknown. However, when considering the background of a minimal historical emphasis on controlling nonpoint source pollution, it does appear that the current efforts, when coupled with possible future emphases, are and will improve the ES of the aquatic ecosystem.

Finally, several of the 8 RFFAs expected to contribute to pollution reduction in the river represent continuations of existing pollution reduction efforts. Accordingly, the sustainability of the aquatic ecosystem is expected to improve over time

Regarding the three categories for ES of water quality, the following specific definitions were used (similarly structured definitions were used for each of the pertinent VECs and their subcomponents):

- Not sustainable -- the composite conditions for the selected indicators do not reflect conditions that would facilitate attainment of permissible use designations, nor would they sustain diverse populations of aquatic organisms.

- Marginally sustainable -- the composite conditions for the selected indicators are such that the attainment of permissible use designations is accomplished for the majority, but not all, of the river miles in the mainstem, and diverse populations of aquatic organisms are occurring along the majority of the River; however, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences.

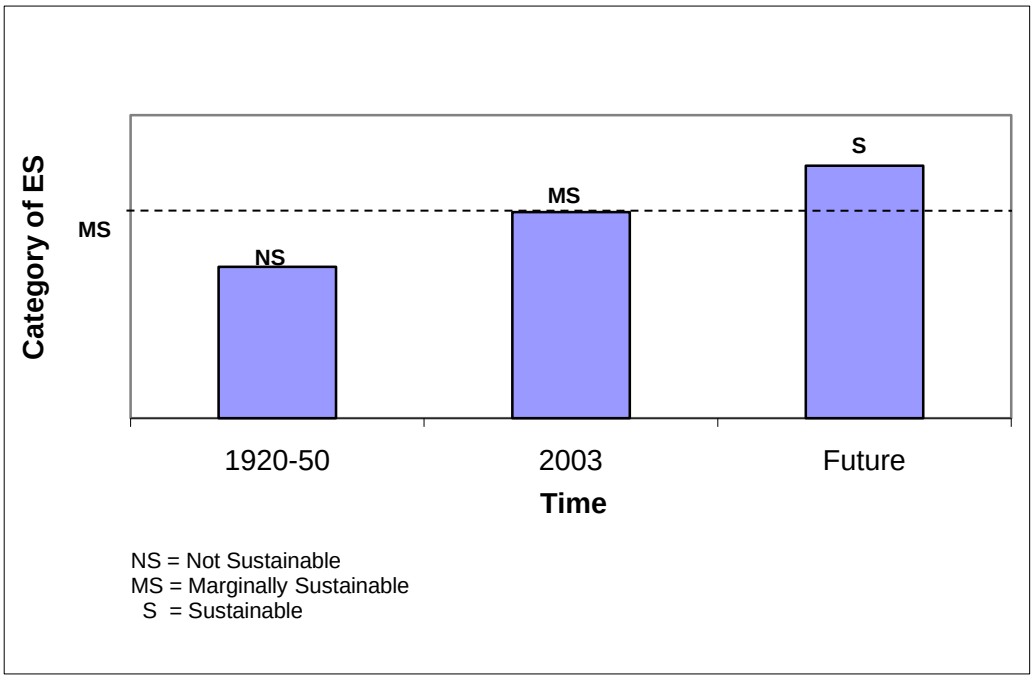
- Sustainable -- the composite conditions for the selected indicators are such that the attainment of permissible use designations is accomplished for essentially all of the river miles in the mainstem, and diverse populations of aquatic organisms are occurring along the majority of the River; further, the conditions of the indicators exceed regulatory thresholds and various governmental programs are in place to control point and nonpoint pollution sources and to emphasize pollution reduction.

Based upon the historical to current affected environment conditions described in Chapter 3, the multiple actions and effects, the tiers of indicators, and the ES categories, the ES of the water quality of the mainstem of the Ohio River can be characterized and depicted in **Figure A-1** as follows:

- In the time period prior to 1920, and continuing up to about 1950, the water quality of the mainstem was in a degraded state characterized by low DO concentrations, low pH levels in the upper River, high bacterial contamination, high nitrogen

concentrations, and remobilization of potentially toxic chemicals that had become associated with River sediments. Essentially no pollution reductions or controls programs, or regulatory programs, were in place during this period. Further, declines in the diversity and health of fish communities in the mainstem also were experienced (see the chapter on fish resources). Accordingly, the ES of the water quality VEC was classified as "not sustainable". Primary contributors to these conditions were the largely untreated and uncontrolled point and nonpoint pollutant discharges from growing municipalities and various types of industries and land uses along the River.

FIGURE A-1
ES of Water Quality



- Due to the programs of ORSANCO, and the requirements of the Federal Water Pollution Control Act (and the amended Clean Water Act), the water quality of the River has shown a steady improvement in recent decades. For example, DO concentrations are typically above the 5.0 mg/L standard, pH levels are between the 7.0 to 9.0 standard, and nitrogen concentrations meet current water quality criteria. However, bacterial contamination primarily associated with NPS pollution is still problematic downstream of major urban areas. Further, legacy "contaminated sediments" are a concern in the upper River along with fish consumption advisories throughout the mainstem. In contrast, the results of algae (plankton) and aquatic macroinvertebrate biological surveys in the five most recent decades have demonstrated steady improvements in these aquatic ecological resources, with the improvements paralleling water quality improvements. Regarding the attainment of permissible use designations, as of 2001, 974 of 981 miles (99.3%) of the mainstem are "fully supporting" aquatic life, and 970.5 miles (98.9%) are "fully supporting" public water supply use. None of the mainstem was "fully supporting" fish consumption due to restricted or no consumption advisories along its total length. For contact recreation use, 804.3 miles (82.0%) are "fully supporting" this

use. Finally, implementation of NPDES permit programs for municipalities, industries, and stormwater has led to the reduction of discharges into the mainstem. Initiatives for increasing the use of BMPs have also been established. Also, information from the fish resources chapter has indicated that the diversity and health of fish communities along the mainstem has considerably improved from the 1920 to 1950 period. Accordingly, at this time (2004), although there are many positive signs, the ES of the water quality VEC was classified as "marginally sustainable". The primary concerns are associated with bacterial contamination and chemical remobilization from legacy-contaminated sediments.

- Regarding the future, it is expected that the water quality of the Ohio River mainstem will further improve as a result of the continuation of source control and other pollution reduction programs, and the implementation of the ERP and other remediation efforts. Therefore, it is anticipated that the ES of the water quality VEC will achieve a "sustainable" condition. However, this characterization should not bring complacency; rather, vigilant efforts are still needed to continue effective water quality and aquatic ecological monitoring and management efforts. In this regard, it may be desirable to plan and implement source monitoring programs for selected RFFAs (actions) considered being of high importance relative to cumulative effects. Further, surveys for legacy-contaminated sediments are needed along with site-targeted efforts to reduce bacterial emissions from CSOs. Furthermore, several actions are expected to be beneficial to the water quality resource in the future. For example, adverse impacts related to barge operation (e.g. queuing, dispersed traffic) will be alleviated to some extent 1) through implementation of nonstructural navigation improvements and 2) through technological improvements related to communications and more environmentally-advanced barge design. Activities that support commercial navigation (e.g. port development and maintenance dredging) will continue to be scrutinized by both regulatory agencies and NGOs and may be more strictly regulated. Land disposal of in-stream dredged materials, for example, may become more common than is practiced today. Some development activity may revive or renovate underused urban space or industrial brownfields areas, with possible long-term water quality benefits related to surface and groundwater clean up. Much development activity, however, will involve conversion of existing floodplain lands (e.g. farmland, riparian woods, and wetlands) that now afford habitat protection, open space and ecosystems values. Once converted, such lands are unlikely to revert to their former more natural states. Increasing emphasis on pollution prevention, erosion control BMPs and implementation of the Phase 1 and 2 NPDES programs could counteract some adverse impacts, particularly in more urban areas. In general, several regulatory initiatives in recent years, including TMDL development, the national CSO policy, and Phase 1 and 2 programs should measurably improve water and sediment quality, but, at this time, it is not possible to predict the magnitudes of their beneficial effects.

A.5.2 Lessons Learned About the AES Approach

The lessons learned regarding the application of the AES approach include the following:

- The approach encourages the user to think about the connections between multiple actions and indicators in both a relative and holistic manner, thus encouraging the synthesis of a large body of information.

- The approach could be strengthened with quantitative information on each action, indicator, and tiers of indicators; however, in the absence of time-related information on each part, a qualitative discussion of the connections can still be useful.

- The structured framework of the approach can be useful for identifying current and future monitoring and mitigation needs, and for planning adaptive management programs, as appropriate.

- One principle of CEA is related to considering the total effects of the direct and indirect effects of past, present, and future actions (Council on Environmental Quality, 1997). The AES approach promotes such a total effects perspective.

- Application of the AES approach to VECs and their subcomponents provides an appropriate focus on the Rs, Es, and HCs of particular concern. This is another fundamental principle of CEA (Council on Environmental Quality, 1997).

A.6 ENVIRONMENTAL SUSTAINABILITY NEEDS

The ES needs (ESN) approach is the fourth method used in this CEA study. The ESN was not applied uniformly to all VECs and their subcomponents; rather, it was applied to the two VECs that were determined to have been subjected to the greatest cumulative effects, and which need the most attention regarding both current and future environmental management. The two VECs were aquatic ecological resources (including water quality and sediment quality, mussel resources, and fish resources) and riparian/floodplain ecological resources. Chapters 3 through 7 herein address these VECs and their subcomponents. The first subsection herein describes a group process that was used to identify, prioritize, and summarize ES needs for aquatic ecological resources. Exhibit D provides details on the group process and findings. A similar process is planned for the riparian/floodplain ecological resources VEC.

The ESN also includes the consideration of an adaptive management program for the two VECs and their subcomponents. Basic information for an adaptive management program is included in the second subsection. Finally, another consideration is related to institutional authorities and policies for mitigating historic and future actions that have damaged the VECs, thus the last subsection summarizes such information for the Corps.

Because the issue of ESN was beyond the original scope of this CEA study, it should be recognized that the ESN approach is still a “work-in-progress”. Additional planning efforts would be required to formalize these findings.

A.6.1 Example of Group Process to Identify ES Needs

To illustrate the ESN approach as mentioned in Step 10 above, the aquatic ecological resources VEC will be used as an example. This VEC includes three subcomponents

consisting of water quality, mussels, and fish. The approach, which is still in progress, consists of the following steps:

- Identification of an Aquatic Sustainability Group consisting of selected members of the IWG; other regional experts from universities, state agencies, and industry; and the Corps' CPT.

- Conducting a one-day "brainstorming meeting" of the Group, and documentation of the central themes and ideas. Advance instructions provided to the Group included the following items:

  (1) Accept that the system is highly modified and will remain so (i.e., it is not reasonable to return the River and floodplain to predevelopment conditions; however, the system is amenable to further modifications that may affect the resource either positively or negatively).

  (2) For now think only about the aquatic ecological resources. Do not worry about who will be responsible for any sustainability actions, who will pay for them, or when they will happen.

  (3) Be prepared to address the following questions:
  "What do we want the resources to look like?"
  "What needs to happen to attain this vision of the Ohio River?"
  "What are possible indicators of environmental sustainability?"

- Summarization of the responses and feedback to the Group for clarification and expansion, as appropriate.

- Prioritization of the responses to the above three questions by the Group.

- Formulation of alternatives and interagency collaborative strategies to improve the long-term sustainability of aquatic ecological resources of the Ohio River. These alternatives and strategies are being developed and will be included in the SIP/PEIS.

The process used to develop ES alternatives follows closely the general principles for ecological management defined by the Interagency Ecosystem Management Task Force, and summarized in the next sub-section (Keiter and Adler, 1998).

A.6.2 Ecosystem Adaptive Management

An emerging theme for strategic-level impact studies is the use of ecosystem management approaches to address larger-scale issues that may involve both policy and scientific uncertainties. Accordingly, the federal government is encouraging the implementation of ecosystem management approaches within and among federal agencies and among federal, state, and local agencies. Ecosystem (ecological) management includes the analysis of both the elements and the interrelationships involved in maintaining ecological integrity (Council on Environmental Quality, 1993). Such management should use a local-to-regional perspective that considers impacts at the

appropriate scale within the context of the entire ecosystem. To facilitate the implementation, the Interagency Ecosystem Management Task Force was formed in the mid-1990s. The work of this Task Force and other entities and individuals has been instrumental in defining the following general principles for ecological management (Keiter and Adler, 1998):

- Common ecological management goals should be socially defined through a collaborative vision process that involves all interested participants and that incorporates ecological, economic, and social considerations.

- Given that most ecosystems and watersheds transcend conventional geopolitical boundaries, ecological management requires coordination among federal, state, tribal, and local governmental entities as well as collaboration with other interested parties.

- Ecological management policies and decisions should be based upon integrated and comprehensive scientific information that addresses multiple rather than single resources.

- Ecological management seeks to maintain and restore biodiversity and ecosystem integrity.

- Ecological management involves management at large spatial and temporal scales that correspond to ecosystems and watersheds.

- Given the finite nature of public funds and other resources, ecological management enables agencies to engage in careful targeting to select achievable solutions and to allocate resources efficiently.

- Ecological management requires an iterative, adaptive management approach to account for changing goals and values and new scientific information concerning ecological conditions.

Adaptive management refers to a relatively new concept that recognizes that scientific uncertainties and unforeseen environmental changes are inevitable when various plans, programs, or policies are implemented in particular environmental settings. Accordingly, the application of the concept in environmental management entails (National Research Council, 2002):

> …"the use of carefully designed and monitored experiments, based on input from scientists, managers, and citizens, as opportunities to maintain or restore ecological resilience and to learn more about ecosystems. These actions are monitored for scientific findings to help improve understanding of how policy decisions affect ecosystems. Findings from ecosystem monitoring are then to be used to appropriately adjust management policies. Adaptive management requires that clear goals and desired outcomes be established so that progress toward desired future conditions can be assured."

Adaptive management has been applied, or is being considered for application, in environmental management efforts related to several large-scale water resources projects and programs. For example, it is included in the Comprehensive Everglades Restoration Plan in Florida, the Glen Canyon Dam in Arizona, and the Upper Mississippi River Basin navigation study in the Midwest; and it has been proposed for the Missouri River Basin ecosystem management program. Further, the concept will be incorporated in the SIP/PEIS for the ORMSS.

A.6.2.1 Elements in an Adaptive Management Program

The key elements associated with an adaptive management program for the ORMSS include, but are not limited to, the following:

- The assemblage of information on the historical and current conditions of key indicators for environmental resources that are potentially subjected to impacts from a plan, program, or project; and the quantitative prediction or qualitative description of these anticipated impacts, along with impacts from other past, present, and reasonably foreseeable future actions (i.e., the cumulative effects), on the key indicators.

- A scientifically-designed monitoring program focused on measuring changes in key indicators of environmental resources subjected to potential cumulative effects.

- A strategic framework that includes periodic evaluations of the implementation of features of the SIP, the monitoring data and other related policy information, and decision-making, as appropriate, relative to adapting management policies or measures for the environmental resources of concern.

- Collaborative long-term agreements among pertinent federal, state, tribal, and local environmental agencies; and a program steering committee comprised of representatives from these agencies.

- Adequate budgetary and personnel resources.

- A peer group of advisors with expertise in public policy analyses, the planning and conduction of environmental monitoring and research, and environmental decision-making.

Each of these elements will be considered, as appropriate, in the adaptive management program within the ORMSS. As suggested, a key feature of adaptive management is the planning and implementation of monitoring programs.

A.6.2.2 Monitoring Planning as a Basis for Adaptive Management

Sadler and Davies (1988) describe three types of environmental monitoring which might be associated with the life cycle of a plan; for example, the SIP in this case. These include baseline (current conditions) monitoring, effects or impact monitoring, and compliance monitoring. Baseline monitoring is the measurement of environmental variables during a representative pre-project or pre-plan period to determine existing

conditions, ranges of variation, and processes of change. Effects or impact monitoring involves the measurement of environmental variables during construction and operation of one to several projects to determine changes that may have been caused, and to develop or evaluate mitigation measures. Finally, compliance monitoring takes the form of periodic sampling and/or continuous measurement of levels of waste discharge, noise, or similar emission, to ensure that conditions are observed and standards are met. It could also include the auditing of compliance with regulatory permit programs of the USEPA, the Corps, and the involved states. Pre-PEIS monitoring includes baseline monitoring, while post-PEIS monitoring encompasses effects or impact monitoring, and/or compliance monitoring. All three types of monitoring should be included in an adaptive management program.

Careful planning and implementation of a monitoring program is necessary for meeting the various purposes of monitoring. Three considerations are important in planning monitoring programs in the United States. First, there is an abundance of environmental monitoring data routinely collected by various governmental agencies and the private sector. This data needs to be identified, aggregated, and interpreted since information is often compiled but never interpreted relative to the quality of the environment being monitored. Second, environmental monitoring programs are expensive to plan and implement. Every effort should be made to use or modify extant monitoring programs. Third, owing to overlapping environmental management and monitoring responsibilities of many local, state, and federal governmental agencies, it will be necessary to carefully coordinate environmental monitoring planning with several agencies.

To illustrate the scientific considerations that may be involved in planning a monitoring program, a generic seven-step conceptual framework for developing a plan for biological and ecological monitoring will be highlighted (Spellerberg, 1991). The framework can be adapted to the monitoring of environmental media, and socioeconomic and/or social impacts. The first step would be to define the monitoring objectives. In many monitoring schemes, the objectives are either not stated or are so complex that they become meaningless (Spellerberg, 1991). The second step would be to determine the spatial locations where the monitoring will take place. The third step would be to make sure the data collected are documented for future use. When monitoring programs extend over long periods of time, such as for the SIP, professionals working on the adaptive management program will change. So the need arises for methods to assure the retention of such data, which should be accessible and understandable to successive professionals. The fourth step entails various arrangements for data collection and storage. The success of a monitoring program depends not only on good planning and logistical support, but also on coordination with other related programs.

The fifth step involves the process of selecting the variables (indicators) to be measured. The ideal variable and process would have a wholly ecological basis but logistic limitations (finances, time and effort) may override these considerations. Due to such logistic limitations, methods for collection of data from the field or assemblage of data from other sources should therefore be considered along with the choice of indicators. Monitoring data can be aggregated into pertinent indices to reflect the composite quality of different environmental categories. For example, several indices for the biological environment have been developed; one example is an Index of Biotic Integrity (IBI) for stream fish assemblages. Chapter 6 herein refers to an Ohio River Fish Index (ORFiN).

The sixth step would involve the preliminary data gathering and baseline surveys. Before biological monitoring should start, biological information from published sources or preliminary field studies should be assembled. Finally, the seventh step involves the analysis and presentation of the data. Considerations of who will use the data, to make recommendations, should be reviewed when the form of data presentation is selected (Spellerberg, 1991). For an adaptive management program, it is anticipated that the program steering committee will use the information to adapt management efforts, as appropriate.

A.7 INSTITUTIONAL CONSIDERATIONS FOR MITIGATION BY THE CORPS

As part of this CEA study, a study was conducted to review and summarize the Corps' statutory authorities, policies, regulations, guidance, and practices associated with mitigation of historical environmental damages from the construction, operation, and maintenance of Corps projects, and/or damages from projects and actions by others (governmental or private); and to review and summarize similar institutional information related to the necessity for mitigation of the potential environmental damages from projects, plans, and/or programs under current planning and development (Canter, 2003). Mitigation of historical damages from Corps actions can be perceived as "mitigation for previous effects", while mitigation of potential damages can be classified as "mitigation for future effects". Mitigation for previous effects includes "ecosystem restoration" projects and activities. The focus of this study was on mitigation related to damages to the "natural environment", thus, it encompasses physical, chemical, and biological characteristics as reflected by mitigation for effects on streambank erosion, water quality, fish, and wildlife; in other words, the effects have occurred or are anticipated to occur on aquatic and riparian/floodplain ecological resources.

The major effort associated with this study consisted of the review of a large number of Corps' policies, regulations, pamphlets, and supporting information related to ecosystem restoration (mitigation for previous effects), mitigation (mitigation for future effects), and either mitigation (for previous or future effects) for water quality management, or streambank erosion. Attention was directed to specific statutory authorities, policies, and requirements associated with mitigation for historical or anticipated environmental damages. Six subsections are included herein. In the first, the institutional context for this study is framed. The second subsection summarizes the general review of key laws, regulations, and executive orders that are related to ecosystem restoration and mitigation. The third subsection is specifically focused on ecosystem restoration authorities and policies, while the fourth does similarly for mitigation. The fifth subsection highlights the laws and policies related to water quality management and streambank erosion. The last subsection delineates the overall conclusions.

A.7.1 Findings on Institutional Context

There is an evolving institutional context regarding historical and future mitigation for Corps plans, programs, and projects. Of major significance are the EOPs issued by the Chief of Engineers in March, 2002; these EOPs are to be included in the Corps planning process. Two specific examples are the goals of achieving ES (EOP #1), and assessing and

mitigating cumulative impacts (EOP #5). These two goals are inclusive of both mitigation for previous or future effects. Further, it is significant that all seven EOPs served as the foundation for EC 1105-2-404 (May, 2003) and ER 200-1-5 (October, 2003). The EC and ER include numerous statements that support the creative integration of ES and other EOPs in the formulation and analysis of water resources plans, including plans focused on both addressing primary problems (e.g., flood damage reduction, navigation, or ecosystem restoration) and secondary problems which provide opportunity for enhanced environmental management.

The Corps' 2002 draft strategic plan for the Civil Works program contains considerable information on, and commitments to, both mitigation for previous or future effects (U.S. Army Corps of Engineers, 2002b). Both types of mitigation are directly mentioned, or inferred, in the Civil Works mission statement, two of the five identified challenges, and several goals and strategic objectives. Full utilization of the existing authorities of the Corps will facilitate the planning and implementation of appropriate mitigation measures for previous or future effects.

Based upon these current Corps activities, the following key conclusions regarding the institutional context for this study are relevant:

- ES is increasingly becoming a key issue in the Corps' development of water resources plans, programs, and projects; in fact, the Corps is taking a leadership role among governmental agencies regarding the promotion of ES throughout its planning and operational missions.

- There are numerous challenges when incorporating ES in water resources planning; they include, but are not limited to, the need to consider past, present, and future cumulative effects on significant natural and environmental resources; the potential need to mitigate for both previous and future effects to enhance the sustainability of significant resources; and the need for multi-agency collaborative efforts to monitor and promote ES on a continuing basis.

- Referrals to "restoring" natural and environmental resources infer that the Corps is not the sole cause of historical degradation; rather, the implications are that such degradation may have been the result of multiple causes, including past actions by the Corps, other governmental entities, and private sector developments.

A.7.2 Findings on Statutory and Other Authorities

The current statutory authority for mitigation of both previous and future effects for Corps plans, programs, and projects is contained in selected sections of four Water Resources Development Acts -- WRDAs (Sections 904, 906, 907, and 1135 of WRDA 1986, Sections 306 and 307 of WRDA 1990, Section 204 of WRDA 1992, and Sections 206 and 207 of WRDA 1996). Commonly used words in the selected sections include "protection" and "restoration", with the former typically denoting mitigation for future effects, and the latter mitigation for previous effects. However, it should be noted that protection could also be a feature of mitigation for previous effects. Mitigation of Corps contributions to historical degradation of natural and environmental resources is specifically included in some of the above sections. Navigation-specific statutory authority related to lock and dam replacement is currently based on Section 205 of WRDA

1992 (funding of major rehabilitation modifications to enhance operating efficiency beyond the original project design). Specific replacement or rehabilitation projects would currently be subject to the requirements of NEPA; therefore, mitigation for future effects, as appropriate, would be considered. Correction of shoreline damages resulting from existing Federal navigation projects is addressed in Section 111 of the RHA of 1968, as amended by Section 940 of WRDA 1986. Such corrections are specific examples of mitigation for previous effects for one type of environmental effect of navigation projects; i.e., shoreline erosion and damage.

Finally, a major law that is intertwined with water resources planning is the FWCA of 1958. This law emphasizes that fish and wildlife resources are to be conserved in the planning and implementation of water resources development projects. Several sections of the FWCA incorporate provisions whereby mitigation for either previous or future effects, or both, should be included in new or modified projects. Another important feature of the FWCA is the requirement that active consultation and coordination occurs between the Corps and the USFWS and/or the NMFS.

Based upon the laws above, along with related EOs (Executive Orders), ERs, and PGLs (Planning Guidance Letters), the following conclusions regarding statutory and other authorities can be noted:

- The Corps has several statutory authorities under which the planning and implementation of mitigation measures for both previous and future effects can be accomplished in association with continuing and new projects and their operation.

- The FWCA is a particularly important law related to water resources planning; it encompasses mitigation for both previous and future impacts on fish and wildlife resources. Further, it requires active coordination between the Corps and the USFWS and/or NMFS regarding mitigation needs and the implementation of mitigation measures.

- Two key EOs which encompass both types of mitigation include the protection of wetlands (EO 11990), and floodplain management (EO 11988). Both wetlands and important floodplains and riparian zones are in the geographical scope of the ORMSS. Further, information related to both types of mitigation can be found in selected ERs (ER 1165-2-26, and ER 1130-2-540) and PGLs (PGL Nos. 46, 49, and 56) of the Corps.

A.7.3 Findings on Ecosystem Restoration

Stated policies regarding the ecosystem restoration mission of the Corps are found in ER 1105-2-100 (Planning Guidance Notebook), ER 1165-2-501 (Civil Works ecosystem restoration), and EP 1165-2-502 (ecosystem restoration – supporting policy information). While the focus of restoration can be characterized as mitigation for previous effects, some features of an actual restoration plan can include protection against future degradation, thus it can also include mitigation elements that address future effects.

Specific authorities for ecosystem restoration are divided into three categories. First, Congressionally authorized studies and provisions in existing laws can be used. One example of a law in the first category is the ORMSS, which resulted in authorization of an

Ecosystem Restoration Program specific to the Ohio River and floodplain. The second category encompasses programmatic authorities, including Section 1135 of WRDA 1986, as amended (project modifications for improvement of the environment); Section 206 of WRDA 1996 (aquatic ecosystem restoration); Sections 204 of WRDA 1992, as amended (beneficial uses of dredged material); and Section 312 of WRDA 1990, as amended (environmental dredging). The third category involves the use of existing operation and maintenance authorities for specific projects. Section 216 of the 1970 River and Harbor and Flood Control Act allows review of completed projects or their operation due to significantly changed physical or economic conditions or for improving the quality of the environment in the overall public interest. Two common themes arise from the above three categories of ecosystem restoration authorities. First, cost sharing is typically required for ecosystem restoration projects. Second, such projects must be environmentally and economically justified via the application of an incremental cost analysis procedure applied to the anticipated environmental benefits and associated costs of various measures comprising the restoration action.

Based upon this information, the following conclusions regarding ecosystem restoration (mitigation for previous effects) can be drawn:

- Ecosystem restoration can and often does include measures related to reducing historical degradation of resources (mitigation for previous effects) as well as measures that are protective against future degradation of those resources (mitigation for future effects).

- Three categories of authorities can be used by the Corps to study, plan, design, and implement ecosystem restoration projects. They include Congressionally authorized studies and provisions in existing laws, programmatic authorities within specific sections of five recent WRDAs, and existing operation and maintenance authorities for specific projects.

- The Corps can engage in the planning and implementation of ecosystem restoration projects where previous Corps projects or actions are the sole contributor to degraded resources, or where they are partial contributors along with projects and actions by other governmental agencies and private developments. Finally, ecosystem restoration planning and implementation of a project can be accomplished when the entire existing degradation is a result of actions by others.

A.7.4 Findings on Mitigation Policies

The Digest of Water Resources Policies and Authorities (EP 1165-2-1) includes information on mitigation requirements for new projects resulting from the discharge of dredged or fill material as addressed under the auspices of the Clean Water Act, and new project reports prepared under the auspices of Section 906 of WRDA 1986 and the FWCA. Further, mitigation requirements resulting from jeopardy and adverse modification opinions under the Endangered Species Act are reflected in the development of reasonable and prudent measures. Regarding existing projects and mitigation for previous effects of experienced negative impacts, Section 216 of the River and Harbor and Flood Control Act of 1970 can be used to study the situation and identify possible measures. However, expenditures under this authority are limited to $20,000 per study. Therefore, Section 216

is used as a reconnaissance type study that leads to a cost-shared feasibility study, and eventually to a cost-shared project.

Mitigation measures, per se, for both new and existing projects must be environmentally justified based on the potential loss of significant fish and wildlife resources, and economically justified by the consideration of the cost effectiveness of various mitigation alternatives. A key issue to note is the need for careful planning and evaluation of a variety of mitigation measures, both singly and in combination, in the development of a justified mitigation project. Further, due to the requirements of the FWCA, the policies and recommendations of the USFWS are important relative to mitigation planning that address both previous and future effects. Coordination by the Corps with the USFWS and the NMFS, as appropriate, is a central feature of the requirements of the FWCA.

Based upon the laws and related Corps policies summarized herein, along with the mitigation policies and guidance of the USFWS in relation to the requirements of the FWCA, the following conclusions regarding mitigation policies are articulated:

- Requirements related to the planning and development of mitigation for future effects features for new water resources projects are found in several laws, including NEPA, the Clean Water Act, WRDA 1986, the Endangered Species Act, and the FWCA. The authority of Section 216 of the River and Harbor and Flood Control Act of 1970 can be used to perform an initial examination of experienced negative impacts of existing water resources projects, and may lead to further study and implementation of cost-shared mitigation for previous effects projects, as appropriate.

- Mitigation measures that address both previous and future effects must be justified based upon the actual or potential loss of significant fish and wildlife resources, and the application of a developed procedure for incremental cost analysis that includes metrics for environmental benefits along with costs for various mitigation features.

- Familiarity with the mitigation policies and typical recommendations for mitigation measures and means used by the USFWS can facilitate the required coordination between the Corps and USFWS under the auspices of the FWCA.

A.7.5 Findings on Policies on Water Quality and Streambank Erosion

ER 1110-2-8154 addresses water quality and environmental management for Corps projects. As such, it is a uniquely important Corps regulation related to mitigation of both previous and future effects. The national policy of the Federal government regarding water quality management is articulated along with the Corps' companion policy, specific commitments, and three management objectives. Regarding mitigation for previous effects, ER 1110-2-8154 indicates that the Corps can address situations where degraded conditions regarding water quality and/or aquatic or riparian habitats are a result of Corps actions alone, and/or combinations of actions by other governmental agencies and the private sector. Further, Chapter 18 of EP 1165-2-1 (Digest of Water Resources Policies and Authorities) stresses the importance of water quality standards in water quality management planning and the development of mitigation projects. The standards can be

used as one basis for determining the significance of degraded conditions and anticipated impacts from new water resources projects.

Corps policies regarding mitigation for previous effects projects for streambank erosion are included in the Planning Guidance Notebook (ER 1105-2-100), Chapter 15 in the Digest of Water Resources Policies and Authorities (ER 1165-2-1), Section 14 of the Flood Control Act of 1946, Section 103(a) of WRDA 1986, and Section 202(a) of WRDA 1996. These policies are primarily focused on remediating erosion problems threatening public facilities and certain non-profit public services.

Based upon this information, the following key conclusions are drawn:

- ER 1110-2-8154 (Water Quality and Environmental Management for Corps Civil Works Projects) is a uniquely important regulation that addresses all mitigation. This ER includes information that directly or indirectly relates to the Corps' EOPs, including the incorporation of ES and the consideration of cumulative effects in water resources planning.

- Water quality management is intricately linked to the promotion of sustainable conditions for aquatic and riparian habitats and associated species. Further, compliance with water quality standards can be used as an indicator of ES for these habitats and associated species.

A.7.6 Overall Conclusions

The overall conclusions of this study are as follows:

- The issuance of seven EOPs in March, 2002, EC 1105-2-404 in May, 2003, and ER 200-1-5 in October, 2003, has provided the foundation and institutional basis for the incorporation of ES in the Corps' development of water resources plans, programs, and projects. In addition, mitigation addressing both previous and future effects is inferred in the EOPs and the EC. Further, CEA requires the consideration of mitigation measures for past, present, and future cumulative effects; thus, planning, coordination, and implementation of both types of measures may be necessary in order to enhance the ES of significant resources.

- The Corps can utilize several statutory authorities for the planning, coordination, and implementation of mitigation measures addressing both previous and future effects for continuing and new projects and their operation. These authorities are contained in selected sections of four WRDAs (Sections 904, 906, 907, 940, and 1135 of WRDA 1986, Sections 306 and 307 of WRDA 1990, Sections 204 and 205 of WRDA 1992, and Sections 206 and 207 of WRDA 1996); and in Section 216 of the RHFCA of 1970. Further, the FWCA of 1958 encompasses mitigation for both previous and future impacts on fish and wildlife resources, and it requires active coordination between the Corps and the USFWS and/or NMFS regarding mitigation. A key point in application of these authorities is that costs must be shared with a non-federal sponsor in order to implement, and in many cases, to study mitigation measure for either previous or future effects.

- The terminology found in various Corps policies, regulations, and guidance is often confusing and overlapping. For example, mitigation can refer to measures addressing the past, present, and/or future. Protection is sometimes subsumed within mitigation or ecosystem restoration, or it may be addressed as a separate measure. Accordingly, careful reading is necessary when searching for Corps policies and practices related to mitigation.

- Ecosystem restoration, which is a current major mission of the Corps, can include measures related to reducing historical degradation of resources (mitigation for previous effects) as well as measures that are protective against future degradation (mitigation for future effects). Three categories of authorities can be used to plan and implement such restoration projects. They include Congressionally authorized studies and provisions in existing laws, programmatic authorities within specific sections of recent WRDAs, and existing operation and maintenance authorities for specific projects. Ecosystem restoration projects can be developed where previous Corps projects or actions are the sole contributor to degraded resources, or where they are partial contributors along with projects and actions by others. Further, in certain circumstances, such projects can be accomplished when the entire degradation is a result of actions by others.

- Requirements related to the planning and development of mitigation features for new water resources projects are found in several laws, including NEPA, the Clean Water Act, WRDA 1986, the Endangered Species Act, and the FWCA. Further, mitigation measures for future effects, as well as measures for previous effects, must be justified based upon the actual or potential loss of significant fish and wildlife resources, and the application of a developed procedure for incremental cost analysis that includes metrics for environmental benefits along with costs for various mitigation features.

ER 1110-2-8154 (Water Quality and Environmental Management for Corps Civil Works Projects) is a uniquely important regulation that addresses mitigation for both previous and future effects. This ER is important because water quality management is intricately linked to the promotion of sustainable conditions for aquatic and riparian habitats and associated species. Finally, policies and practices related to mitigation for previous effects projects for streambank erosion are delineated in the Planning Guidance Notebook (ER 1105-2-100) and the Digest of Water Resources Policies and Authorities (EP 1165-2-1).

- It is important to note that, while there are numerous authorities for study and implementation of mitigation for previous effects (or ecosystem restoration), costs must be shared with a non-federal sponsor in order to implement, and in many cases, to study either mitigation measures.

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Exhibit B

SCOPING

B.1 SUMMARY OF U.S. ARMY CORPS OF ENGINEERS PUBLIC SCOPING PROCESS

B.2 ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

SUMMARY OF U.S. ARMY CORPS OF ENGINEERS' PUBLIC SCOPING PROCESS OHIO RIVER MAINSTEM SYSTEM STUDY (ORMSS)

These materials summarize comments received during the scoping process for the Cumulative Effects Assessment (CEA) of the USACE Ohio River Main Stem System Study (ORMSS) during Summer 2001. An important first step in developing a large-scale environmental impact statement, scoping is mandated by the National Environmental Policy Act whenever major federal actions can significantly affect the quality of the environment. Scoping creates opportunities for the public, agencies and other groups to provide input on potential issues related to a proposed project. By identifying significant environmental issues and potential alternatives, the scoping process will influence development of the CEA.

SUMMARY OF ORMSS SCOPING PROCESS

Scoping for the CEA began with publication of a notice in the Federal Register on June 26, 2001. It also was publicized through a press release announcing the CEA scoping process and inviting comments, a mailing to all addressees on the ORMSS mailing list, and legal ads in major regional newspapers. Interested parties also were encouraged to provide written comments or submit questions to the CEA Project Manager at USACE Louisville District by regular mail or e-mail (celrl-ormss@usace.army.mil) by August 31, 2001. Information about the CEA also was available on the project web site: http://www.lrl.usace.army.mil/ormss/. Additionally, a color brochure was developed and provided to those who attended the public meetings and to others upon request.

A series of six public scoping meetings (one set in each state along the Ohio River) was held during Summer 2001. Each set consisted of a daytime meeting with governmental agencies and an evening meeting open to the public. Meetings were scheduled as follows:

July 10, 2001 - Banterra Bank, Metropolis, IL
July 12, 2001 - Victory Theater, Evansville, IN
July 31, 2001 - Mid-Ohio Valley Regional Council , Parkersburg, WV
August 1, 2001 - Community College of Beaver Co., Monaca, PA
August 6, 2001 - Kenton Co. Public Library, Covington, KY
August 7, 2001 - Shawnee State University, Portsmouth, OH

Forty-four people attended the six meetings with agency representatives. More than half the participants represented federal and state resource or regulatory agencies. The remaining participants represented various public agencies or business interests.

A total of 141 people signed in at the six public meetings. Nearly 50 percent of the participants were interested citizens. Approximately 25 percent represented business or development interests, with the largest representation from the shipping industry. The remaining participants included fishermen, elected officials, and representatives of environmental groups, the media and government agencies.

Questionnaires also were available at the meetings and online. Nineteen completed questionnaires were submitted. Additionally, written comments received during scoping consisted of several personal and agency letters and e-mail messages. By late summer, 24 written responses had been received.

ISSUES IDENTIFIED DURING SCOPING

The accompanying table summarizes issues that emerged during scoping and indicates the number of related comments. A more detailed summary of the USACE's scoping process will be part of the Cumulative Effects Assessment when it is completed.

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
OHIO RIVER MAINSTEM SYSTEMS STUDY (ORMSS)		
1) Study may overemphasize transportation and river commerce	1	Comment noted
2) Sufficiency of input from other federal agencies	1	Currently being addressed
3) Issuance of an official Record of Decision (ROD) for ORMSS	1	Will occur
4) Application of Ohio River Navigation Investment Model to ORMSS	1	Will occur
5) Relationship between ORMSS and completion of Olmstead L/D	1	Will be addressed
6) Integration of ORMSS with the U.S DOT Marine Transportation Study	1	Will be addressed
7) Sufficiency of public meeting notification process	4	Comment noted - Notification procedures being revised
8) Procedures for obtaining additional ORMSS information	1	Addressed in meetings
9) Date public scoping period ends	2	Addressed in meetings
10) How to get on mailing list for future meetings or follow-up information	2	Addressed in meetings
11) Use of Waterways Journal to communicate ORMSS information	1	Currently being addressed
12) Use of AWO and DINAMO to notify towing industry of public meetings	1	Currently being addressed
13) Interest in including major tributaries in project scope	3	Comment noted
14) How ORMSS study will affect Greenup L/D upgrade	1	Addressed in meeting
15) Need for ORMSS to address liveability issues of 2-for-3 (EMD) plan	1	Comment noted.
16) Inclusion of no-action alternative in ORMSS	1	Will be addressed
17) Effect an individual can have on ORMSS process	1	Addressed in meeting
18) Need for ongoing coordination & cooperation with concerned agencies &groups	3	Currently being addressed
19) USACE misrepresented intent of scoping meetings and should re-hold them	1	Comment noted - No Further Meetings Planned
CUMULATIVE EFFECTS ASSESSMENT (CEA)		
1) Tendency for CEAs to emphasize negative impacts	1	Comment noted
2) Need for CEA to consider more than navigation structures	3	Will be addressed
3) Need to learn from other CEAs	1	Currently being addressed
4) Interest in including a vision for the river in the year 2060	1	Will be addressed
5) Methods to be used for assessing water quality	2	Currently being addressed
6) Clarification of relationship between CEA and site-specific impacts	2	Addressed in meeting
7) Accuracy of models for predicting population growth & development	2	Will be addressed
8) Relationship between CEA findings and USACE actions	3	Will be addressed
9) Development of ongoing program to reevaluate cumulative effects every 5 years	1	Comment noted
10) How CEA is weighed against cost effectiveness of a project	1	Comment noted
11) Relationship between CEA and SIP product schedules	1	Comment noted
13) Importance of including commercial dredging & associated permitting process in CEA	2	Will be addressed
14) Need to adhere to Council on Environmental Quality's 1997 guidelines for CEAs	1	Currently being addressed
15) Need to consider 404 application approvals and resultant actions as direct USACE actions	1	Comment noted
16) Need to consider most operations of commercial navigation system as direct USACE actions	1	Comment noted
17) Use CEA as a guide in assessing the propriety of USACE projects	1	Comment noted
18) Interest in receiving an executive summary of the CEA	1	Comment noted
19) Interest in documenting CEA process and using the OR CEA as a model for other efforts	1	Comment noted

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
BASELINE CONDITIONS		
1) Need to define, limit and establish parameters of baseline conditions.	10	Currently being addressed
2) Importance of coordination with resources agencies in determining baseline conditions	2	Currently being addressed
3) Need to define parameters for Reasonably Foreseeable Future Actions (RFFAs)	3	Currently being addressed
4) Importance of understanding baselines for different environmental components	2	Currently being addressed
5) Will aquatic studies be performed for baseline condition or construction	1	Addressed in meeting
BARGE OPERATIONS		
1) Loss of shoreline trees and river property caused by barge activity	7	Will be addressed
2) Reliability of barge traffic forecasts	5	Will be addressed
3) Failure of barges to stay in designated shipping lanes	2	Comment noted
4) Increased spills and accidents potentially affecting aquatic life and impairing water quality.	1	Will be addressed
5) Changes in shipping demand as low sulfur coal reserves near depletion in next 25 years	2	Comment noted
6) Possible trash hauling by barges in the future	2	Comment noted
7) Difficulty in gaining access to Monroe Co., OH park property at Sunfish Creek near L/D 14 due to barge loading	1	Will be used & addressed under recreation
8) Why USACE expects only 1% increase in barge traffic, while a 3% increase in gross domestic product is expected	1	Addressed in meeting
9) Barges shine lights into residences.	2	Comment noted
10) OH Division of Watercraft receives many complaints about barges damaging shoreline near Greenup L/D	1	Will be addressed
11) Safety concerns related to uneven arrangement of barges on towboats	1	Comment noted
NAVIGATION INFRASTRUCTURE		
1) Navigation structures presently not keeping pace with traffic demands	3	Will be addressed
2) ORMSS schedule possibly lagging behind future navigation needs	5	Will be addressed
3) Clarification of scheduling and frequency of lock closures	1	Addressed in meeting
4) Eligibility of locks for classification as historic structures	1	Addressed in meeting
5) Possible issuance of bonds to fund navigation improvements	1	Addressed in meeting
6) View of navigation improvements as benefiting only shipping industry	1	Comment noted
7) Status of funding for John T. Myers L/D project	1	Comment noted
8) Assessment and documentation of Olmstead construction	1	Addressed in meeting
9) Why economic forecast model is based on use of auxiliary locks	1	Addressed in meeting
10) Has ORNIM (navigation investment model) been run on the system	1	Addressed in meeting
11) Status of Dashields L/D	1	Addressed in meeting
12) What are current cost estimates onlock extensions at John T. Myers and Greenup L/Ds	1	Addressed in meeting
13) Effects of Greenup L/D/ improvements on barge queueing	1	Addressed in meeting - will be included in CEA
14) What is priority of vessels at locks	1	Addressed in meeting
15) Support expressed for value & maintenance of OR navigation system	3	Comments noted.

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
WATER QUALITY		
1) Cumulative effect of discharges to river may offset water quality improvements.	4	Will be addressed
2) Challenge to water quality presented by CSOs and SSOs	2	Will be addressed
3) High levels of mercury, arsenic, fecal coliform bacteria and agri-chemicals in surface water	1	Will be addressed
4) Need for more stringent discharge permitting procedures or moratorium on permits	2	Comment noted
5) Importance of coordination between USACE and OR public water suppliers	1	Will be addressed
6) Prolonged bureaucratic procedures in obtaining discharge permits	1	Comment noted
7) Possibility of implementing mechanical aeration in mainstem pools	1	Comment noted
8) Importance of continued water quality improvements as a high priority	1	Will be addressed
GROUNDWATER		
1) Overall effects of navigation structures and activities on groundwater levels	1	Will be addressed
2) Need to protect public groundwater supplies.	1	Will be addressed
SEDIMENTATION		
1) Mouths of tributaries silted in, impairing fish habitat, limiting access and damaging property	5	Will be addressed
2) In-stream sedimentation forming bars and causing vessel groundings	1	Will be addressed
3) Need to improve sediment and erosion control from public and private developments	1	Comment noted
4) Need for long-term plan to address silt removal and prevent future sedimentation	1	Comment noted
DREDGING		
1) Damage/destruction of mussel beds and fish spawning areas	4	Will be addressed
2) Possible use of dredge spoils to improve riparian or island habitat or for upland filling	2	Will be addressed
3) Impaired water quality & bioaccumulation in fish tissue of harmful substances stirred up by dredging	2	Will be addressed
4) Importance of maintaining shipping channel	2	Will be addressed
5) Potential partnering with private enterprise to remove marketable aggregates when dredging	1	Comment noted
6) Number of comments that were voiced about in-channel disposal	1	Comment noted
7) Habitat damage caused by Corps permitted commercial sand and gravel dredging		
BANK/SHORELINE INSTABILITY		
1) Bank undercutting & failure caused by increased barge traffic & queuing and wave action	7	Will be addressed
2) Bank erosion caused by USACE-controlled pool fluctuations	3	Will be addressed
3) Shoreline instability threatening costly restoration projects in wildlife management areas	1	Will be addressed
4) Severe erosion occurring at Slough Wildlife Mgmt. Area (downstr. from Henderson, KY)	1	Comment noted

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
POOL ELEVATIONS		
1) Potential adverse effects of higher elevations on bridges, other infrastructure and property	6	Will be addressed
2) Pools maintained at higher level than agreed on in flowage easement contracts with property owners	2	Comment noted
3) Need for elevation management to prevent water levels from exceeding flood stage	1	Comment noted
4) Effects on recreation and quality of life of raising Montgomery pool level	1	Comment noted
5) Coordination of TVA and USACE on management of pool elevations below Tennessee River	1	Comment noted
6) Economic impacts if pool elevations change	1	Comment noted
7) Potential effects on siting of proposed Beaver County Industrial Museum	1	Comment noted
LAND USE		
1) Loss of significant farmland to urban development along river corridor	3	Will be addressed
2) Loss of green space & wildlife habitat with development of marina facilities	5	Will be addressed
3) Development of floodplains & wetlands resulting in increased runoff and habitat loss	4	Will be addressed
4) Need to develop comprehensive plans for development along river	3	Will be addressed
5) Need for coordination with community floodplain coordinators along river	1	Will be addressed
RECREATION/FISHING		
1) Need more public access ramps in each pool to reduce recreational crafts' usage of locks	5	Will be addressed
2) Degradation of recreational value of river caused by increased industrialization	2	Will be addressed
3) Health and safety concerns related to increased traffic and development	3	Will be addressed
4) Effects on fishing caused by water level fluctuations	3	Will be addressed
5) Underrepresenting of fishermen in ORMSS scoping process	1	Comment noted
6) Interest by Ohio to promote Ohio River as a vacation destination	2	Will be used under recreation
7) Increase in barge loading/unloading facilities limiting fishing access from shore	1	Will be addressed
8) Danger to recreational users of submerged trees toppled by bank erosion	1	Will be used under recreation
9) Need for examination of those licensed to operate recreational craft	1	Comment noted
10) Suggestion of greater use of levees for passive recreation	1	Comment noted
11) Increased development of scenic byways and bikeways	2	Comment noted
12) Effects on recreation and heritage sites in Illinois, including Tower Rock Recreation Area	1	Will be used & addressed under recreation
13) Include recreational facilities as design components of L/D revitalization & construction projects	1	Comment noted
14) Need for long-term plan for replacement & maintenance of existing recreational launch ramps	1	Will be addressed
15) Need more access ramps in each pool for emergency response and boating safety officials	1	Will be addressed
FISH & WILDLIFE		
1) Need for fish habitat improvements, including fish passages around locks and dams	2	Will be addressed
2) USACE role when fish kills occur	1	Comment noted
3) Loss of wildlife corridors as shoreline develops	2	Will be addressed under land use
4) Stress and disruption of waterfowl migratory patterns caused by barge traffic	1	Will be addressed under aquatic resources
5) Loss of unique, sensitive species due to water quality problems and habitat modifications	2	Will be addressed.

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
THREATENED & ENDANGERED SPECIES		
1) Need for USACE to coordinate with U.S. Fish and Wildlife Service on these issues	1	Currently being addressed
2) Potential displacement of interior least tern from Cottonwood Island	1	Comment noted.
3) Riverfront development constraints related to endangered species	1	Comment noted
4) Effects related to 3 crayfish species, 2 fish species and 7 freshwater mussel species in IL	2	Will be addressed
EXOTIC/INVASIVE SPECIES		
Need to prevent distribution of exotic /invasive plants and animals through USACE actions	1	Will be addressed
OHIO RIVER ISLANDS		
1) Many islands posted for day use only	2	Comment noted
2) Concern that landowners must sell at USACE's price for OR Islands Nation Wildlife refuge	2	Addressed in meeting - not a USACE project
3) Potential instability of OR islands & futility of creating islands wildlife refuge	2	Will be addressed
CULTURAL RESOURCES		
1) Need to address the Native American Grave protection and Repatriation Act (NAGPRA)	2	Will be addressed
2) Need to contact state historic preservation offices when specific projects are proposed	1	Comment noted
TRASH		
1) Trash increasingly becoming a problem for property owners and river users	6	Comment noted
2) Need for stricter litter laws	1	Comment noted
3) Role of USACE related to litter and debris in river, especially at locks and dams	3	Will be addressed
AESTHETICS		
Impairment of scenic value of river corridor for millions of people living in the Ohio Valley	1	Will be addressed under aesthetics
PRIVATE PROPERTY		
1) Procurement and control of land by the federal government	3	Comment noted
2) Restrictions placed on property owners participating in federal programs	2	Comment noted
ENERGY		
Possibility of developing hydroelectric power at dams	5	Comment noted
ENVIRONMENTAL REGULATIONS		
1) Need to increase funding for & improve enforcement of current regulations & develop new ones	2	Comment noted
2) Estimated number of officers that enforce shipping regulations along OR	1	Comment noted
3) Centralize enforcement efforts	1	Comment noted

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
INTERMODAL TRANSPORTATION FACILITIES		
1) Enhancement of river transportation capabilities through corresponding development/improvement of intermodal transportation facilities	2	Will be addressed
2) Need for long-range coordination with FHWA , state & local transportation agencies	1	Currently being addressed
3) Need to integrate navigation with other transportation modes	2	Will be addressed
ECOSYSTEM RESTORATION PROGRAM (ERP)		
1) How, when and where the ERP will be funded and implemented	7	Addressed in meeting
2) Clarification of relationship between ORMSS and ERP	6	Addressed in meeting
3) Understanding of what constitutes ecosystem restoration	2	Addressed in meeting
4) Potential difficulty in finding non-federal partners	2	Comment noted
5) Ability of partners to raise 35% local match for ecosystem restoration projects	2	Comment noted
6) Inconsistency of ERP with USACE's main objectives	1	Comment noted
7) Potential application of eminent domain in the ERP	1	Comment noted
8) Need for eminent domain in restoration of Ingram Island	1	Comment will be forwarded to ERP team
9) Clarification of relationship between ERP and treatment of municipal stormwater	1	Comment noted
10) Reason only certain construction activities are included in the ERP	1	Comment noted
11) ERP seems to favor projects outside Illinois.	1	Comment will be forwarded to ERP team
12) Will strategic planning for ERP occur	1	Comment will be forwarded to ERP team
13) Need to focus on riparian corridors & green space near power plants	1	Comment will be forwarded to ERP team
14) Importance of considering ERP in the ORMSS "future without project "condition	1	Comment noted
OTHER QUESTIONS/CONCERNS		
1) Clarification of difference between floodway and floodplain	1	LRL owes a response
2) Occurrence of site-specific mitigation for site-specific projects	1	Comment noted
3) Need for USACE to encourage uniformity in navigation charts along length of OR	1	Comment noted
4)Consideration by USACE of side-aside amount and other enhancements separate from mitigation	1	Comment noted
5) Will USACE do site-specific environmental documents for each action	1	Addressed in meeting
6) What about ancillary movement of goods and services in emergencies e.g. bridge destruction	1	Will be addressed
7) Will USACE suggest different BMPs related to certain activities e.g. clamshell unloading	1	Comment noted
8) Effects on 4 Wild & Scenic Rivers proposed for Illinois	1	Will be addressed
9) Importance of continued air quality improvements as a high priority	1	Comment noted
10) Need for adequate financial resources to complete the mitigaiton requirements within the 401 certification program	1	Comment noted

* Denotes total number of times comment was made during the scoping process.

Appendix C
LAND USE

C.1 TABLE OF CONTENTS

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C.2 DEFINITION OF RIVER-RELATED LAND USE

Land uses are related to socioeconomic and ecological resources in the CEA planning context. Consequently, this appendix includes information relevant to several VECs. Land use changes occur as a result of population increases or decreases in localized areas. Economic development and infrastructure projects can also lead to direct changes in land use as well as associated changes in population density. River-related land use applies these concepts to address how human use of the Ohio River has shaped or influenced associated land use patterns and what land use changes may be anticipated in the foreseeable future.

C.3 OBJECTIVES AND SCOPE OF THE LAND USE STUDY

C.3.1 Objectives

This chapter assesses the system-wide cumulative land use impacts of all likely major navigation improvements along the mainstem of the Ohio River from 2000 - 2060. Land use impacts that are directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present and reasonably foreseeable future actions (RFFA) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFA. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, and predictions of general economic expansion and development.

The results of the cumulative effects assessment are intended to contribute to two topics of subsequent public debate; whether the impacts of the RFFAs constitute acceptable outcomes for the affected resources and how the proposed navigation improvements contribute to those outcomes.

C.3.2 Geographic Scope

The geographic focus for land use impacts includes those regions most directly impacted by operation and maintenance of the navigation system. This includes lands along either bank of the Ohio River lying “between the bluffs.” This “floodplain zone” is defined as the meander channel of the Ohio River and includes the 100 and 500 year floodplains as well as terraces of level land lying above these flood zones. Land use patterns are also discussed in the context of larger adjacent regions (e.g. counties adjacent to the main stem of the Ohio River or multi-county metropolitan areas). Statewide land use patterns are discussed for purposes of comparing the Ohio Valley area to regional patterns and trends.

C.3.3 Time Frame

The established time frame for this project is 1920 to 2060. The earlier date approximates the initiation of Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the Ohio River Main Stem Study (ORMSS).

Discussion of land use patterns requires consideration of settlement and development patterns prior to 1920. Understanding some of the general factors that contributed to the land use patterns (and ongoing trends) along the Ohio River in 1920 will be important to

discussion of how the lock and dam construction activities contributed to subsequent changes in land use patterns.

C.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. A more detailed discussion of the scoping meetings is presented in Chapter 2 – Procedure and Special Methods.

185 people attended the meetings and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Comments that directly or indirectly addressed land use issues are presented in **Table C-1**.

TABLE C-1
Comments from Public Scoping Meetings

Direct Land Use Comments	Total
Loss of green space & wildlife habitat with development of commercial and recreational docking/loading facilities	5
Development of floodplains & wetlands resulting in increased runoff and habitat loss	4
Loss of significant farmland to urban development along river corridor	3
Need to develop comprehensive plans for development along river	3
Need for coordination with community floodplain coordinators along river	1
Other Comments with Land Use Implications	
Loss of shoreline trees and river property caused by barge activity	8
Bank undercutting & failure caused by increased barge traffic, queuing and wave action	7
Potential adverse effects of higher pool elevations on bridges, other infrastructure and property	6
Bank erosion caused by USACE-controlled pool fluctuations	3
Possible use of dredge spoils to improve riparian or island habitat or for upland filling	2
Shoreline instability threatening costly restoration projects in wildlife management areas	2
Loss of wildlife corridors as shoreline develops	2

C.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

Land use patterns in this chapter are discussed primarily with reference to use definitions and measurements of the Natural Resources Conservation Service (NRCS) National Resources Inventory (NRI). The NRI is conducted every five years (most recently in 1997) and measures actual use of nonfederal lands. Use categories include cropland (row crops such as corn, soybeans or wheat), pastureland (grazing and hay production), forest land, developed land, and other (primarily federal land plus open water). The category for developed land is intended to identify lands that have been

permanently removed from the rural land base and includes: large tracts of urban and built-up land, small tracts (<10 acres) of built-up lands, and land outside of built-up areas that is in roads, railroads and associated rights-of-way (USDA, Dec. 2000). The NRI provides published data at the state level for the years 1982, 1987, 1992, and 1997.

NRI data for 1992 was also utilized in development of the National Land Cover Data Project (NLCD92). This product was prepared by the National Land Cover Characterization project and provides thematic mapping of land use patterns for the coterminous U.S. This multi-agency project (USGS, NRCS, EPA, others) utilized satellite data and supporting information including topography, census, agricultural statistics, soil characteristics, other land cover maps, and wetlands data to determine and label the land cover type at 30 meter resolution. Twenty-one classes of land cover were mapped, utilizing a modified Anderson level II classification (Vogelmann, 2001).

Indicators of environmental sustainability, which vary by VEC, generally provide benchmarks for measuring cumulative effects on a given resource or VEC. In the context of this study, the principal environmental sustainability indicators would appear to be developed land and the rate at which other land uses are converted to developed land.

C.6 LAWS, REGULATIONS, ORDINANCES AND PROGRAMS

Land use patterns in the U.S. are primarily unregulated or locally regulated, no federal or state laws directly control how privately owned land is used within the six states of the Ohio Valley. A limited set of federal and state resource protection regulations (wetlands mitigation, dredge and fill permits, protection of cultural features) may provide some indirect influence on land use decisions, but these regulations do not specifically prohibit any proposed development. Land use planning and zoning is traditionally the responsibility of local municipalities, supplemented by the coordinating role of regional planning authorities in some locations.

Most planning authorities treat agricultural uses within their jurisdiction as unregulated and focus on the management (or promotion) of development activities. Planning authorities typically seek to achieve identified outcomes by establishing zones for specified activities and providing (or withholding) infrastructure related to the desired activity. Competing actions of individual municipalities can be counterproductive and regional authorities are intended to balance development so that all participants may benefit. The regional approach often focuses on development of regional transportation infrastructure and larger scale industrial zones to keep or attract desired business activities. However, economic growth or decline in any area is dependent on a large and complex set of factors and planning authorities are likely to operate in a primarily reactive mode when economic change proceeds contrary to predicted or desired outcomes.

C.7 PAST TO CURRENT BASELINE CONDITIONS

C.7.1. Settlement and Development Patterns Prior to 1920

Pioneer settlement within the Ohio River valley prior to the 1790's was constrained by French and British interests in maintaining their claims of sovereignty within the region. While these efforts did prevent or postpone early colonization efforts, American interests were well aware of resource opportunities in the region as the cumulative result of

military and peacetime surveying expeditions dating from the French and Indian Wars of 1754 ($USACE_c$ pg. 3-4). Pressure to colonize the area was furthered by the awarding of lands in the Northwest Territories to veterans of the American Revolution. However, Native American resistance (often supported by British influences) continued to minimize colonial settlements in the area. It was not until Anthony Wayne's victory at the Battle of Fallen Timbers in northwestern Ohio in 1794 and the conclusion of the Treaty of Greeneville in 1795 that the threat of Indian attacks on Upper Ohio River settlements was eliminated and the development of towns and communities in the river valley could proceed unimpeded ($USACE_c$ pg. 3-8). The population within the Ohio Valley grew from 125,000 in 1790 (the first Federal Census) to 850,000 in 1810 ($USACE_c$ 3-55).

The decades of pre-settlement military activity necessitated the establishment of several fortifications along the Ohio River or its tributaries and these often became the sites of the earliest settlements within the region. The most notable example is Pittsburgh, located at Fort Pitt (circa 1758), other examples include fortifications preceding the establishment of towns at Marietta, OH and Wheeling and Point Pleasant, WV ($USACE_c$ 3-8). Other factors contributing to the initial location of towns along the Ohio River generally included the availability of high ground for a town site above the flood zone, connectivity between the town and a productive hinterland, and certain 'port development opportunities' such as the Falls of the Ohio at Louisville or location of the national road crossing at Wheeling. Initial settlements within the region tended to cluster along the Ohio River because the river was the primary access to the region.

A variety of factors influenced the subsequent growth and decline of Ohio River towns from 1830's to 1920's. Some early riverfront settlements subsequently prospered as hubs or service centers to interior regions accessed through these towns. As the hinterlands developed, the river towns continued to grow as ports for the assembly and shipping of the region's produce. During the early decades of this period, the Ohio River provided the primary mode of transportation, both for immigration of new settlers and for transport of regional products. The earliest flatboats and keelboats mostly provided one-way transport downstream, necessitating shipment of produce through New Orleans and coastal shipping to reach eastern markets. The arrival of steamboats around 1815 permitted two-way traffic and greatly reduced travel times ($USACE_c$ 3-60). However, the Ohio River remained largely unimproved prior to the 1920's and the ability to move produce was constrained by the seasonal availability of high water flows sufficient to support navigation. Development of the Ohio River in the 1800's included the removal of snags, completion of the initial canal and locks around the Falls of the Ohio at Louisville in 1833, and completion of the first wicket dam (Davis Island, Pittsburgh) in 1885.

Inland canals provided the first significant alternative or supplement to river transport, beginning in 1825 with completion of the Erie Canal from Buffalo to New York City. Important canals in the Ohio River Valley included the Ohio & Erie which connected Lake Erie to Portsmouth, OH; the Pennsylvania Mainline from Pittsburgh to Philadelphia; and the Pennsylvania & Ohio, connecting Pittsburgh to the Mahoning River Valley in Ohio ($USACE_c$ 3-21). By 1830, approximately 3,000 miles of canal operated in the United States. Canals provided nearly year-round transportation and the ability to ship products more directly to eastern markets instead of overland from Upper Ohio, Allegheny, or Monongahela ports. On balance, canal development probably supplemented river traffic more than it competed with or replaced river traffic; steamboats hauled goods to canal terminals on the Ohio River, creating an early form of multi-modal ports.

Railroads provided a far more significant level of competition to river transport and quickly became the primary means of commercial transportation in the region. They provided true year-round transport capabilities, greatly reduced transport times, and could be quickly built to serve any point-to-point opportunity. The first railroad in the Middle Ohio River Valley was completed in the 1840's, connecting Lake Erie with the Ohio River. By 1850, 242 miles of track were completed in the Middle Ohio River Valley. By 1855, this number exploded to 1247 miles, and virtually saturated rail transport opportunities in the region. Rail mileage in the region grew only an additional 80 miles by 1860 ($USACE_c$ 3-25). Railroads almost immediately rendered canals obsolete, sometimes laying track beside or over the abandoned canals.

Commercial river transport also declined at a slow but steady pace in competition with railroads. The year-round operability of rails had a distinct advantage over the seasonal limitation of steamboats. Inland cities with good rail connections grew substantially. To a large degree, the early river port towns along the Ohio River either prospered or perished with the railroads, depending on their ability to attract rail service. Subsequently, further prosperity came to most towns able to establish railroad bridges across the Ohio River.

The latter part of this era includes the period of heavy industrial development along the middle and upper Ohio River. This development centered on the iron and steel industry in Pittsburgh, with its convergence of proximity to raw materials, coal, river water and rail and river transportation to move materials and produce in and out of this center. An almost continuous band of industrial development became established along the Ohio River floodplain from Weirton to Pittsburgh. To compensate for the limited availability of high ground within this corridor, industries built up elevation of the floodplain for their developments. The steel industry typically used large quantities of slag as fill material (Rieger, personal communication).

C.7.2 Settlement and Development Patterns 1920 to Present

Construction of the system of wicket locks and dams ultimately revitalized the Ohio River as a major transportation corridor. Following construction of the first project in 1885 (Davis Island) the next lock and dam was not finished until 1904. Surprisingly, initial construction of the dams was opposed by some members of the barge industry, who feared that breaking up multiple barge tows for passage through the locks would make river freight impractical ($USACE_c$: 1-18). However, completion of the initial projects proved the advantages of this navigation development. Six lock and dam projects were completed between 1904 and 1910, 23 were completed between 1911 and 1920, and the entire system of 50 lock and dam projects was completed by 1929. The original design for a navigation depth of six feet was modified in 1910 to provide for a nine-foot depth.

Sentiment of rivermen began to change to favor canalization after the Davis Island Lock was in operation. During an unexpected flood in July 1888, one hundred coal barges sank along the Ohio River, but no barge in the harbor behind Davis Island was lost. Industry located along the Davis Island pool benefited from a more reliable water supply. Fears that the pool would be stagnant and a breeding ground for disease proved unfounded. Instead, sewage and other obnoxious effluents which had formerly rotted along the

shoreline during low water periods were washed away. Both rivermen and industrialists urged the extension of canalization downriver (Johnson 1977:95).

Even as construction of the slackwater system continued, river traffic declined. In 1917, cargo carried on the river reached a low of about 4.6 million tons, a nadir caused largely by the abrupt halt of coal shipments from Pittsburgh to New Orleans. The turning point for the slackwater system was during World War I. Wartime shipping overburdened the country's land transportation system and by 1920, cargo volume on the Ohio River had risen to almost 9.4 million tons, a total that increased further to 10.8 million tons in 1924 (Froggett 1926a), 16 million tons by 1925 (Froggett 1926b), and 22.3 million tons by 1930 (Robinson 1983:28-29; USACE-ORD 1979:22). Where traffic once consisted primarily of coal and steel products moving downstream, new products were being added as the century progressed. Freight soon included petroleum and its products, iron and steel, dry and liquid chemicals, grain, cement, and a variety of other items (Gaum 1970:487), and upstream traffic substantially increased in volume.

Commerce on the river grew steadily through the 1930s and 1940s while development of diesel towboats and larger barges created opportunities for larger scale, more efficient movement of commodities. Designed for about 15 million tons of commerce annually, the old locks and dams handled more than 70 million tons in 1954; in addition, traffic moving upstream on the Ohio had nearly equaled that moving downstream. Plans to improve system efficiency and accommodate the larger tugs and barges called for reducing the number of dams by building high-lift projects with larger capacity locks. The final plan, approved in 1954, envisioned a total of 19 high-lift projects with dual lock chambers and began with the construction of Greenup and New Cumberland L&Ds, although construction of Emsworth, Dashields, Montgomery and Gallipolis L&Ds during the 1930s had already replaced some old locks and wicket dams on the upper river. Implementation of the current phase of lock extensions overlaps completion of the mid-century modernization program. Olmsted, which will complete the 1954 modernization plan, will replace L&D 52 and 53 (Johnson, 1992).

During this era of sustained urban growth, the demands of industrial and commercial development outpaced the availability of land within some of the rapidly growing riverfront urban centers. Within the Huntington and Louisville Districts, a series of levee and floodwall projects were completed during the 1930s and 1940s to secure more land for development as well as to protect existing properties against flooding. Rapidly growing cities also expanded beyond the river floodplain to higher ground, utilizing mass transit (light rail, bus) and automobiles to connect their expanding fringe with the urban riverfront core.

The availability of reliable, inexpensive electric power contributed significantly to the industrial and commercial growth of the Ohio Valley. Construction of the wicket dams contributed to bulk transport of the region's coal and provided stable pool elevations for the construction of coal fired utilities on the Ohio River and its primary tributaries. Over the years, economies of scale have favored development of the very large power plants that are now a part of the riverfront landscape of the Ohio Valley.

C.7.3 Current Land Use Patterns and Trends in the Ohio River Valley

C.7.3.1.Enhanced Satellite Data

The National Land Cover Data 1992 (NLCD92) product was prepared by the National Land Cover Characterization project and provides thematic mapping of land use patterns for the coterminous U.S for the year 1992. The project utilized satellite data and supporting information including topography, census, agricultural statistics, soil characteristics, other land cover maps, and wetlands data to determine and label the land cover type at 30 meter resolution. Twenty-one classes of land cover were mapped, utilizing a modified Anderson level II classification (Vogelmann, 2001). {Note: The growing need for land-cover and other geospatial data within the federal government culminated in reforming the MRLC Consortium again in 2000 (MRLC 2001), with a second generation national land-cover data set to be developed from year 2000 data called National Land Cover Data 2000 (NLCD 2000). This land-cover mapping effort will be developed using a database approach, which provides flexibility in developing a suite of independent data layers that provide more generic flexibility in applying the database to even more relevant applications. Full production development is anticipated to begin in 2002, with completion targeted for 2004.}

The following illustrations were derived from the NLCD92 data source to provide a qualitative overview of land use patterns within the Ohio River floodplain and adjacent lands. **Figures C-1 through C-11**, plus a description of land cover classifications, are provided at the end of this Exhibit.

Pittsburgh, PA to Steubenville, OH; river mile 0 to 62 (see **Figure C-1**, Ohio River at Pittsburgh, PA).
The floodplain is very constricted, with the river at ordinary high water typically accounting for 30 to 60 per cent of total area of the floodplain (defined as approximately level terrain between steeper bluffs). Low and high-density urban uses (commercial, industrial, high-density residential and low-density residential) dominate all the floodplain, including islands in the upper half of the river reach. Deciduous forest dominates bluffs or steep areas adjacent to the river outside urbanized areas, low-density residential or deciduous forest dominates bluffs within the urbanized areas. Eight islands (3 very small) are visible in the imagery (at maximum magnification).

Low and high-density urban uses dominate upland areas in the eastern half of the area (Pittsburgh area) and also in Beaver, PA and East Liverpool, OH. Deciduous forest and pasture are the principal land uses outside of the urbanized areas. Only a few small areas of cropland or mixed forest (mixed deciduous and evergreen forest) are visible.

Steubenville, OH to Parkersburg, WV; river mile 62 to 187 (**Figure C-2**, Ohio River, Wheeling, WV to Steubenville, OH and **Figure C-3**, Ohio River, Parkersburg, WV to New Martinsville, WV).
The floodplain is very constricted. Significant low and high-density urban uses occur along the full length of this reach and are the dominant land use within the floodplain upstream of Moundsville, WV. The floodplain is primarily in row crops or pasture outside of the urbanized areas, with only a few small areas of deciduous forest. Deciduous or

mixed forest dominates bluffs or steep areas adjacent to the river. Nineteen islands (6 very small) are visible in this reach.

Deciduous forest dominates land use in the upland areas, with pasture as the secondary use. A few urban patches are scattered through upland areas upstream of Moundsville but are confined to upland areas adjacent to the river in communities downstream to Parkersburg. Patches of mixed forest occur throughout the uplands. Only a few small areas of row crop use are visible, some mining or transitional surface use is also visible.

Parkersburg, WV to Ironton, OH; river mile 187 to 323 (**Figure C-4**, Ohio River, Huntington to Parkersburg, WV).
The floodplain is very constricted, widening somewhat in the Huntington to Ironton area. The reach between Huntington and Parkersburg is primarily rural, with only a few small urban areas visible at Gallipolis/Point Pleasant, WV, Cheshire, OH, and Pomeroy, WV. Land use in the floodplain in this section is a mixture of pasture and row crop. Urban land uses dominate the floodplain between Huntington and Ironton. Four islands are visible.

Deciduous forests dominate Upland areas, with pasture the secondary land use. Patches of mixed forest and areas of mining or transitional surface use occur throughout the uplands. Only a few small areas of row crop use are visible.

Ironton, OH to Foster, KY; river mile 323 to 439 (**Figure C-5**, Ohio River, Maysville to Ashland, KY).
The floodplain remains wider from the Ironton/Huntington area to west of Portsmouth, OH then gradually returns to the constricted configuration of the upper river. Land use within the floodplain is primarily row crops with some pasture and a few small areas of wooded wetlands (bottomland hardwoods). Slopes or bluff areas adjacent to the river are primarily deciduous. Urban land use within the floodplain is visible at Ironton/Greenup, Portsmouth, and Maysville. Three islands are visible.

Upland areas are predominately deciduous forest in the eastern and central portions of this area, but give way to mixed pasture and row crops in the western third. Significant row crops are also evident in the broad floodplain of the Scioto River above Portsmouth and significant wooded wetlands occur in floodplains of the Little Sandy River southeast of Portsmouth. Areas of mining or transitional use are scattered through the eastern portion of this area.

Foster, KY to Ghent, KY; river mile 439 to 537 (**Figure C-6**, Ohio River at Cincinnati).
The floodplain remains constricted through the eastern portion of this reach, with the river surface typically accounting for 40 to 60 per cent of the floodplain area. Following the confluence with the Great Miami River, the floodplain broadens somewhat, with the river surface typically accounting for 20 to 40 per cent of the floodplain area. Low and high-density urban use dominates the floodplain in the Cincinnati/Covington/Newport area. Urban use is also visible west of Cincinnati at Cleves, Oh and Lawrenceburg and Rising Sun, IN. Land use in the floodplain east of Cincinnati is primarily a mix of row crops and pasture. Row crops dominate land use in the broader floodplain west of Cincinnati, with some pasture and a few small areas of wooded wetlands. One island is visible in this reach.

Urban uses dominate upland areas adjacent to the Cincinnati area and also occur in scattered patches north, east and south of Cincinnati. Non-urban areas throughout the region include a mix of row crop, pasture, and deciduous forest, with significant row crop areas in the Great Miami floodplain and several areas of wooded wetlands in the floodplains of tributary streams in Kentucky.

Ghent, KY to West Point, KY; river mile 537 to 630 (**Figure C-7**, Ohio River at Louisville).
The floodplain returns to the more constricted form, with river surface accounting for 40 to 60 per cent of the floodplain area. Low and high-density urban use dominates the floodplain in the Louisville/Clarksville/Jeffersonville area. Urban use is also visible east of Louisville at Madison, In, Carrolton, KY, and Vevay/Ghent. Floodplain use outside of urban areas includes a mix of row crops, pasture, and some wooded wetlands. Deciduous forest dominates bluff areas adjacent to the river. Six islands are visible in this reach.

Urban uses dominate upland areas surrounding Louisville and are also visible as smaller patches throughout the area. Non-urban areas throughout the region include a mix of row crop, pasture, and deciduous forest use, with significant areas of wooded wetlands in tributary floodplains northeast of Louisville and scattered patches of mixed forest in Indiana. The large commercial/other area north of Louisville is the Indiana Army Ammunition Plant (INAAP).

West Point, KY to Lewisport, KY; river mile 630 to 737 (**Figure C-8**, Ohio River at Fort Knox).
The floodplain gradually widens from east to west through this reach of the river, with river surface accounting for 20 to 40 per cent of floodplain area in the western area. Urban land use within the floodplain is restricted to a few small centers, including Tell City, IN and Brandenburg, KY. Row crops and pasture are the dominant land uses within the floodplain, with a few small areas of wooded wetlands. Deciduous forest is prominent along bluffs adjacent to the river. One small island is visible in this reach.

Upland areas include deciduous forest (dominant in the central area) and mixed row crop and pasture (dominate in the east and west portions of the area). Significant urban use is located in the Fort Knox area and significant wooded wetlands are located in bottomlands of the Salt River on the east side of Fort Knox.

Lewisport, KY to Wabash River, IN; river mile 737 to 848 (**Figure C-9**, Ohio River at Evansville).
The floodplain continues to widen from east to west through this reach of the river, with river surface accounting for 10 to 20 per cent of floodplain area near the Wabash River confluence. Limited urban land use occurs in floodplain areas of Evansville, IN and Henderson and Owensboro, KY but the majority of urban area for these cities is located on adjacent uplands. Extensive areas of row crop agriculture dominate floodplain land use, with significant secondary areas of wooded wetlands and some pasture and deciduous forest. Deciduous forest is also prominent along bluffs adjacent to the river. Sixteen islands (5 very small) are visible.

Row crop agriculture and pasture (including significant row crop agriculture in the Wabash River floodplain) dominate land use in upland areas, with lessor tracts of deciduous forest and some significant areas of wooded wetlands along tributary floodplains. Several areas

of mining activity, scattered tracts of mixed forest, and a few urban centers (Morganfield and Sebree, KY) are also visible.

Wabash River, IN to Cairo, IL; river miles 848 to 981 (**Figure C-10**, Ohio River at Confluence with Wabash River and **Figure C-11**, Ohio River at Confluence With Mississippi River and Paducah, KY).
The floodplain is narrowed somewhat near Shawnee National Forest southwest of Wabash River but returns to broad floodplain configuration from Paducah to the confluence with the Mississippi River. Limited urban land use occurs in floodplain areas of Paducah, KY and Metropolis and Cairo, IL. Row crop agriculture is the dominant floodplain land use, with significant secondary areas of wooded wetlands and some pasture and deciduous forest. Deciduous forest is also prominent along bluffs adjacent to the river. Nineteen islands (4 very small) are visible.

Upland land use includes a mix of row crop agriculture, pasture and deciduous forest, with significant areas of wooded wetlands in tributary bottomlands and some fairly large blocks of mixed forest. Significant urban land use is visible in areas adjacent to Paducah and at Calvert City, KY.

C.7.3.2 National Resource Inventory (NRI) Data

The NRI is conducted every five years and measures actual use of nonfederal lands. Use categories discussed in this report include cropland (row crops such as corn, soybeans or wheat), pastureland (grazing and hay production), forest land, developed land, and other (primarily federal land plus open water). The category for developed land is intended to identify lands that have been permanently removed from the rural land base and includes: large tracts of urban and built-up land, small tracts (<10 acres) of built-up lands, and land outside of built-up areas that is in roads, railroads and associated rights-of-way (USDA, Dec. 2000). The NRI provides published data at the state level for 1982, 1987, 1992, and 1997. NRI data for the six states in the study area is presented in **Table C-2** and data for groups of counties adjacent to the Ohio River is presented in **Table C-3**.

TABLE C-2
Statewide Land Use Patterns

State	Year	Total Acreage	% Crop Land	% Pasture Land	% Forest Land	% Rural Land	% Developed
IL	1982	36,058.70	68.6%	8.9%	9.9%	89.2%	7.5%
	1987	36,058.70	68.8%	8.2%	10.0%	88.8%	7.9%
	1992	36,058.70	68.8%	7.7%	10.1%	88.5%	8.1%
	1997	36,058.70	68.6%	6.9%	10.5%	87.8%	8.8%
IN	1982	23,158.40	59.5%	9.5%	16.3%	88.5%	7.9%
	1987	23,158.40	60.4%	8.3%	16.4%	88.0%	8.4%
	1992	23,158.40	60.1%	7.9%	16.4%	87.5%	8.9%
	1997	23,158.40	59.5%	7.9%	16.3%	86.7%	9.8%
KY	1982	25,863.40	22.9%	23.0%	40.4%	89.1%	4.4%
	1987	25,863.40	21.9%	22.8%	40.6%	88.1%	5.2%
	1992	25,863.40	21.3%	22.8%	41.0%	87.3%	5.8%
	1997	25,863.40	21.3%	22.0%	41.2%	86.3%	6.7%
OH	1982	26,444.80	47.1%	10.5%	25.2%	86.7%	10.5%

State	Year	Total Acreage	% Crop Land	% Pasture Land	% Forest Land	% Rural Land	% Developed
	1987	26,444.80	46.9%	9.3%	26.1%	85.9%	11.3%
	1992	26,444.80	46.3%	8.8%	26.2%	84.8%	12.3%
	1997	26,444.80	45.2%	7.6%	26.8%	83.5%	13.7%
PA	1982	28,995.20	20.3%	9.0%	53.5%	86.2%	9.7%
	1987	28,995.20	19.8%	8.5%	53.8%	85.5%	10.4%
	1992	28,995.20	19.6%	7.9%	53.2%	84.0%	11.9%
	1997	28,995.20	19.2%	6.4%	53.4%	82.1%	13.7%
WV	1982	15,508.20	7.1%	12.2%	67.1%	88.0%	3.8%
	1987	15,508.20	6.4%	11.3%	68.2%	87.7%	4.0%
	1992	15,508.20	5.9%	10.4%	68.2%	86.6%	4.5%
	1997	15,508.20	5.6%	9.8%	68.2%	85.5%	5.6%
TOTALS	1982	156,028.70	40.9%	12.0%	32.3%	88.0%	7.6%
	1987	156,028.70	40.8%	11.2%	32.7%	87.4%	8.2%
	1992	156,028.70	40.4%	10.7%	32.7%	86.5%	8.9%
	1997	156,028.70	40.0%	9.9%	32.9%	85.4%	10.0%

Source: USDA Dec 2000

TABLE C-3
Land Use Patterns for Counties Along the Ohio River

State	Year	Total Acreage	% Crop Land	% Pasture Land	% Forest Land	% Rural Land	% Developed
IL	1982	1,334.10	50.7%	13.9%	17.8%	82.4%	2.5%
	1987	1,334.10	51.9%	12.2%	18.0%	82.1%	2.6%
	1992	1,334.10	52.3%	11.1%	17.9%	81.3%	2.7%
	1997	1,334.10	51.9%	11.0%	18.3%	81.2%	2.9%
IN	1982	2,646.40	37.0%	16.0%	29.9%	82.9%	7.8%
	1987	2,646.40	37.4%	15.0%	30.0%	82.4%	8.2%
	1992	2,646.40	36.7%	15.0%	29.9%	81.6%	8.5%
	1997	2,646.40	36.7%	14.7%	29.8%	81.2%	9.2%
KY[1]	1982	1,491.50	12.9%	24.4%	50.9%	88.2%	7.5%
	1987	1,491.50	12.6%	23.2%	51.5%	87.3%	8.5%
	1992	1,491.50	11.1%	22.2%	53.5%	86.8%	9.6%
	1997	1,491.50	11.0%	18.3%	55.3%	84.6%	11.5%
KY[2]	1982	3,388.10	36.3%	21.6%	24.6%	82.5%	7.7%
	1987	3,388.10	36.2%	19.2%	26.0%	81.4%	8.8%
	1992	3,388.10	36.0%	17.7%	26.5%	80.2%	9.9%
	1997	3,388.10	34.3%	17.3%	26.7%	78.3%	11.5%
OH	1982	4,494.10	21.4%	16.4%	45.3%	83.1%	8.2%
	1987	4,494.10	21.4%	14.5%	46.8%	82.7%	8.8%
	1992	4,494.10	20.9%	13.9%	46.7%	81.5%	9.5%
	1997	4,494.10	20.3%	11.2%	48.5%	80.0%	10.7%
PA	1982	2,994.50	18.0%	12.6%	47.9%	78.5%	15.8%
	1987	2,994.50	16.7%	12.2%	48.2%	77.1%	17.8%
	1992	2,994.50	16.3%	11.1%	47.0%	74.4%	19.8%
	1997	2,994.50	16.8%	8.2%	46.9%	71.9%	22.6%
WV	1982	2,209.30	10.8%	15.7%	62.8%	89.3%	4.0%
	1987	2,209.30	10.1%	14.7%	64.1%	88.9%	4.3%
	1992	2,209.30	9.0%	14.1%	64.7%	87.8%	4.8%
	1997	2,209.30	8.3%	13.5%	64.9%	86.7%	6.0%
TOTALS	1982	17,223.90	26.7%	17.2%	39.9%	83.8%	7.6%
	1987	17,223,90	26.6%	15.9%	40.7%	83.1%	8.4%
	1992	17,223,90	26.0%	15.0%	40.9%	81.9%	9.3%
	1997	17,223.90	25.6%	13.5%	41.5%	80.6%	10.6%

[1]KY – Boone County and East; [2]KY– West of Boone County
Source: USDA Dec 2000

C.7.3.3 Statewide Data

This data may not be directly comparable to land use patterns along the Ohio River, but should be approximately comparable to data for the Ohio River Valley (ORV). **Table C-3** illustrates the preponderance of cropland in Illinois, Indiana and Ohio and forestland in West Virginia and Pennsylvania. Kentucky has the highest percentage of pastureland and ranks third in forestland. Four of the six states in the ORV (OH, PA, IL, IN) have a

higher proportion of developed area than the national average, which was 6.6% in 1997. For the six-state total, 10.5% of the area was developed as of 1997.

With respect to statewide trends, all six states show significant increases in the amount of developed land. Additionally, the rate of development increases during the reporting period for all six states. Cumulatively for the six states, 0.6% of total land area was developed from 1982 to 1987, 0.8% was developed from 1987 to 1992 and 1.2% from 1992 to 1997 (double the 1982-1987 development rate). The total area of developed land within the six states increased by 32% during the 15 years covered by this data. This compares closely to the national increase of 34% during the same period. Nationally, an average of 1.4 million acres per year was developed from 1982 to 1992. This increased to an average of 2.2 million/year from 1992 to 1997.

It seems likely that the accelerating rate of development illustrated above has continued from 1997 to 2002. Housing construction has not slowed down the past two years, partly because of federal interest rate reductions that have contributed to record low mortgage rates. A conservative estimate would set land developed from 1997 to 2002 as equal to the total developed from 1992 through 1997, or 1.2% of total land within the six states. Thus it is estimated that 11.7% of total land area within the six states has been developed for urban/commercial/industrial use as of 2002.

C.7.3.4 Data for Counties Adjacent to the Ohio River

These data have been grouped to provide regional information for individual segments of the river. NRI data is collected via a sampling protocol and grouping is necessary to avoid distortions due to sampling error that may occur when data is reported for individual counties. Information about the groups of counties adjacent to the Ohio River can be compared to statewide data or to the NLCD92 imagery.

The seven-county area in Illinois that lies adjacent to the river accounts for only 3.7% of the state's total land area. Row-crop land use of 52% reflects extensive use of the broad floodplain for this type of production. Percentages for pasture (11%) and forested (18%) land use reflect the general mixed-use pattern in the upland areas. Only 2.9% of this region is developed, which is consistent with the scarcity of urban/commercial areas in the NLCD92 imagery.

Extensive row-crop agriculture in the broad floodplain of the western Ohio River is also reflected in the cropland percentages for Indiana (37%) and western Kentucky (35%). These counties also reflect a mixed-use pattern of cropland, pasture (IN-15%, KY-18%) and forestland (IN-30%, KY-27%) in areas away from the floodplain similar to the patterns in southern Illinois. Indiana counties adjacent to the Ohio River account for about 11% of the state's land area, while Western Kentucky counties (Gallatin to Ballard) account for about 13% of that state's total.

Development in Indiana's river counties (9.2%) is similar to the state average (9.8%), but reflects a somewhat slower rate of growth over the 15-year reporting period (18% vs. 24%). Western Kentucky's development is well ahead of the state composite (11.5% vs. 6.7%) but the rate of growth is about the same (49% vs. 52.3%). The NLCD92 imagery illustrates the primary growth near Louisville and other growth areas of Owensboro, Henderson and Paducah, Kentucky and Evansville, Clarksville and

Jeffersonville, Indiana. The NLCD92 imagery also illustrates that most urban growth, which originated on the river, is now occurring on inland areas above the floodplain.

Ohio counties adjacent to the Ohio River encompass about 17% of the total area of the state. These counties have almost twice as much forestland as the state average (48% vs. 27%) but less than half the state average for cropland (20% vs. 44%). The developed area of 10.7% is close to the state average of 12.4% and the rate of development (30% vs. 33%) is also close. The NLCD92 imagery illustrates that the Ohio River floodplain is quite narrow throughout most of this stretch and also illustrates the dominance of forest cover except for the Cincinnati urban areas in Hamilton and Clermont counties. The imagery also illustrates the concentration of development within the floodplain in middle and upper reaches of the river in contrast with the rural nature of the surrounding countryside.

Eastern Kentucky counties from Boone to Boyd are quite similar to their Ohio counterparts across the river, with 55% forest cover and 11.5% developed area, although more of the cultivated land is in pasture rather than row crops. These counties account for about 5.8% of total state area and are considerably ahead of the state in terms of developed area (11.5% vs. 6.7%). However, the rate of development is approximately equivalent (53.3% vs. 52.3%). The NLCD92 imagery shows that most of the development is located in the Boone, Kenton and Campbell county area opposite Cincinnati, with a secondary concentration in the Ashland/Greenup area.

West Virginia Counties on the Ohio River account for about 15% of the state's land area and closely resemble statewide averages in all categories. The NLCD92 imagery shows that these counties are heavily forested, with most of the developed and row crop areas concentrated in the floodplain along the river.

Only two counties in Pennsylvania are adjacent to the Ohio River. NRCS data presented here represents the six Pennsylvania counties in the Pittsburgh MSA. As would be expected, the developed area for this metropolitan region is higher than the state average and higher than the mixed urban/rural zones covered by the other county groupings. The overall rate of development (43%) is close to the state average of 41%.

C.7.3.5 Demographic Data

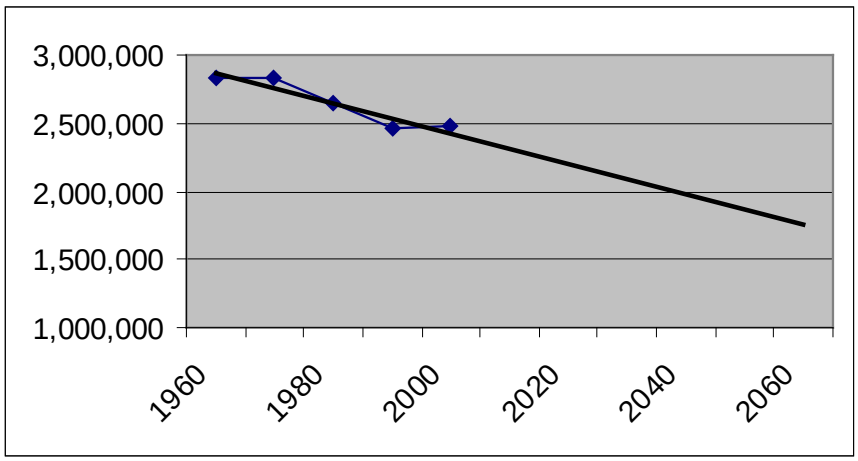
County populations and trends can provide an additional perspective on land use patterns described in the preceding discussions. **Figures C-12 through C-25** illustrate population and trends for Metropolitan Statistical Areas (MSAs) along the Ohio River and for groups of rural counties adjacent to the Ohio River between the metropolitan areas. The trends are simple straight-line projections based on the five data points shown in the figures.

These figures illustrate a dramatic contrast between long-term population declines on the upper river, potentially level trends in the middle reach, and ongoing growth along the lower river.

The population of the Pittsburgh MSA (**Figure C-12**) has been declining steadily from a 1960 peak of 2,838,797 to the 2000 Census population of 2,470,770. The MSA consists of an urban core county (Allegheny) and six outlying counties. Two counties,

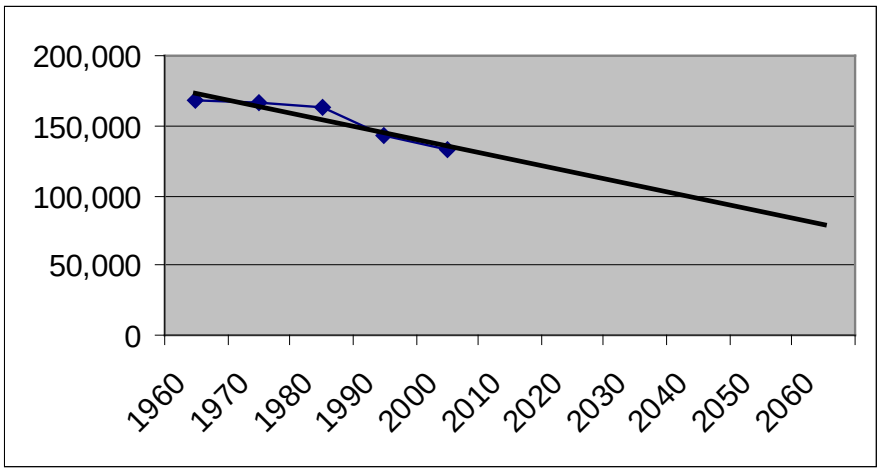
Allegheny and Beaver, are adjacent to the Ohio River. The core county and four of the outlying counties (including Beaver) have been experiencing population declines during 1960-2000. However, the area of developed land use within the MSA has continued to expand in spite of the declining population trend. Between 1982 and 1997, Pittsburgh's developed area grew by 201,800 acres, an increase of 43% (USDA 2000).

FIGURE C-12
Pittsburgh MSA Population Trend



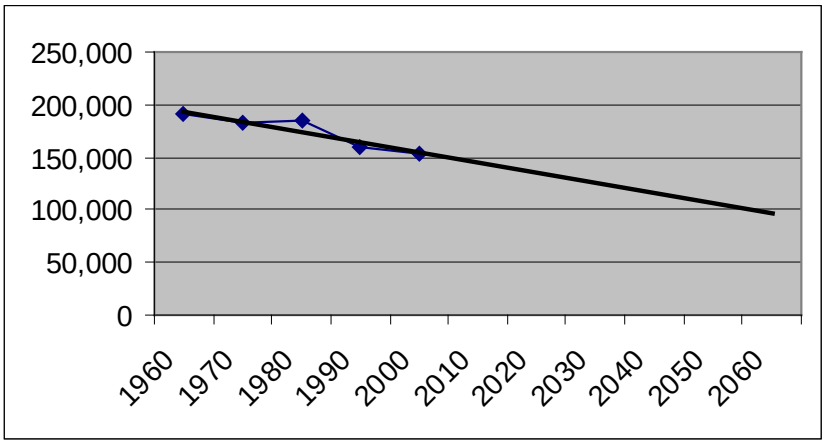
Downstream from Pittsburgh and adjacent to the Pittsburgh MSA, the Steubenville/Weirton MSA (**Figure C-13**) represents three counties in Ohio and West Virginia, all adjacent to the river. The MSA has been declining from a 1960 peak of 167,756 to the current population of 132,008. All counties within the MSA are experiencing general population decline.

FIGURE C-13
Steubenville-Weirton MSA Population Trend



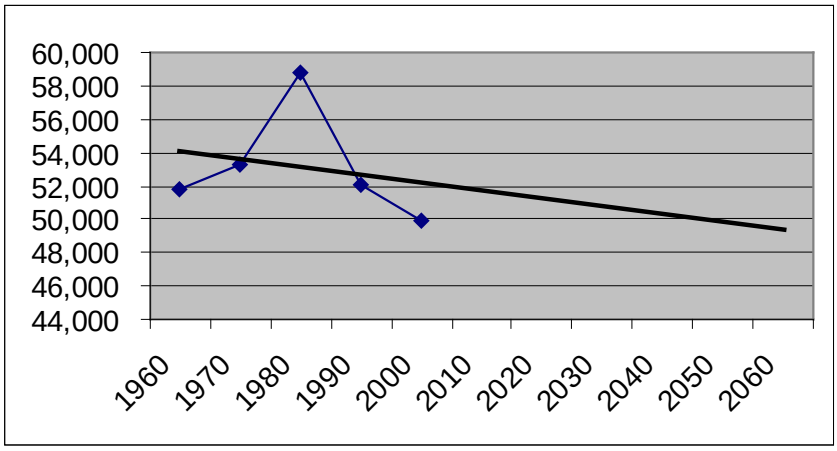
A similar pattern of decline is evident in the Wheeling MSA (**Figure C-14**), which lies downstream of and adjacent to the Steubenville/ Weirton MSA. This MSA also consists of three counties in Ohio and West Virginia that are adjacent to the river and experiencing sustained population declines. The population of the Wheeling MSA peaked in 1940 at 208,918 and now stands at 153,172.

FIGURE C-14
Wheeling MSA Population Trend



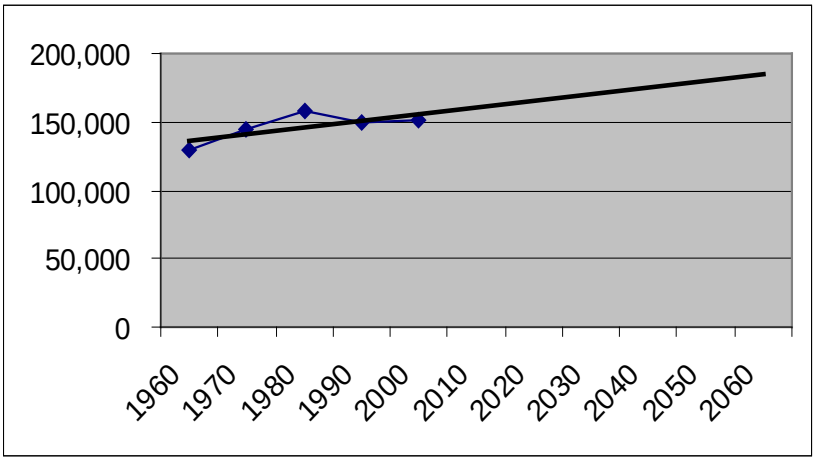
Four rural counties in Ohio and West Virginia are adjacent to the Ohio River between the Wheeling and Parkersburg MSAs (**Figure C-15**). The population of these counties peaked in 1900 at 77,500 and declined to a low of 51,765 in 1960. Population then grew to 58,812 in 1980 before declining again to the current level of 49,979. All four counties show similar growth and decline patterns for the period of 1960 to 2000.

FIGURE C-15
Wheeling to Parkersburg Population Trend



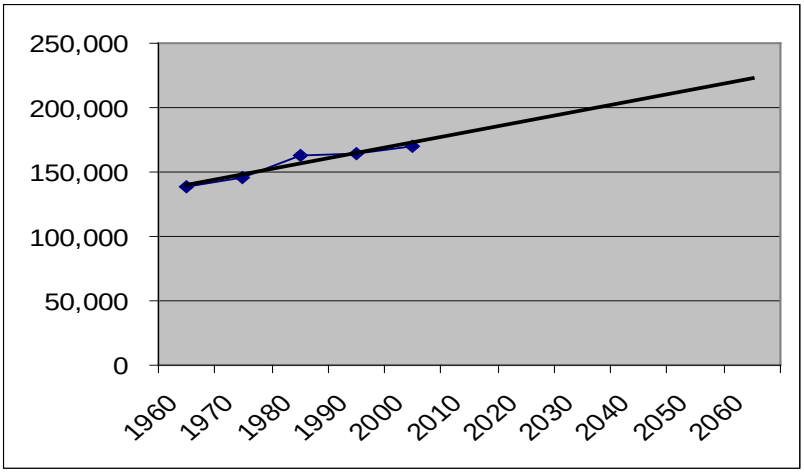
The Parkersburg/Marietta MSA (**Figure C-16**) includes two counties whose populations grew steadily from 1900 to a peak of 157,914 in 1980 before declining to the present population of 151,237. While a trend line from data for 1960 through 2000 suggests continued slow growth for this community, a trend line based on more recent data (1980 through 2000) suggests a level or slowly declining population.

FIGURE C-16
Parkersburg/Marietta MSA Population Trend



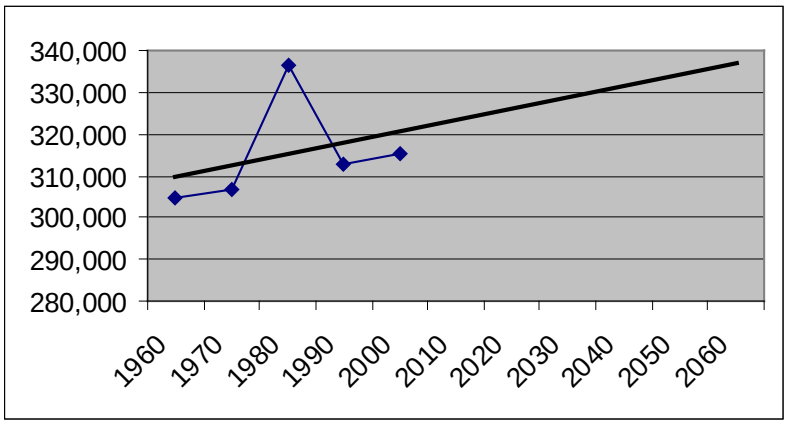
Five rural counties in Ohio and West Virginia are adjacent to the Ohio River between the Parkersburg/Marietta MSA and the Huntington/ Ashland MSA (**Figure C-17**). This area declined slowly from a 1900 population of 142,397 to a 1950 population of 132,812. The area has since experienced gradual but steady growth to its current level of 170,321. This growth is broadly shared by four of the counties, with one remaining approximately level during the 1950 to 2000 period.

FIGURE C-17
Parkersburg to Huntington Population Trend



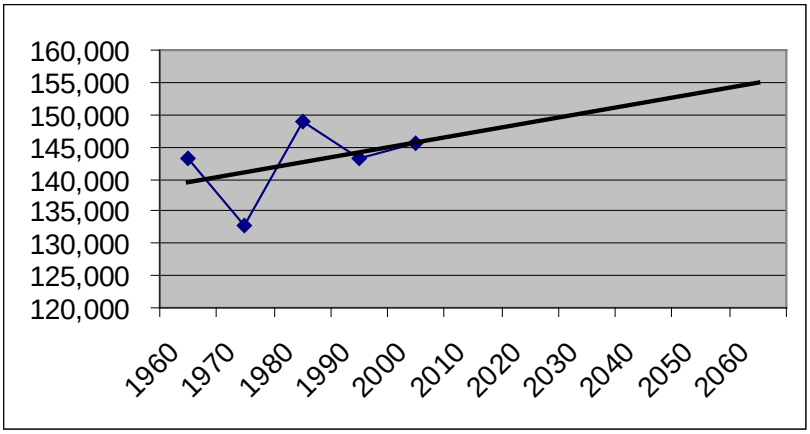
Six counties are included in the Huntington/Ashland MSA (**Figure C-18**), five of which border the Ohio River. Long term growth in this area continued from 1900 to a peak of 336,410 in 1980 before declining to the current population of 315,538. All six counties share the same general growth/decline pattern from 1960 to 2000, which also closely resembles the pattern for counties between Wheeling and Parkersburg.

FIGURE C-18
Huntington/Ashland MSA Population Trend



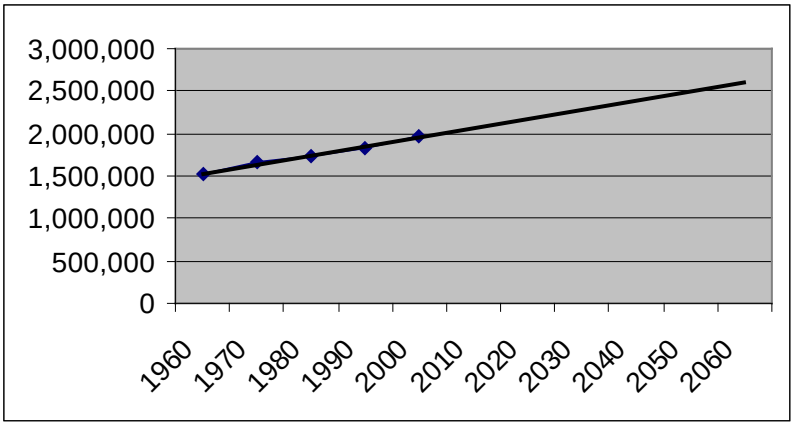
Five rural counties in Ohio and Kentucky are adjacent to the Ohio River between the Huntington/Ashland MSA and the Cincinnati Consolidated MSA (CMSA) (**Figure C-19**). These counties experienced a long-term growth trend that peaked in 1950 at 152,411. This was followed by a decline to 1970 before experiencing the 1980 peak and decline pattern that resembles the pattern experienced by the Huntington/Ashland MSA and the Wheeling to Parkersburg counties. However, the trend is not evenly distributed among all counties within this group. Adams County grew from 24,328 to 27,330 between 1980 and 2000, while most of the population decline occurred in Scioto County, which fell from 84,595 to 79,195.

FIGURE C-19
Huntington to Cincinnati Population Trend



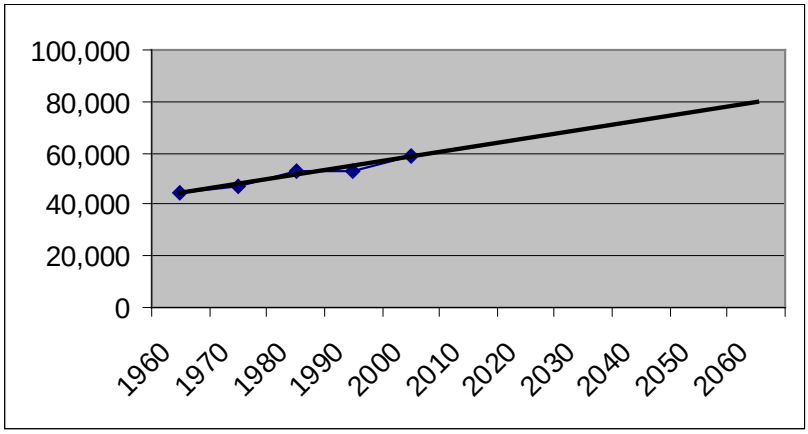
The upstream pattern of short-term volatility around a longer trend of stable or slowly declining population appears to end at the Cincinnati CMSA (**Figure C-20**). Cincinnati contains a core urban county surrounded by twelve outlying counties, all but three of which border the Ohio River. The CMSA has experienced sustained growth throughout the period from 1900 to 2000, growing from 741,031 to 1,979,202. However, the central county peaked in 1970 at 924,018 and has declined each succeeding decade to 845,303 in the 2000 census. All outlying counties have experienced growth from 1980 to 2000, but the majority has been concentrated within the three Ohio and three Kentucky counties that constitute the inner ring of adjacent counties.

FIGURE C-20
Cincinnati CMSA Population Trend



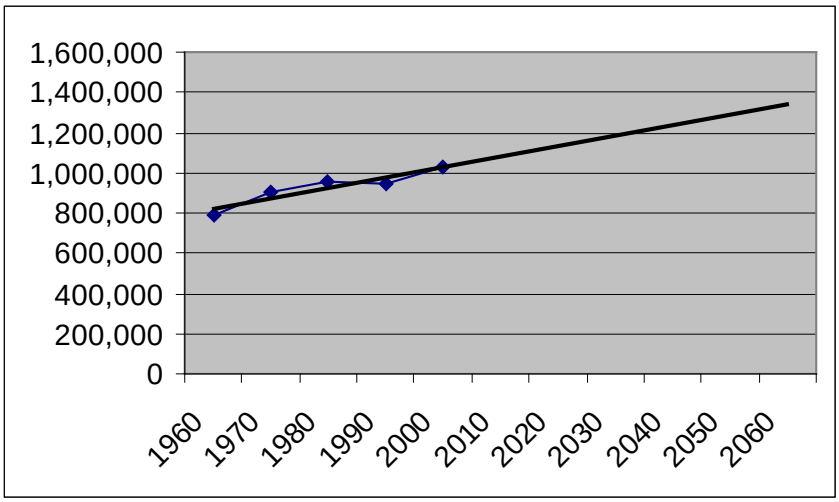
Four rural counties in Kentucky and Indiana are adjacent to the Ohio River between the Cincinnati CMSA and the Louisville MSA (**Figure C-21**). These counties declined from a peak population of 51,850 in 1900 to a low of 41,117 in 1930 and remained approximately level through 1950. All of the counties have since experienced gradual but steady growth, reaching a 2000 total of 59,050.

FIGURE C-21
Cincinnati to Louisville Population Trend



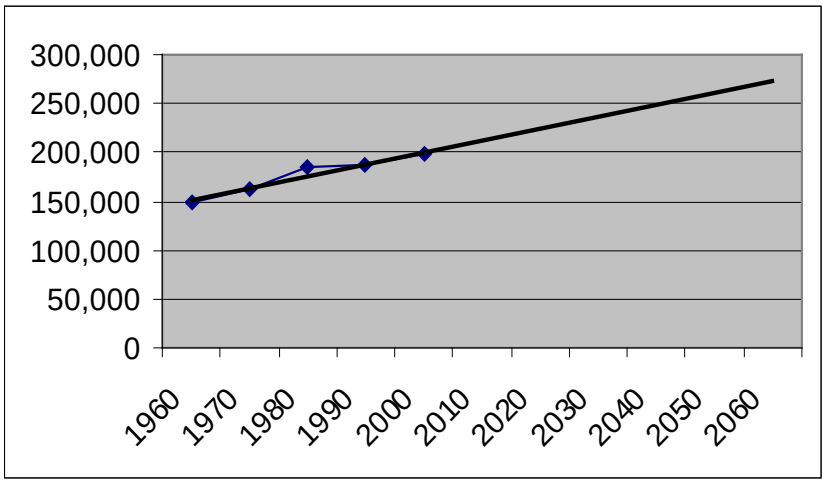
The Louisville MSA (**Figure C-22**) includes a core county and six outlying counties which have collectively experienced sustained growth from 341,191 in 1900 to 1,025,598 in 2000. Jefferson County (the core) peaked at 695,055 in 1970, declined to 664,937 by 1990, then recovered to 693,604 in the 2000 census. Growth in the outer counties is generally dispersed through five of the six counties, although all are experiencing growth.

FIGURE C-22
Louisville MSA Population Trend



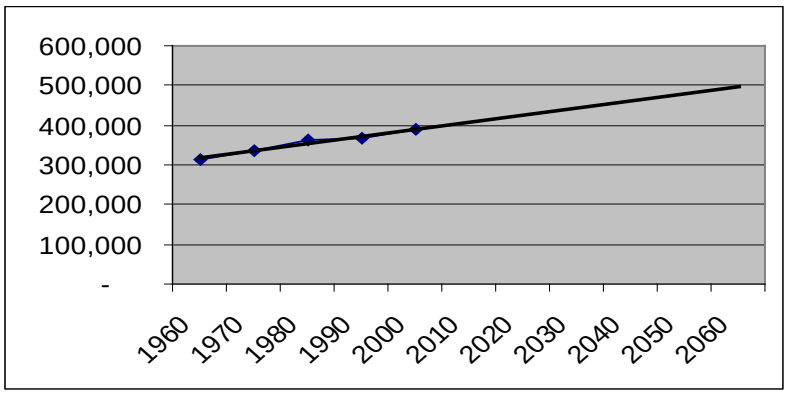
The river reach from Louisville to Evansville (**Figure C-23**) includes seven rural counties in Kentucky and Indiana adjacent to the Ohio River. These counties declined from 117,579 in 1900 to a low of 95,968 in 1930, then grew strongly to a total of 184,901 in 1980. Slower growth has continued to the present population of 197,596. Growth is broadly distributed among the counties, although Hardin County, KY, which includes Ft. Knox, accounts for about 48% of the total population.

FIGURE C-23
Louisville to Evansville Population Trend



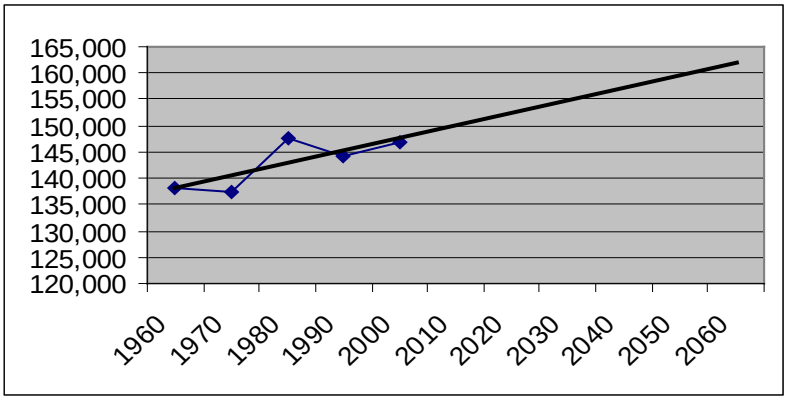
The Evansville MSA (**Figure C-24**) encompasses five counties and includes the MSAs for Owensboro and Henderson, KY. All counties in this area have shared in steady growth dating from a population of 188,005 in 1900 to 387,740 in the 2000 census. Evansville, IN functions as the 'urban core' for this area, with a 2000 population of 171,922.

FIGURE C-24
Evansville MSA Population Trend



Below Evansville (**Figure C-25**) are ten rural counties adjacent to the river in lower Illinois and western Kentucky. Collectively, these counties experienced a fairly stable population of about 155,000 from 1900 to 1940, then declined to 137,347 in 1970. This area experienced a peak and decline pattern between 1970 and 1990 that resembles the pattern experienced by several areas on the upper and middle portions of the river. However, collective numbers for this group mask broad disparities among individual counties. McCracken County (Paducah, KY) shows steady growth through every decade since 1900 and now accounts for 45% of this area's population at 65,514. Eight of the ten counties show net population declines from 1900 to the present and several now have less than half of their original 1900 populations. From 1960 to 2000, three of the five Illinois counties experienced declining populations, one has been stable, and one experienced moderate growth from 14,341 to 15,161. The other four Kentucky counties have experienced stable to slight population growth for the same period.

FIGURE C-25
Population Trend below Evansville



C.8 INTERACTIONS WITH OTHER VECS

The existing land use patterns within the floodplain create opportunities and impose restraints on potential future activities. The free-flowing river of the 1920's has been replaced by a series of 20 slackwater pools and general hydrology of the river is controlled by the navigation dams, upstream flood control reservoirs, and levee and floodwall construction in numerous communities along the river. In the upper river from Pittsburgh to Parkersburg, fill material (often slag from iron and steel operations) was used to create significant areas of elevated land along the river, which resulted in the loss of floodplain within the filled areas.

There are numerous environmental implications of various land uses. For example, nonpoint pollution (e.g., nutrients) from agricultural land will differ from that associated with industrial zones or residential areas. The timing and quantities of storm water discharges also change with the increase of impervious surfaces in developing areas. Noise levels also differ with land use as do air pollutant emissions. Further, infrastructure demands (roads, water supply, sanitary sewer lines, and storm water sewers) also vary with land use categories. The implications of these changes need to be considered when addressing the environmental consequences of land use changes.

Within the physical landscape described above, the current patterns and trends of settlement and development define the context of ongoing land use impacts. Numerous business and economic forces influence population growth or loss, and related economic and land use changes, along the Ohio River mainstem. The navigation system and its associated economic influences are one such force in the overall land use patterns of the corridor.

The relationship between the navigation system and current and future land use patterns can be reviewed in various ways. One can address the contribution of the navigation system to the current physical landscape of the river and the network of economic activities that benefit from this system. This is an ongoing contribution as excess capacity for commercial traffic growth facilitates future industrial growth. The navigation system can also be viewed as a potential tool for management of the Ohio River. In concert with management of upstream flood control reservoirs, navigation dams could be used to manipulate river flows to improve habitats, minimize damaging impacts, or achieve other desired land use outcomes.

C.9 RELEVANT ACTIONS AFFECTING LAND USE

Reasonably Foreseeable Future Actions (RFFA) were evaluated using the RFFA Matrix (see Chapter 2 for discussion of RFFA matrix). The matrix evaluation process resulted in identification of 31 RFFAs with potentially high importance to future land use patterns and 27 RFFAs with medium importance. These RFFAs are presented in **Table C-3**.

RFFAs likely to be of high importance to future land use patterns include:

- the activities of proactive interest groups
- government regulations and programs
- ongoing industrial and commercial activities that are oriented to the river and/or barge transportation, and

- actions affecting key infrastructure that can influence the feasibility of certain types of development.

Proactive interest groups identified in the RFFA Matrix represent six categories of water-based recreation: boating, fishing, personal watercraft (PWCs), hunting, wildlife watching, and sight-seeing. The importance rankings are based on the assumption that these recreational users are likely to take a proactive interest in land use decisions affecting their resource of interest. Although not explicitly recognized in the RFFA Matrix, interest groups represented by environmental and resource conservation oriented organizations are also likely to be of high importance to public decision processes affecting future land use patterns.

Government regulations and programs currently exert very little direct influence over land use patterns, but have the potential to be a key influence if there is enough public support for such approaches. Activities with potentially high importance include site remediation, more stringent environmental standards, wetland mitigation banking, farmland preservation, Corps permitting programs, endangered species act, and public funding of recreation facilities, parks and preserves. Activities given a medium importance ranking include Phase 1 and 2 NPDES programs, pollutant source control, carbon sequestration, and environmental awareness education.

Industrial and commercial activities associated with the river and/or river transportation include; mining (instream or floodplain), coal utilities and industries, other industrial activities, agriculture, and silviculture. These activities have constituted the dominant force shaping past land use patterns along the river and are expected to continue to play an important role in future land use issues. Industrial development is the primary land use on floodplains and terraces of the upper river, agriculture is the primary land use on floodplains and terraces of the middle and lower river, and silviculture is the primary land use on adjoining slopes along the length of the river.

Infrastructure development in and around the Ohio River has been the key element necessary to creating opportunities for commercial, industrial, and residential development. In many cases, key infrastructure plays a direct role influencing subsequent land use patterns. Categories expected to continue to be of high importance include; bridges, marinas, levees/floodwalls, ports, and marinas.

TABLE C-3
RFFA Cumulative Effects Matrix for Land Use VEC

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Land Use - Impacts
Navigation Investment Actions					
Lock Extensions/New Locks/Replacement or Rehabilitation	Corps planning (districts); ORNIM study outputs	A	H	SL	M
L&D operation and maintenance	Corps O&M records, J.T. Myers & Greenup Locks Improvements EIS	A	H	SL	M

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Land Use - Impacts
Other Corps Actions					
Channel dredging/dredged material disposal	Corps (districts), J.T. Myers & Greenup Locks Improvements EIS	A	H	E	M
Flood damage reduction projects					
levees/floodwalls	EAs and EISs from individual communities, Corps O&M records, ERP projects list	A	L	E	H
dry dams, other projects off mainstem	EISs in Corps planning offices (districts), projects planned on tributaries	A	L	SL	M
channel modifications	Point Pleasant project, projects planned on tributaries	A	H	SL	M
nonstructural measures (relocation)	FEMA, flood relocation reports, Corps planning, Mill Creek project	A	H	SL	M
Emergency streambank stabilization (Sec. 14)	Corps planning & operations (districts)	A	H	E	M
Modification of Corps structures for environmental improvements (Sc. 1135)	Corps planning & operations (districts)	A	M	SL	M
Environmental restoration of aquatic ecosystems (Sec. 206)	Corps planning & environmental offices (districts), EA for ERP	A	M	SL	M
Recreation facilities - Construction and O&M	Corps recreation planning, and operations (districts), navigation charts	A	H	SL	M
ERP Projects - 5 categories	EAs for ERP divided by habitat type	A	M?	SL	H
Port development (Sec. 107) and maintenance dredging	Corps planning , operations & historic records, state port authorities, navigation charts, state transportation plans	A	H	SL	H
"But for" Actions					
Commercial Navigation					
terminals	Navigation charts, Sec.401 & 404 permits, Mangi questionnaire	A	H	SL	H
multi-modal sites	Navigation charts, riverfront development plans, Mangi questionnaire, state transportation improvement plans	A	H	SL	H
increased traffic	Corps traffic forecasts by Huntington economics group	A	H	E	M
Instream sand and gravel mining	State mineral extraction agencies, navigation charts (?), 1981 Corps EIS, Corps economics group (Huntington)	A	H	SL	H
Floodplain sand and gravel mining	State mineral extraction agencies, navigation charts, aerial photos	A	H	SL	H
Limestone aggregates mining	State mineral extraction agencies, navigation charts, aerial photos, National Mining Association	A	H	SL	H
Coal utilities	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders	A	H	SL	H
Other coal industries	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders	A	M/L?	SL	H
Industrial users, excluding coal-related	ORSANCO , NPDES permits	A	H	SL	H

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Land Use - Impacts
Recreation facilities - Construction and O&M	State tourism offices, DNRs, SCORPs, Land & Water Conservation Fund	A	H	SL	H
Actions by Others					
Park development and operations	OR Island National Wildlife Refuge EIS & Plan, state park planners, Nature Conservancy, Audubon, Land & Water Conservation Fund, Pt. Pleasant Riverfront Park Feasibility Study	A	H	E	H
Public forest development and operations	Forest Land & Resource Mgmt. Plans, state forest plans, Land & Water Conservation Fund	A	H	SL	H
Floodplain development					
residential	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	A	H	SL	M
commercial	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	A	H	SL	M
industrial	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	A	H	SL	H
Crossings					
bridges	State long-term transportation plans, KY bridges and Corridor D (WV) web sites, navigation charts, EISs, River Fields (Louisville) web site	A	H	SL	H
Marina development & operation	navigation charts, historic trends, LANDSAT images, Sec.404 & NPDES permits	A	H	SL	H
Water -based recreation					
boating	State registration agencies, recreation surveys	A	H	E	H
fishing	State resource agencies, recreation and creel surveys	A	H	E	H
PWCs	State boat registration agencies, recreation surveys	A	H	E	H
hunting	State resource agencies, recreation surveys	A	H	SL	H
wildlife watching	State resource agencies, NAWMP, recreation surveys, environmental groups	A	H	E	H
sight-seeing	State tourism offices, recreation surveys	A	H	E	H
Silviculture	NRCS, state resource agencies, woodland management associations	A	H	SL	H
Agriculture	NRCS, state agricultural agencies, aerial photos	A	H	SL	H
WWTP discharges					
municipal	ORSANCO, navigation charts, NPDES permits, state regulatory agencies	A	H	SL	M
Stormwater discharges	Stormwater mgmt. utilities, Phase 1 & 2 communities, exempt communities with CSOs	A	H	SL	M

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Land Use - Impacts
	and SSOs				
Brownfields redevelopment	Riverfront dev. plans, port authorities, federal and state brownfields redevelopment funding authorities	A	H	SL	M
Trail/bikeway development	Regional planning organizations., state tourism offices, Rivers, Trails & Con. Assistance program, state transportation plans	A	H	E	M
Casinos	State gaming commissions	A	H	SL	M
Hazardous waste sites	HAZMET inventory	A	H	SL	M
Natural Climatic Events					
floods	Historical data from Corps, FEMA, state climatology agencies	A	H	E	M
Regulatory Environment					
Phase I & 2 NPDES program	USEPA Regulatory Agenda Updates, state agencies administering program, CWA amendments	A	H	SL	M
Site remediation	USEPA Regulatory Agenda Updates, amendments to RCRA, CERCLA & SARA, new or amended state laws	A	H	SL	H
More stringent quality standards for environmental	USEPA Regulatory Agenda Updates, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal and state environmental media laws	A	H	E	H
Pollutant source control	USEPA Regulatory Agenda Updates, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal and state environmental media laws	A	H	E	M
Wetland Mitigation Banking	Updates to federal guidance by Corps, USEPA, NRCS, USFWS and NOAA; Institute for Water Resources)	A	H	SL	H
Carbon sequestration	US Dept. of Energy	2,3	M	E	M
Farmland preservation	Policy updates from NRCS, amendments to federal Farm Bills, state agriculture or natural resource agencies	A	H	SL	H
Effluent trading	Policy and/or regulatory updates from USEPA, amendments to CWA; ORSANCO, state water and/or pollution control agencies	A	H	SL	M
COE permitting programs	Corps (3 districts, division, and headquarters), amendments to CWA, WRDA and other pertinent laws	A	H	E	H
Small navigation projects	Corps (headquarters), amendments to RHA and WRDA	A	H	SL	M
Environmental Awareness Education	USEPA policies and programs, educational components of CWA, SDWA, CAA, RCRA, ESA and natural resources laws (current or based on amendments), state programs	A	H	E	M
ESA (Endangered Species Act)	Policy and/or regulatory changes of USFWS, amendments to ESA, USFWS candidate species list, recovery plans, OR Valley Ecosystem Team, biological assessment for ORMSS	A	H	SL	H

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Land Use - Impacts
Environmental sustainability practices	President's Council on Sustainable Development, environmental NGOs	2,3	M	E	M

[1] Reasonably Foreseeable Future Actions

[2] Plans, regulations, sampling data, maps, trend analyses, etc.

[3] Time period in which the RFFA may occur: 1 = within 10 years, 2 = in 10 - 25 years
3 = in 25 - 60 years, A=all time periods

[4] Occurrence probability or likelihood RFFA will happen: H = high M=medium L= low

[5] Location or setting on river where RFFA is expected to occur: U = upper (Pittsburgh - Huntington)
M = middle (below Huntington - Louisville) L = lower ((below Louisville - mouth)
E = along entire length of river SL = specific location U = urban setting R = rural setting

C.10 CUMULATIVE EFFECTS: PAST TO CURRENT AND REASONABLY FORESEEABLE FUTURE ACTIONS

An initial attempt at describing near term land use patterns assumes that current trends will continue with minimal change. With respect to population projections for specific areas, this approach assumes that changes over the next twenty years or so will be about the same as the past twenty to forty years. For land use patterns, a possible assumption is that rates at which land has recently been developed provide a reasonable indicator of trends for the near future. While these are very simplistic assumptions, they at least provide a picture of the near future that may inform further assumptions and analysis.

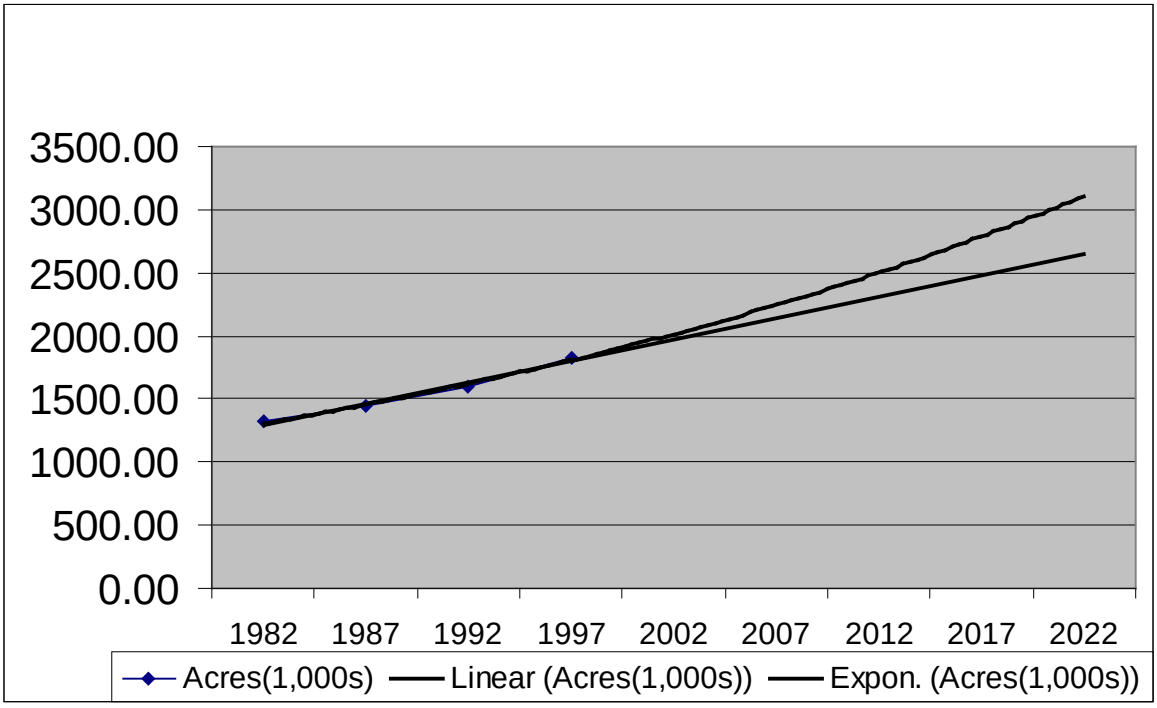
Population and land use trends through 2020 are presented in **Table C-4 and Figure C-26**. Land areas included in the table are the counties adjacent to the Ohio River as previously described in the Baseline Conditions section. Two population projections are presented, one based on average changes over the past 40 years (5 data points), and the other based on average changes for the past twenty years (3 data points). For the overall study area, these result in net growth projections of 1% to 3%. Projections for individual areas vary from –11% for counties in West Virginia adjacent to the river to a maximum of 16% for Eastern Kentucky counties.

The figures for developed area represent the percentage of total land in each group of Ohio River counties that were reported as developed by the NRCS National Resource Inventory for 1982, 1992 and 1997. The land use projections assume a linear progression based on the average rate of change for the reporting period of 1982 to 1997. This is a conservative estimate compared to the accelerating rate of development represented by an exponential progression of the data (**see Figure C-26**). For the overall study area, the linear assumption predicts that 15.6% of the total land surface in the study area will be developed by 2022.

TABLE C-4
Population and Land Development Projections in Study Area Counties

State	1960	1980	2000	2020(60)	2020(60)	2020(80)	2020(80)
Pennsylvania	2731793	2529695	2358695	2,197,624	-7%	2,199,254	-7%
Ohio	1846555	2043903	2176589	2,371,099	9%	2,317,889	6%
West Virginia	480040	515305	457489	446,743	-2%	406,160	-11%
Kentucky East	393976	455109	523418	609,403	16%	601,980	15%
Kentucky West	959850	1141195	1211860	1,370,948	13%	1,286,901	6%
Indiana	462304	558648	618481	722,950	17%	684,722	11%
Illinois	42409	41207	38167	36,258	-5%	35,351	-7%
Total	**6,916,927**	**7,285,062**	**7,384,699**	**7,634,402**	**3%**	**7,485,699**	**1%**
State	**DV 1982**	**DV 1992**	**DV 1997**	**DV 2002**	**DV 2007**	**DV 2012**	**DV 2022**
Pennsylvania	15.8%	19.8%	22.6%	24.9%	27.1%	29.4%	33.9%
Ohio	8.2%	9.5%	10.70%	11.5%	12.4%	13.2%	14.9%
West Virginia	4.0%	4.8%	6.0%	6.7%	7.3%	8.0%	9.3%
Kentucky East	7.5%	9.6%	11.5%	12.8%	14.2%	15.5%	18.2%
Kentucky West	7.7%	9.9%	11.5%	12.8%	14.0%	15.3%	17.8%
Indiana	7.8%	8.5%	9.2%	9.7%	10.1%	10.6%	11.5%
Illinois	2.5%	2.7%	2.9%	3.0%	3.2%	3.3%	3.6%
Total	**7.6%**	**9.3%**	**10.6%**	**11.6%**	**12.6%**	**13.6%**	**15.6%**
Source: US Census 2000 and USDA, 2000.							

FIGURE C-26
Land Development Projections in Ohio Corridor



Source: USDA 2000.

The simplest assumption, that current trends will continue for the next twenty years or more, also serves to illustrate where the ongoing development will occur. The heaviest concentrations of new residential and commercial development will be in counties adjacent

to the major urban core counties of Louisville, Cincinnati and Pittsburgh. All of the counties in the Evansville/Henderson/Owensboro area would be expected to continue their current growth. At a more local level, specific patterns of growth will follow the expansion of infrastructure, including new roads, sanitary sewer service, and new interchanges on limited access highways. These patterns are well illustrated in the NLCD92 imagery.

Some development impacts can be predicted to concentrate in specific areas within the floodplain. Such areas would include locations for the expansion of commercial navigation infrastructure: multimodal terminals, areas for storage and transfer of bulk materials, highways and rail spurs to connect the multimodal functions. Other floodplain developments would include mining activities, and general expansion of existing types of industrial activities. New residential and commercial growth would be primarily located on higher terraces or in areas protected by floodwalls and levees. Growth of marinas and other recreational facilities would be concentrated in embayments. Some of this development activity has the potential to revive or renovate underused urban space or industrial brownfields areas, but much of it will involve the conversion of existing floodplain land uses: agriculture, riparian woods, and wetlands.

As these development pressures increase, opportunities to protect habitat, open space and ecosystem function values, such as those identified in the Ecosystem Restoration Program, will become scarce and expensive. Well funded, proactive conservation programs will become increasingly more important to achieve protection of the dwindling resources.

As discussed elsewhere in this report, the existing commercial navigation system has sufficient excess capacity to accommodate traffic growth resulting from predicted economic growth in the region. In other words, the existing commercial navigation system would continue to support similar types and patterns of land use development as have occurred since completion of the high lift system. Lock expansions and other transportation efficiency improvements addressed in the SIP would reduce delays associated with repair events, but would have no perceptible impact on the broader pattern of economic development and therefore would have no impact on broad land use patterns.

C.11 ASSESSMENT OF EFFECTS

This section discusses land use impacts that may result from continued operation of lock and dam projects on the Ohio River. The discussion includes direct actions such as lock construction and maintenance, navigation system operation and maintenance, commercial navigation, recreation and other activities. Such actions meet the “but for” criteria to the extent they are dependent on continued operation and maintenance of the navigation system. Indirect actions include activities which may derive some benefit from the existence of the improved navigation system, but would likely have developed regardless of navigation system improvements and would be expected to persist with or without maintenance or additional improvements to navigation. Potential impacts from each class of activities are summarized.

C.11.1 Actions by Corps of Engineers

C.11.1.1 Construction of Lock Chamber Extensions

Specific land use impacts were addressed in the EIS documentation prepared for the Greenup and J.T. Myers locks extension projects. This information can be used as a first step towards assessing the cumulative land use impacts that may result from construction of projects described in the SIP.

Most land use impacts identified for Greenup and Myers were considered to be temporary. The improvements would not be expected to directly displace or alter existing land uses on a permanent basis. For example, construction of the proposed improvements would not be expected to require or result in the permanent loss or conversion of prime farmland or other important agricultural uses. At both locations, sufficient government owned property was available to support all construction-related activities on-site. Following the completion of construction, areas used for construction activities, access roads, temporary material storage and disposal sites and an on-site concrete batch plant would be restored to their original land uses (recreation, wooded habitats). Further, since construction jobs at the lock would be temporary, the need for additional housing would not be expected. Thus, the presence of workers during construction would not be expected to precipitate changes in existing land use patterns.

Any additional lock extension projects that may occur over the 60-year study period would be distributed over the 900+ mile length of the Ohio River. It seems reasonable to assume that time and distance would isolate the temporary impacts of individual projects sufficiently to preclude any permanent land use impacts.

Permanent impacts associated with Greenup & Myers concerned the disposal of excavated and dredged materials resulting from the construction project. The Myers project estimated that 900,000 cu. yd. of material would require 20 acres filled to a depth of seven feet. The Greenup project estimated that 20 acres filled to a depth of ten feet would be required. Both projects addressed a variety of in-river, on-site, and off-site disposal options. These options included creation of in-river aquatic habitats, treatment of disposed materials to reestablish prior use of the disposal site, and conversion of the site from farmland to woodland.

The potential issue of special waste classification of the dredged material was discussed, although it was not expected to be applicable to either site. Kentucky defines special waste as “wastes of high volume and low hazard which include, but are not limited to, mining waste, utility wastes, sludge from water or wastewater treatment facilities, cement kiln dust, gas and oil drilling muds, and oil production brines.” If classified, the wastes would have to receive special handling and would be disposed of in a permitted facility.

Some of the proposed disposal sites were located within the 100-year floodplain of the Ohio River. However, there was no discussion of whether this issue affected the disposal options.

The cumulative issue of excavated and dredged materials disposal may have some similarities to potential on-land disposal of materials from channel maintenance dredging. Feasible solutions from one activity may be applicable to the other.

C.11.1.2 Lock Maintenance, Repair, and Rehabilitation

Ongoing commercial use of the lock and dam facilities will require periodic upkeep and maintenance. This will include major and minor repairs of both the (existing) primary locks and the auxiliary locks. As the existing locks age, the need for such repairs will become more frequent. The frequency of repairs will also increase in proportion to ongoing increases in the amount of commercial traffic (and resultant use of the lock chambers) on the Ohio River. For the 60-year study period, these repair events are expected to occur on an average of once every five years for each lock and dam project ($USACE_a$).

Each lock repair event will produce similar but smaller scale temporary impacts on government owned land for parking, maintenance, and lay-down yards. However, maintenance and repair activities would not be expected to require the disposal of significant quantities of dredged or excavated materials.

Maintenance and repair events will continue to occur following completion of lock extensions. However, completion of lock extensions can reduce repair activities and associated land use impacts in three ways. First, it may be feasible to schedule each lock extension so as to eliminate one complete auxiliary chamber repair event. Second, each extension creates a lock in new condition, allowing for a longer time interval between the auxiliary chamber repair events. Finally, the original full-sized lock will be used less, since total lockages can be shared equally between the two full sized locks allowing for a longer time between the main chamber repair events ($USACE_{a1}$, Sept. 2000). Effects from major lock rehabilitation would be similar to those of repairs, but would likely occur over longer periods of time.

C.11.1.3 Nonstructural Navigation Improvements

Nonstructural navigation improvements refer to project alternatives that do not involve lock and dam infrastructure. These include efficiency measures such as vessel scheduling and prioritization, self-help coordination among towboat coordinators and expanded mooring facilities near locks and dams. Some measures, such as expanded mooring facilities, may require modest, temporary land use impacts during construction and installation. Other measures such as vessel scheduling may require improved communication and position tracking systems, but would have no direct land use impacts. It is expected that nonstructural navigation improvements will be implemented wherever they prove to be feasible, independently of other lock extension or repair scenarios.

C.11.2 Other Direct Actions by U.S. Army Corps of Engineers

The Corps conducts a wide variety of other activities within the Ohio River. Activities with potentially significant land use impacts include: major rehabilitation of the dams, channel maintenance dredging, construction of levees or floodwalls, channel modifications for flood control, nonstructural flood reduction programs such as relocation of threatened housing, emergency streambank stabilization (Sec. 14), modification of

Corps structures for environmental improvements (Sec. 1135), environmental restoration of aquatic ecosystems (Sec. 206), construction and operation of recreation facilities, Ohio River Ecosystem Restoration Program (ERP) projects, and port development and maintenance dredging.

The largest of these activities involves major rehabilitation of the dams (as opposed to rehabilitation of lock chambers). While the timing of rehabilitation projects is subject to numerous variables, this activity primarily corresponds to the useful life cycle of the dam. Of the 20 dams currently on the river, 6 have been rehabilitated in the past two decades, at an average age of 60 years following their initial construction. Assuming a life cycle of 60 years, all of the dams currently on the Ohio River may require major rehabilitation during the 60-year cycle of the study period.

Land use impacts from dam rehabilitation projects will be similar to construction site impacts described previously for lock extension projects. The activities will require similar temporary impacts for construction parking and lay down yards and would likely entail similar needs for the disposal of dredged materials.

Channel maintenance dredging involves the removal and disposal of sand and gravel deposits from the navigation channel of the Ohio River to maintain a nine-foot depth. Dredged materials from the upper river are disposed on upland sites. Past practices in the middle and lower river have generally utilized in-stream disposal of dredged materials and thus had minimal land use impacts. However, potential future constraints on in-stream disposal may require use of upland sites for disposal of these dredged materials. Alternatively, dredged materials may be utilized in some cases to create new land or instream structure (sandbars, islands) or supplement losses to existing structure within the river. These ongoing activities will occur independently of lock maintenance or extension activities.

The construction of levees and floodwalls had significant historic impacts that contributed to the present day distribution of urban/commercial developments in floodplains. However, it seems unlikely that significant additional lands will be affected by new floodwall/levee projects. There is also a low probability of retiring any of the current system of flood reduction structures.

The following activities each constitute a significant potential of land use impacts that is dependent on the scope of future projects:

- Channel modifications for flood control
- Nonstructural flood reduction programs
- Emergency streambank stabilization (Sec. 14)
- Modification of Corps structures for environmental improvements (Sec. 1135)
- Construction and operation of recreation facilities
- Ohio River Ecosystem Restoration Program (ERP) projects
- Port development and maintenance dredging

C.11.3 Direct Actions by Others

C.11.3.1 Commercial Navigation

The full spectrum of commercial navigation activities constitutes one of the most significant sources of impacts on land use patterns within the Ohio River floodplain. This is primarily reflected in the hundreds of terminals, intermodal operations, and integrated port facilities located along the full length of the Ohio River floodplain. These facilities transfer coal, limestone, sand & gravel, gypsum, grains, petroleum, chemical stocks, and other bulk materials, as well as providing for interim storage of materials in transit. The quantity of materials shipped on the Ohio River has grown steadily since the 1920's and is expected to continue to grow for the foreseeable future. This continued growth will require new terminals, expanded capacity at existing terminals, and expanded land based storage and transfer facilities, all of which will contribute to ongoing land use changes within the floodplain.

Continued expansion of existing facilities and the establishment of new facilities can be expected to occur in response to general economic/population expansion and subsequent growth in loads carried by barge transport. Traffic projections prepared by the Corps indicate that barge traffic growth will occur independently of navigation improvements addressed by this study. The second generation of high-lift lock and dam projects, which was largely completed in 1980, provides sufficient capacity to meet most of the projected barge traffic growth (see Transportation chapter). Therefore, it can be expected that expansion or addition of barge loading facilities will occur independently of navigation improvements.

Barge queuing is an aspect of commercial navigation that is an important factor to several VECs (see the Air Quality and Aquatic chapters) because of the environmental impacts of such activity. Queuing occurs as a result of both lock extension and lock repair activities, which are referred to as construction delay queuing. Queuing also occurs during heavy traffic when locks are in normal operation (operational delays). However, queuing activities are expected to have no significant land use impacts.

C.11.3.2 Mining Activities

Significant impacts to floodplain land use patterns result from mining activities along the Ohio River. These include instream sand and gravel mining, floodplain sand and gravel mining, and floodplain limestone aggregates mining. Continued growth of such activities is expected to occur in proportion to ongoing population and urbanization/development growth along the Ohio River. These mining activities tend to congregate along the river in areas proximate to growing metropolitan areas or in support of major construction projects such as Olmsted dam or major highways.

Mining activity along the Ohio River benefits directly from the availability of barge transport. If such transport were not available, some mining activity would be replaced by mine sites in other locations. Thus, mining activity at least partially meets the 'but for' criteria. However, capacity within the existing navigation system is adequate to

accommodate any anticipated growth of mining activity and no additional growth would be expected as a result of the navigation improvements addressed by this study.

C.11.3.3.Industrial Activities

A number of industrial activities congregate along the Ohio River or its major tributaries and benefit directly from the availability of barge transport and/or availability of water supplies associated with maintenance of the navigation pools. While some of these activities are conducted within major urban centers, much is dispersed through less populated areas along the length of the floodplain. These include coal-fired electric utilities, other industries utilizing coal as a fuel and/or process material, and other industries with bulk transport needs. Continued growth of these industries is expected to occur in proportion to ongoing population and urbanization/development growth within the broader economy of the Ohio Valley region or the nation at large.

These industrial activities account for the majority of projected growth in barge transport on the Ohio River system. In fact, coal transport alone currently accounts for more than 55% of all barge traffic on the Ohio River and is projected to account for a larger percentage of traffic for the foreseeable future.

C.11.3.4 Recreational Activities

Recreational activities and the infrastructure of marinas, parks, and other support facilities also significantly impact land use patterns within the Ohio River floodplain. The recent rate of growth appears to outpace population and development growth rates and is expected to continue to do so for the foreseeable future. Marina facilities tend to be located in embayments and can be found throughout the floodplain, although they concentrate somewhat in proximity to urban areas. Other facilities supporting boating and non-boating activities include urban or rural riverfront parks, riverfront hotel/restaurant complexes, and casino boat/resort complexes.

A number of demographic and economic factors unrelated to river navigation improvements contribute to the past and ongoing growth of recreation activities. However, virtually all the ‘recreation infrastructure’ discussed above has been built in relation to and is dependent upon continued maintenance of the existing system of navigation pools. Thus this class of activities at least partially meets the ‘but for’ criteria.

The embayments in which marinas and related facilities concentrate are a very limited resource within the Ohio River floodplain. Additionally, dredging activity within these embayments is generally required to maintain accessibility to the marinas. The expected continued growth of marinas and dredging of embayments will likely compete with or displace other resource values of the embayments, including riparian wetland and aquatic fishery habitats. Focused resource protection initiatives will likely be required to protect, maintain or restore these resource values.

C.11.3.5 Park/Forest Development and Operations

The ridges and slopes adjacent to the Ohio River floodplain are primarily forested. Most of this forestland is privately owned, but portions of Wayne, Hoosier and Shawnee national forests and some state forest lands are included. By contrast, most of the

bottomland hardwoods and/or forested wetlands of the floodplain have been converted to other land uses. Other than Ohio River Islands NWR (river miles 0 to 400) few public resource agencies have significant holdings in floodplain areas. The importance of protecting and restoring some of these resources is addressed in documentation for the ORMSS Ecosystem Restoration Program ($USACE_b$).

If protection levels approaching the goals of the Ecosystem Restoration Program are to be achieved, numerous public resource agencies, private conservation organizations and participating private landowners will need to be involved and significant public funding sources will be required. Potential participating entities include national forest and wildlife refuges; state parks, forests, wildlife refuges, wildlife management areas and nature preserves; local/regional parks, trailways and nature preserves; and properties managed by private conservation organizations.

C.11.3.6 Industrial Development

Industrial development within the floodplain is expected to continue to grow in proportion to general economic/population expansion within the broader Ohio Valley region. Many industries in the Ohio River Basin are to some degree dependent on the existence of an efficient and reliable navigation system. This includes industries that may never have shipped via barge and have no plans for doing so. In fact, some of the most highly dependent industries on waterway transportation do not ship on the rivers, but depend on the cost-savings that it provides to their suppliers, making them both more competitive. The waterway transportation system allows for lower transportation costs, and therefore lower delivered costs of basic raw materials; most importantly coal, stone, ores and chemicals, to secondary producers of goods such as electricity, coke, specialty chemicals, and construction materials. In turn, these industries generally induce demand for tertiary producers of items like steel coils and slabs, aluminum, and paper products, which are then used in factories that produce final consumer goods such as automobiles, appliances, utensils, packaging, and food products ($USACE_{a2}$, April 2000).

C.11.3.7 Brownfields Redevelopment

The availability of funding support for redevelopment of brownfields and other former hazardous waste sites is contributing to reutilization of some of these formerly abandoned sites. Limited availability of undeveloped land within some areas of the floodplain further reinforces the reuse of formerly developed sites. These abandoned or underutilized sites represent an important portion of historic urban/commercial development patterns and are an important component of many redevelopment programs. Successful redevelopment of such sites may contribute to reduced land use change impacts associated with general industrial development in the vicinity of brownfields.

C.11.3.8 Agriculture and Silviculture

Agriculture and forest products constitute the largest land use activities (by area) within or adjacent to the Ohio River floodplain. Agriculture is the dominant land use throughout most of the floodplain. Most future conversions of land use will occur on land currently in agricultural use. Privately owned forest is the primary land use on slopes and ridges adjacent to the floodplain and is relatively less threatened by land use conversions.

Forested slopes adjacent to growing metropolitan areas are subject to low-density residential development.

C.11.3.9 Transportation

Highways and railroads constitute a significant land use pattern throughout the Ohio River floodplain. In some portions of the upper river, roads and track are in place along both banks. However, transportation infrastructure throughout most of the floodplain appears to be built close to feasible capacity. Very little new construction of track seems likely for the foreseeable future and road construction will most likely be confined to widening/upgrading of existing routes rather than new construction within the floodplain.

C.11.4 Natural Disasters

Original settlement patterns along the Ohio River were directly influenced by flood patterns and indirectly influenced by periodic events such as severe storms or drought. Completion of the lock and dam navigation system, in conjunction with levees and floodwalls on the main stem and flood control reservoirs throughout the watershed, has significantly reduced the impact of flooding events. Additionally, the 100 and 500-year floodplains are fairly well defined along the main stem. Future land use patterns outside these known flood zones are unlikely to be significantly influenced by natural disasters.

C.11.5 Regulatory Environment

As discussed previously in the section on laws, regulations, ordinances, and programs; historic and contemporary land use patterns have developed with little or no influence from regulatory factors. While direct regulatory control of future development appears unlikely, a number of program areas could have some indirect influence. Brownfields programs (discussed previously) may help to focus developments on previously abandoned or underutilized sites. Other forms of publicly subsidized infrastructure development such as bridges, highways and commercial river ports can also influence future patterns.

From an opposite perspective, programs such as wetlands mitigation banking, farmland preservation, or ecosystem restoration can influence land use patterns by protecting portions of the landscape from some types of development. However, these activities would need significant expansion from current funding levels to produce significant impacts within the Ohio River corridor.

NLCD LAND COVER CLASS DEFINITIONS
[Appearance in Land Use Appendix, FIGURES C-1-11]

Land uses shown on NLCD Land Cover maps:

Water - All areas of open water or permanent ice/snow cover.

- Blue - *Open Water* - all areas of open water, generally with less than 25% cover of vegetation/land cover. *[Ohio River, other streams, lakes]*
- *Perennial Ice/Snow* - all areas characterized by year-long surface cover of ice and/or snow. *[None]*

Developed - Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).

- Light Pink - *Low Intensity Residential* - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.
- Red - *High Intensity Residential* - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to100 percent of the cover.
- Red or Orange - *Commercial/Industrial/Transportation* - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.

Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

- *Bare Rock/Sand/Clay* - Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material. *[None]*
- Dark Purple - *Quarries/Strip Mines/Gravel Pits* - Areas of extractive mining activities with significant surface expression.
- Gray - *Transitional* - Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.).

Forested Upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.

- Light Green - *Deciduous Forest* - Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.
- *Evergreen Forest* - Areas dominated by trees where 75 percent or more of the tree species `maintain their leaves all year. Canopy is never without green foliage. *[None]*
- Dark Green - *Mixed Forest* - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.

Shrubland - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

- *Shrubland* - Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms. *[None]*

Non-natural Woody - Areas dominated by non-natural woody vegetation; non-natural woody vegetative canopy accounts for 25-100 percent of the cover. The non-natural woody classification is subject to the availability of sufficient ancillary data to differentiate non-natural woody vegetation from natural woody vegetation.

- *Orchards/Vineyards/Other* - Orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals. *[None]*

Herbaceous Upland - Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.

- *Grasslands/Herbaceous* - Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing. *[None]*

Planted/Cultivated - Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.

- Yellow - *Pasture/Hay* - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.
- Brown - *Row Crops* - Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.

- Brown - *Small Grains* - Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.
- None or Yellow - Areas used for the production of crops that do not exhibit visable vegetation as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.
- None or Yellow - *Urban/Recreational Grasses* - Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.

Wetlands - Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al.

- Light Blue - *Woody Wetlands* - Areas where forest or shrubland vegetation accounts for 25-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.
- *Emergent Herbaceous Wetlands* - Areas where perennial herbaceous vegetation accounts for 75-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water. *[None]*

C.12 REFERENCES

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Similarities and differences between Anderson and NLCD systems are as follows:

Urban or built-up classes: Commercial, Industrial, Transportation, and Communications/Utilities (all separate Anderson Level II classes) were treated as one NLCD class (Commercial/Industrial/Transportation). No attempt was made to derive Anderson Level III classes in NLCD. “Recreational” grasses, such as those that occur in golf courses or parks (treated as an urban class by Anderson) are considered to be a non-urban class in NLCD (a subdivision of “Herbaceous Planted/Cultivated). Residential (an Anderson Level II class) was divided into Low and High Intensity classes in NLCD.
Water: Anderson Level II Water classes (Streams/Canals, Lakes/Ponds, Reservoirs, Bays, Open Marine) were classed as a single class (Open Water) in NLCD.
Agriculture: Agricultural areas that are herbaceous in nature (Cropland and Pasture; Anderson Level II) are subdivided into four NLCD classes: Pasture/Hay, Row Crops, Small Grains and Fallow.
Rangeland: No rangeland class (Anderson Level I) is identified by NLCD. Rather, “rangeland” is subdivided by NLCD into Grasslands/Herbaceous and Shrubland classes.
Forest land: Evergreen Forest, Deciduous Forest and Mixed Forest are the same in both Anderson and NLCD. Clearcut and burned areas are classed as “Transitional Bare” areas in NLCD.
Wetlands: Two classes are defined by NLCD. These are Woody wetlands and Emergent/Herbaceous wetlands. These are very analogous to the Anderson Level II wetland classes.

Bare: Three NLCD classes are recognized. These are: Bare Rock/Sand Clay, Quarries/Strip Mines/Gravel Pits and Transitional Bare. These represent a consolidation of Anderson Level II classes.
Tundra: While "tundra" is treated as a distinct Anderson Level I class, tundra (including arctic/alpine vegetation) is considered to be either "Grasslands/Herbaceous" or "Shrubland" classes by NLCD.

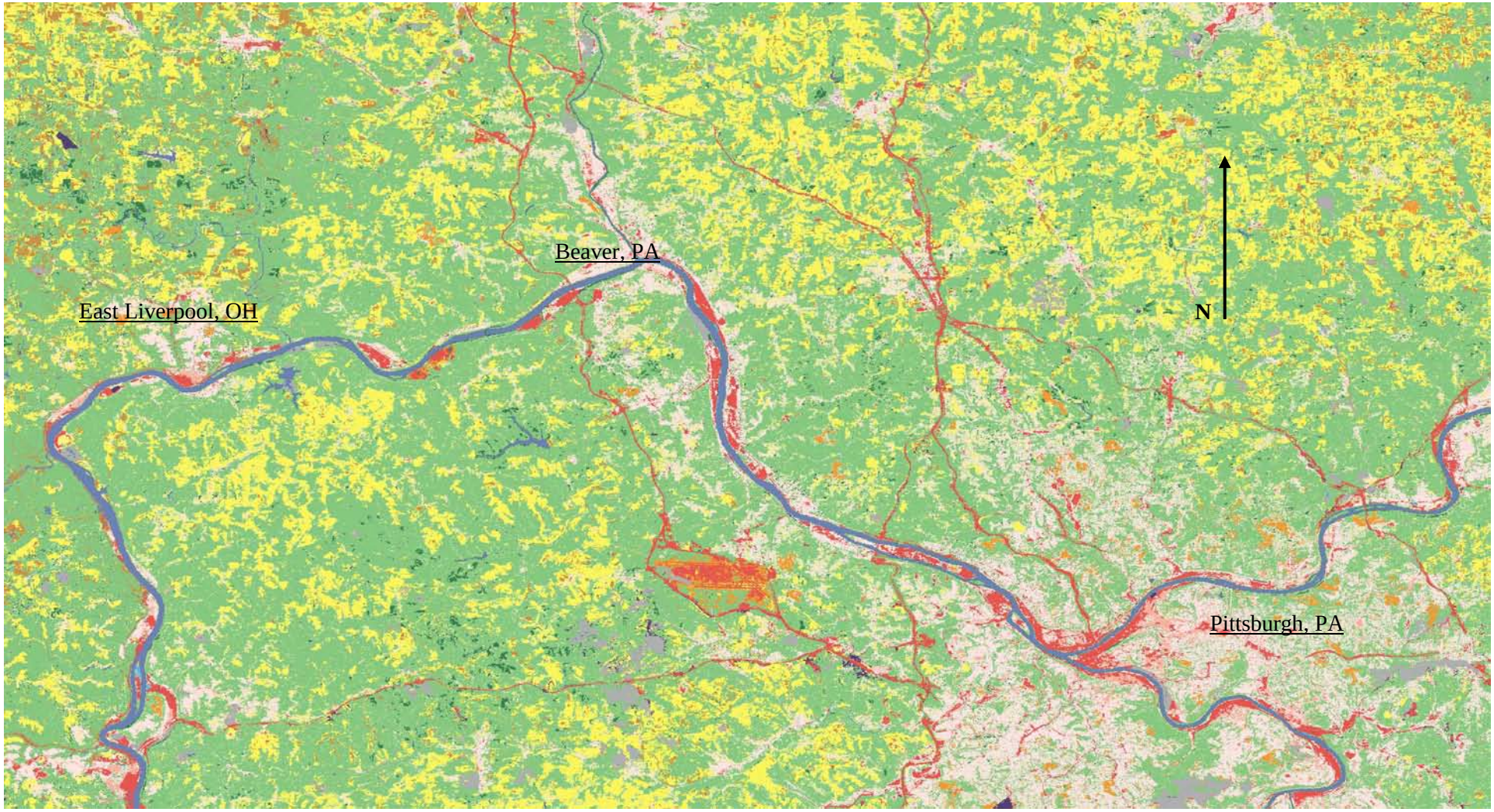

FIGURE C-1
Ohio River at Pittsburgh, PA
Source: USGS – The National Map http://seamless.usgs.gov/

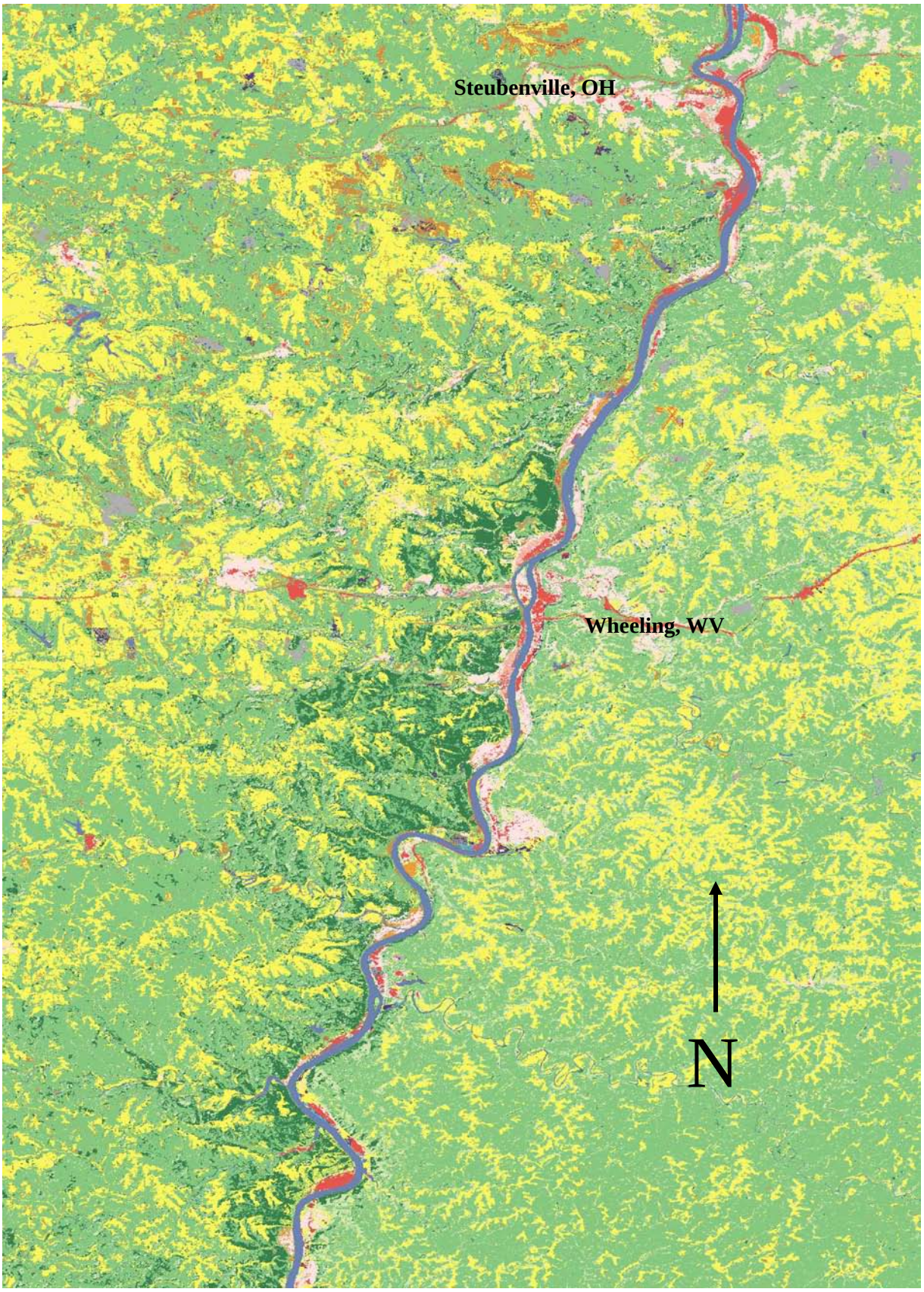

FIGURE C- 2
Ohio River, Wheeling, WV to Steubenville, OH
Source: USGS – The National Map http://seamless.usgs.gov/

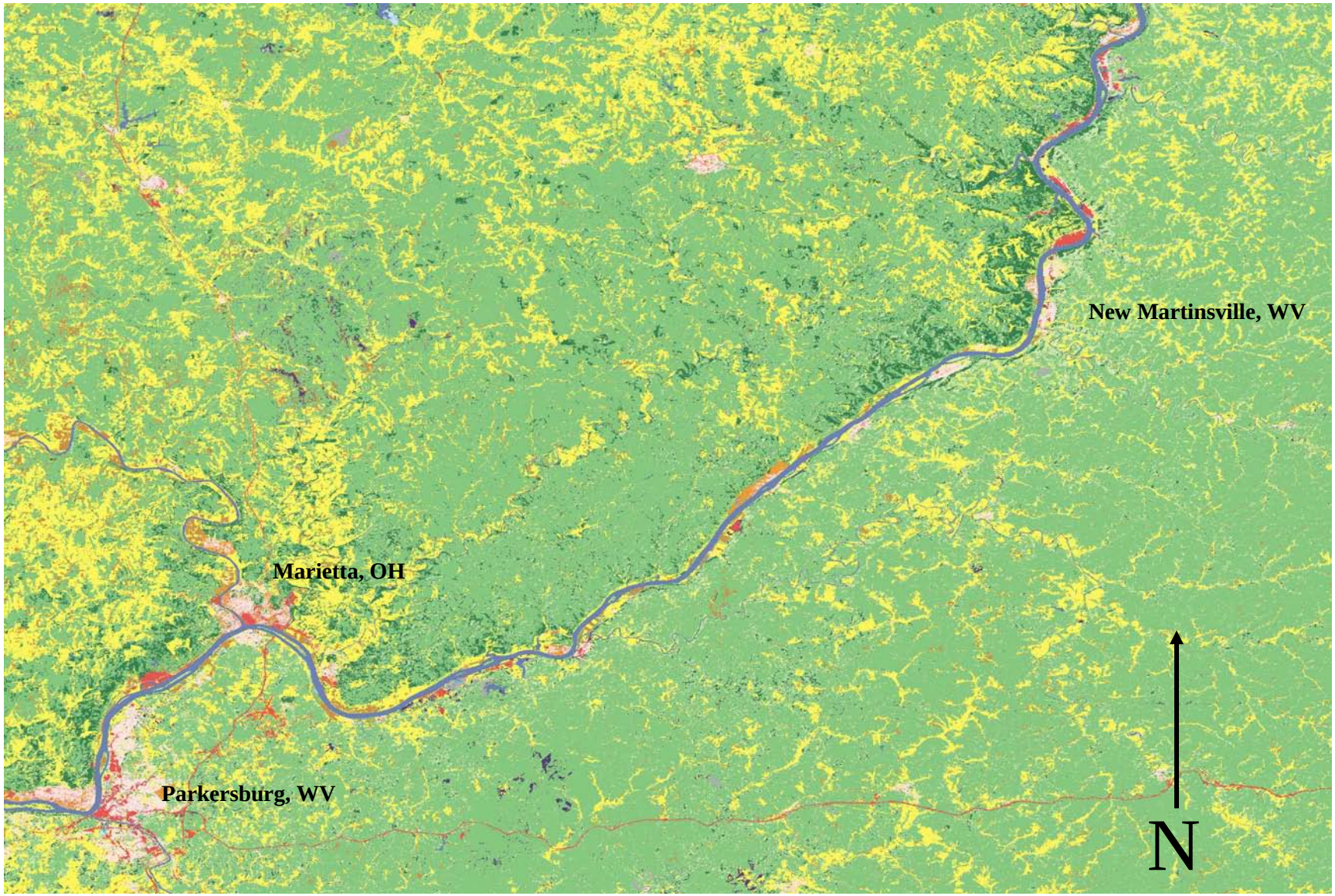

FIGURE C-3
Ohio River, Parkersburg to New Martinsville, WV
Source: USGS – The National Map http://seamless.usgs.gov/

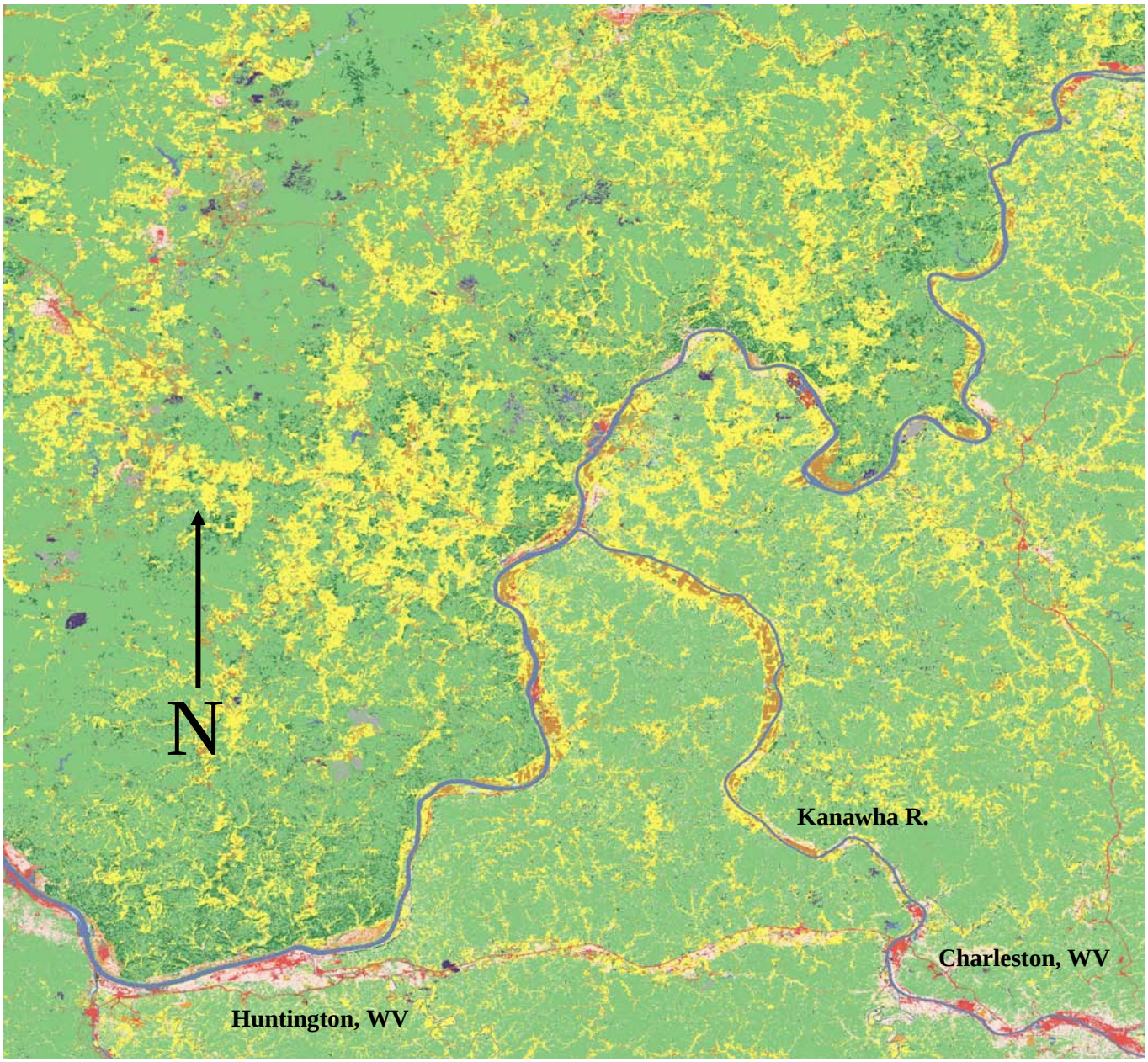

FIGURE C-4
Ohio River, Huntington to Parkersburg, WV
Source: USGS – The National Map http://seamless.usgs.gov/

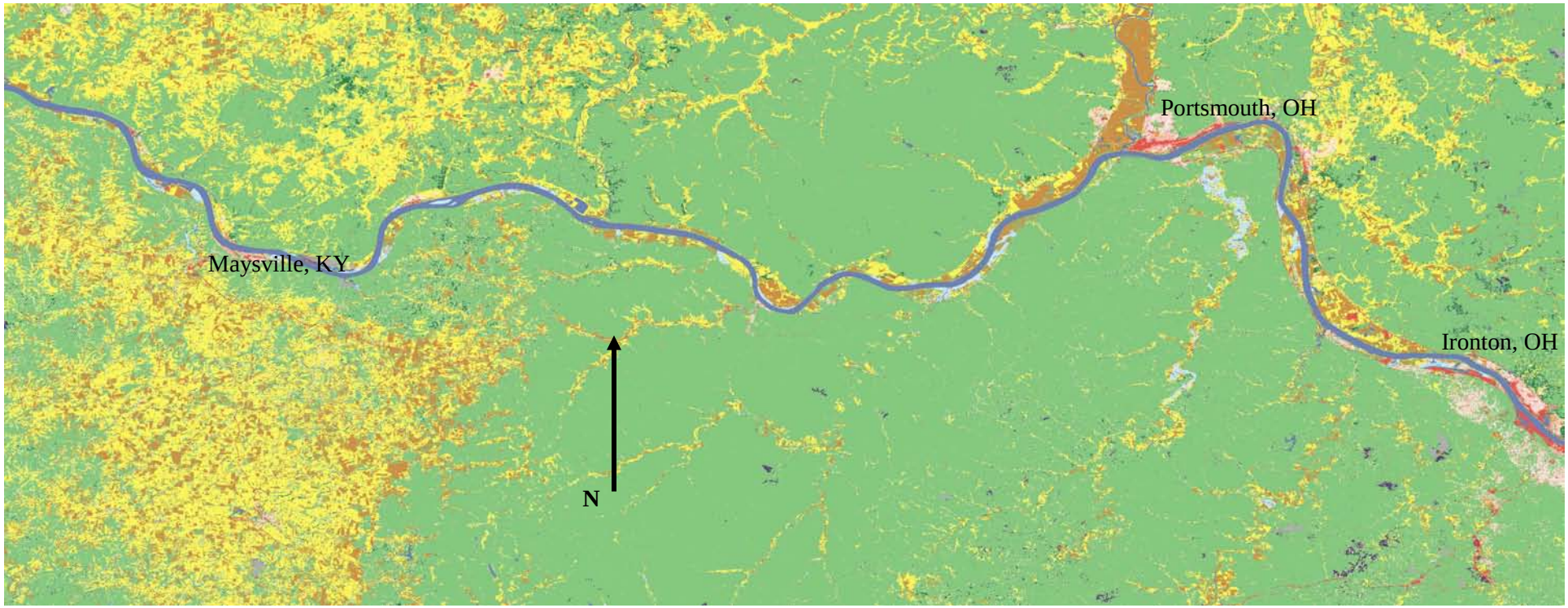

FIGURE C-5
Ohio River, Maysville to Ashland, KY
Source: USGS – The National Map http://seamless.usgs.gov/

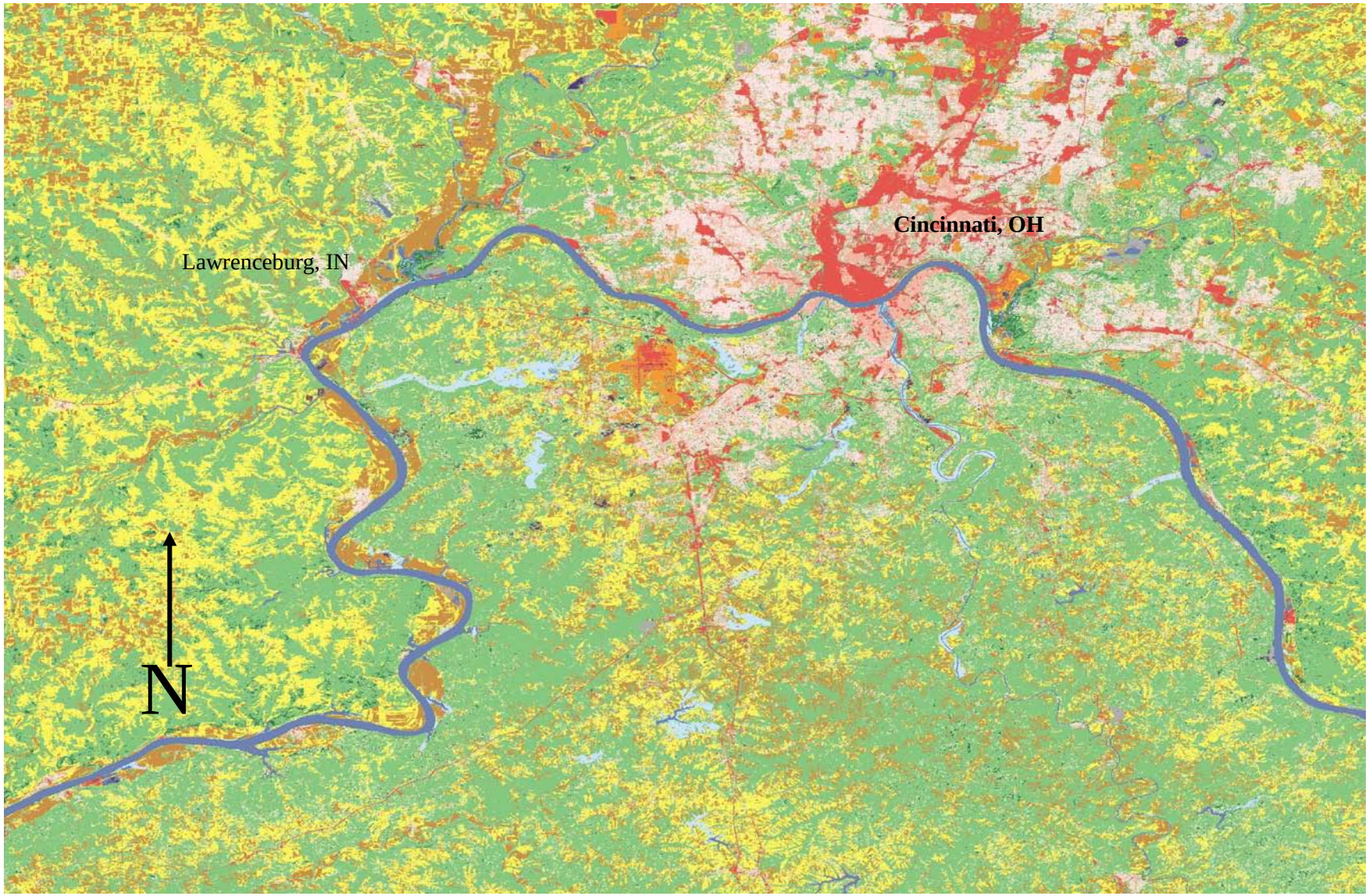

FIGURE C-6
Ohio River at Cincinnati, OH
Source: USGS – The National Map http://seamless.usgs.gov/

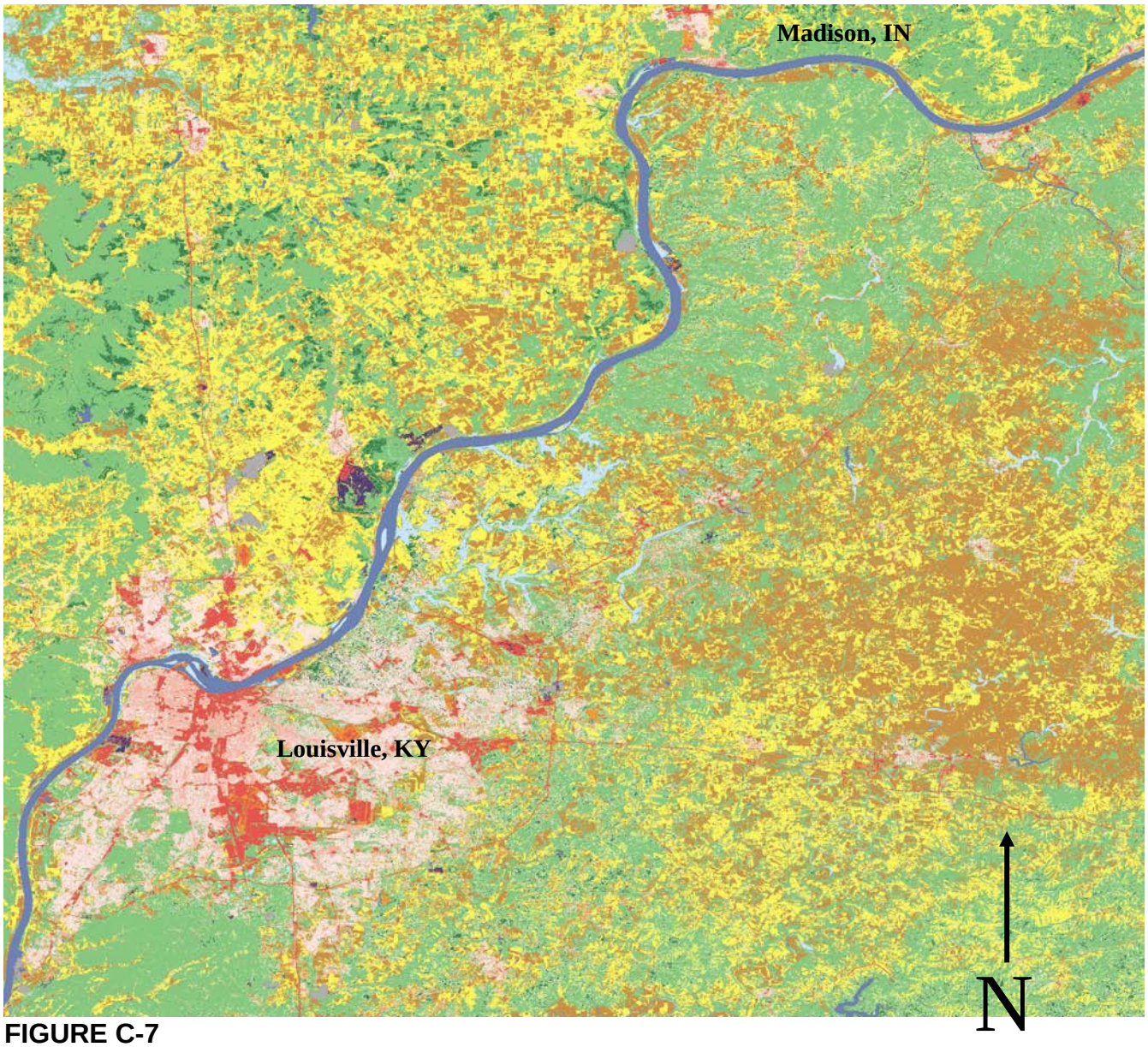

FIGURE C-7
Ohio River at Louisville, KY
Source: USGS – The National Map http://seamless.usgs.gov/

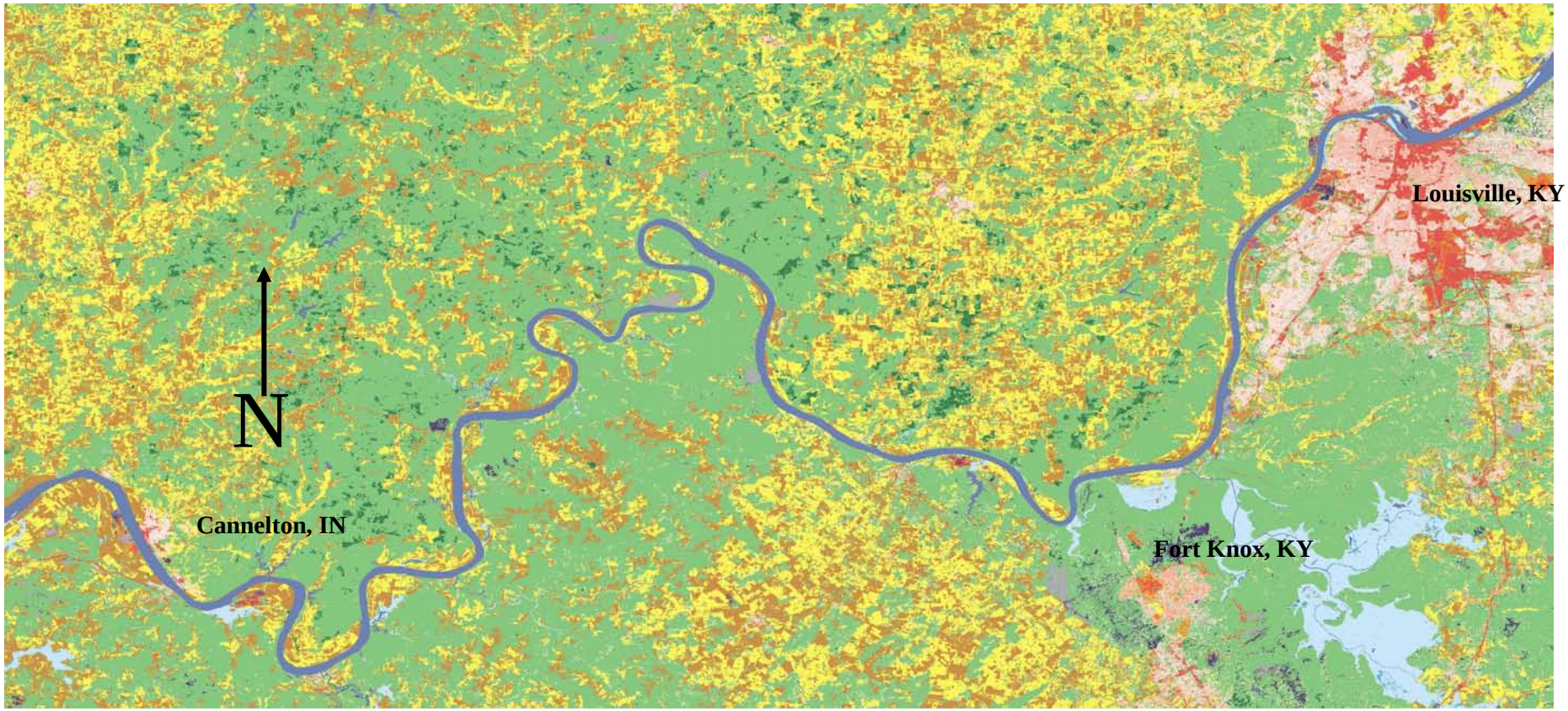

FIGURE C-8
Ohio River at Ft Knox and Louisville, KY
Source: USGS – The National Map http://seamless.usgs.gov/

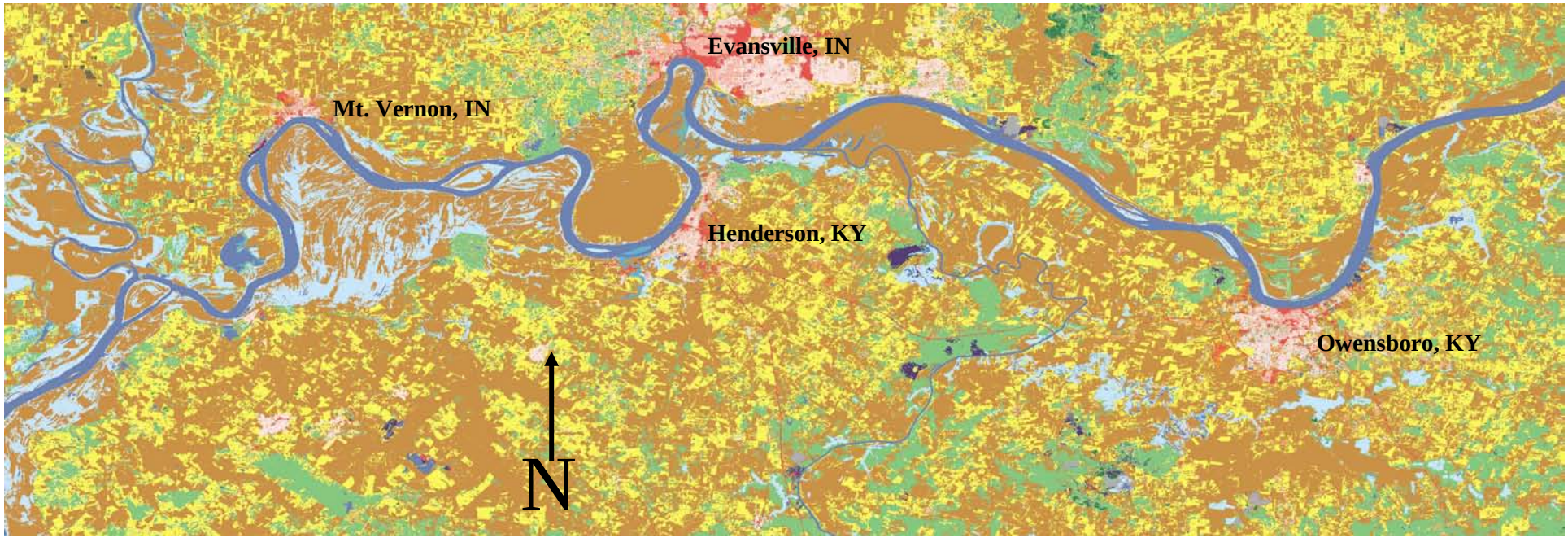

FIGURE C-9
Ohio River at Evansville, IN and Owensboro, KY
Source: USGS – The National Map http://seamless.usgs.gov/

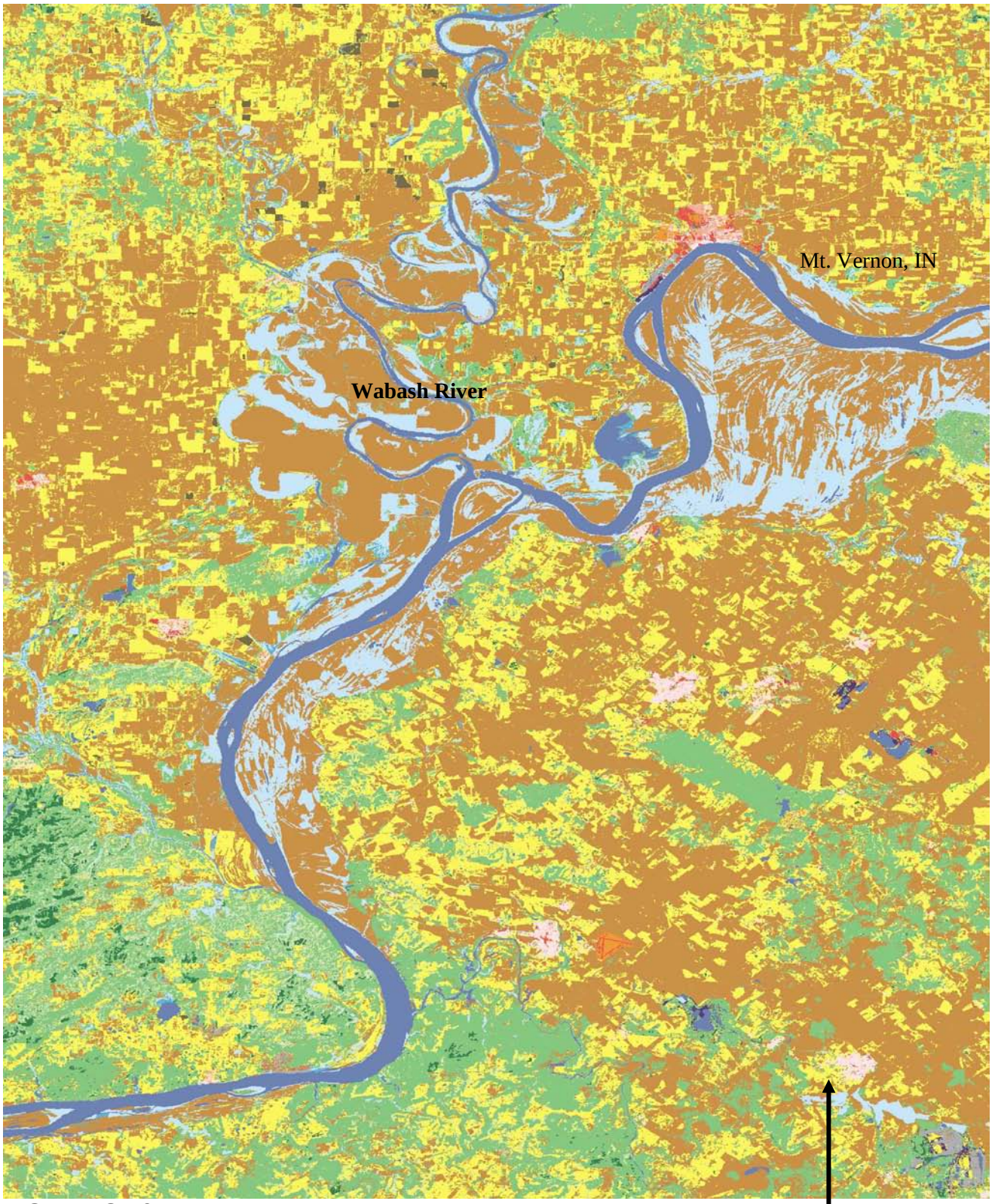

FIGURE C-10
Ohio River at Confluence with Wabash River and Mt. Vernon, IN
Source: USGS –The National Map http://seamless.usgs.gov/

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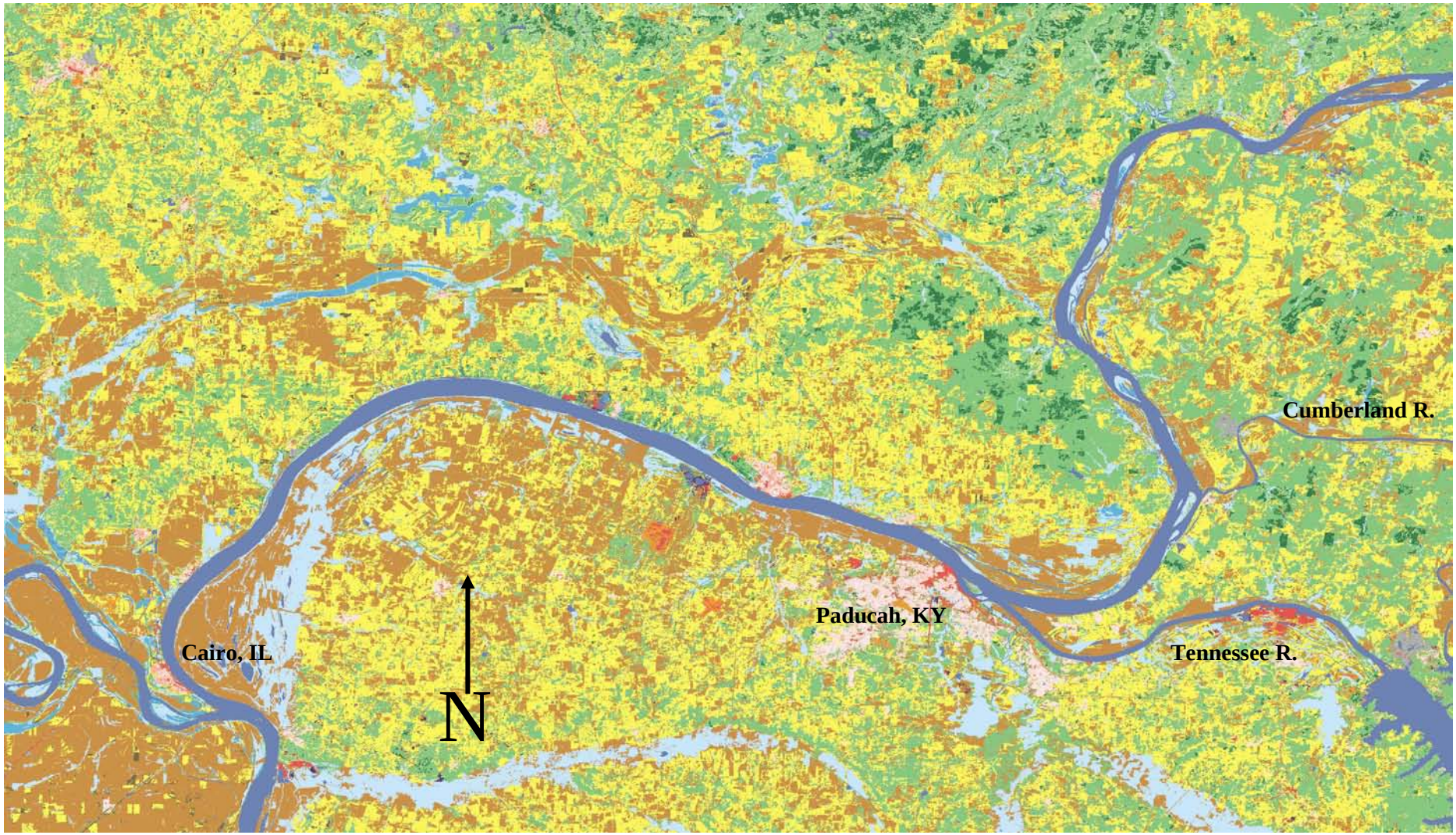

FIGURE C-11
Ohio River at Confluence with Mississippi River and Paducah, KY
Source: USGS – The National Map http://seamless.usgs.gov/

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1) Document MR Main Report & EIS
2) Document EC Economics Appendix
3) Document EC Attachment 3 – ORS Traffic Demand Forecast
4) Document ED-2 Greenup L&D Engineering Site Appendix

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US Army Corps
of Engineers
Great Lakes and Ohio River Division
LOUISVILLE DISTRICT / HUNTINGTON DISTRICT / PITTSBURGH DISTRICT

Ohio River Mainstem Systems Study (ORMSS)

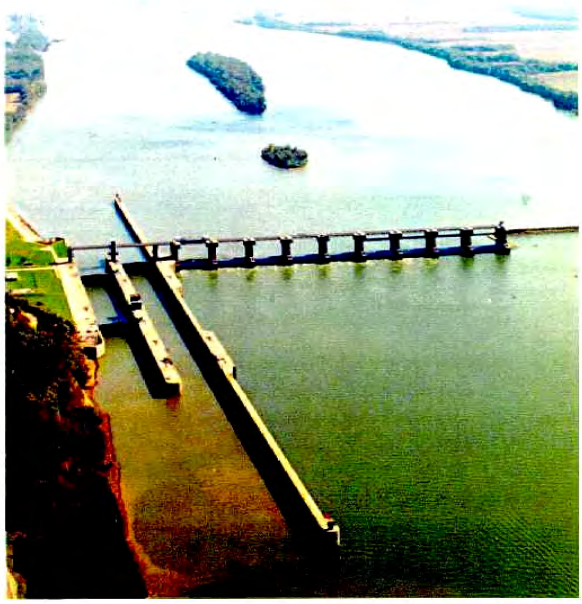
System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

ENVIRONMENTAL APPENDIX: Volume 2 of 2
NAVPAT Report
Aquatic Studies
Fish and Wildlife Coordination Act Report
Cultural Resources

COMMUNICATIONS APPENDIX

OHIO RIVER R/H 41A



May 2006

DEPARTMENT OF THE ARMY
U.S. ARMY ENGINEER DISTRICT, LOUISVILLE
CORPS OF ENGINEERS
P.O. BOX 59
LOUISVILLE, KENTUCKY 40201-0059

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Environmental Appendix (Vol. 2 of 2):

NAVPAT Report
Aquatic Studies
Fish and Wildlife Coordination Act Report
Cultural Resources

Communications Appendix

May 2006

NAVPAT APPLICATION TO THE

OHIO RIVER MAINSTEM SYSTEMS STUDY AND

THE EVALUATION OF NAVPAT HABITAT RELATIONSHIPS

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I. Introduction

The Corps of Engineers has conducted substantial research on the effects of commercial navigation on habitats in large river systems of the United States, including the Mississippi, Ohio, and Illinois rivers. The primary goal of this research has been to assess the potential for commercial tows to disturb bottom substrates and interfere with fish reproduction, recruitment, and feeding. To address these concerns and further assess potential incremental biological effects of various navigation planning scenarios, more than 20 years ago the Louisville District of the Corps began to develop the Navigation Predictive Analysis Technique (NAVPAT). During the 1990s, the Louisville District and the US Army Engineers Research and Development Center (ERDC) developed the physical force relationships described in NAVPAT and described to some extent in Maynord (1990). Since its inception, many refinements have been made to the NAVPAT model in efforts to yield the most useful and accurate information.

The goal of NAVPAT is to provide quantitative results, which can assess positive or negative effects of tow movement on available aquatic habitat quality for a river reach or a specific area of a river cross-section (called a "cell"). Although NAVPAT focuses on certain fish species having a total of 15 species/life stages, NAVPAT does not provide specifics on the response of any particular species. Instead NAVPAT generally links tow movements to possible habitat effects. The habitat relationships in NAVPAT were developed by an interdisciplinary team from state and federal resource agencies. The original NAVPAT model is documented in USACE (1995), which states that NAVPAT "provides quantitative values of projected environmental effects of various navigation proposals at one or more time intervals in units that are habitat-based and are essentially 'habitat units'. The model was developed to assess individual tow movement on specific cells or points in a river cross-section. NAVPAT was also developed as an overall summary for multiple river reaches for numerous tow passages." The Fish and Wildlife Coordination Act report (December 1993), prepared by the U.S. Fish & Wildlife Service for the Marmet Lock project (Kanawha River, WV) states that NAVPAT should not be used as a "predictor of absolute impacts, but rather as a planning level tool" to rank navigation project alternatives.

The developers of NAVPAT emphasize that it is a useful tool for evaluating traffic-induced impacts, but NAVPAT should not be extrapolated to other human activities on or in the river. It remains unclear whether verification of NAVPAT results could be made by long-term monitoring, primarily because of the potential cumulative impacts of other human activities that could be difficult to distinguish from impacts of commercial navigation traffic.

Bearing in mind NAVPAT's purpose and limitations, the current study was designed to quantify the potential for effects on fish habitat of the Ohio River, under two different project conditions (termed "With Project" and "Without Project"), and under five different traffic scenarios that are related to national air quality policy. A secondary objective of this study was to present NAVPAT cell information in a GIS format for ease of use not only by the Corps of Engineers, but also by other agencies and river users.

Section II of this report presents additional details about NAVPAT, including information on selected fish species and their life stages. It also discusses the project conditions and traffic scenarios mentioned in the previous paragraph. In Section III, data input files are described for cross sections, traffic, tow position frequency, river stage, discharge and flow windows. Section IV addresses the methodology used in this study and provides details concerning data collection, creation of input files, analytical constraints, and analysis and interpretation. Results are presented in Section V and discussed in Section VI. Finally, recommendations (Section VII) are made for future NAVPAT modifications and applications. References, and detailed figures and tables are found in the final sections.

II. NAVPAT Description

The basis for a primary input component of NAVPAT was the selection of fish life-stages representative of fish guilds of all major habitats and life stages occurring in the large inland river systems for which NAVPAT was designed. In consultation with the USFWS, the Louisville District selected 15 life stages representing seven species which utilize a variety of large river habitats. **Table 1** presents these life stages, the identifying number each stage is assigned in NAVPAT, the rationale for species selection, and potential impacts of concern.

Table 1
Fish Life Stages Selected for Ohio River NAVPAT Model

Fish Species	Life Stages of Concern (NAVPAT number)	Rationale for Species Selection	Potential Impacts of Concern
Emerald shiner	Spawning (1) Fry (2)	Represents open water spawners in areas of lower ambient current velocity and fry with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of nonadhesive eggs as water velocity increases with tow passage 2) Destruction of fry caused by entrainment through propellers or associated pressure and turbulence
Paddlefish	Spawning (3) Larval stage (4)	Represents open water spawners in areas of moderate ambient current velocity and fry with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of adhesive eggs as water velocity increases with tow passage 2) Destruction of fry caused by entrainment through propellers or associated pressure and turbulence
Freshwater drum	Adult food (5)	Represents open water spawners in	1) Destruction of egg/larval stages caused by entrainment through

Fish Species	Life Stages of Concern (NAVPAT number)	Rationale for Species Selection	Potential Impacts of Concern
	Egg/larval stages (6)	almost any portion of a river and adults that feed on organisms found in bottom sediments	propellers or associated pressure and turbulence 2) Dislodgment of substrates caused by water velocity from tow passage
Sauger	Spawning (7) Larval stage (8)	Represent spawners in relatively high ambient current in areas with coarse substrate and larvae that move to areas of lower ambient current velocity with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of adhesive eggs as water velocity increases with tow passage and/or abrasion of eggs due to substrate scouring 2) Destruction of larvae caused by entrainment through propellers or associated pressure and turbulence
Channel catfish	Young-of-year (9)	Represents species whose young feed primarily on aquatic insects in shallow water with low ambient current velocity	Dislodgment of substrate caused by water velocity from tow passage which could reduce the availability of aquatic insects on which these fish feed
Black crappie	Spawning (10) Fry food (11) Juvenile food (12) Adult food (13)	Represents nest spawners in shallow water and fry, juveniles, and adults that feed significantly on benthic aquatic insects in predominantly different portions of a river channel throughout their lives	1) Dislodgment of eggs from nests because of water velocity increases with tow passage and vulnerability of eggs to predation 2) Disturbance of substrate that could deposit on eggs and smother them 3) Disturbance of substrate that could reduce the availability of aquatic insects on which these fish feed
Spotted bass	Spawning (14) Juvenile food (15)	Represents nest spawners in moderate depth water with coarse substrates and juveniles that feed significantly on small benthic invertebrates	1) Dislodgment of eggs from nests because of water velocity increases with tow passage and vulnerability of eggs to predation 2) Disturbance of substrate that could reduce the availability of aquatic insects on which these fish feed

SOURCE: U.S. Army Corps of Engineers, Environmental Effects of Commercial Navigation Traffic – McAlpine Lock and Dam Project, NAVPAT and QUEPAT (not dated).

The three other primary NAVPAT inputs are:

- river reach characteristics – including information describing multiple reaches of a river which share basic aquatic habitat conditions; i.e., reaches with similar bathymetry, substrate, depth, and velocity profiles
- economic scenarios – including data on various navigation forecasts, as well as data simulating various tows by length, width, speed, travel direction, horsepower, propeller dimensions, and other measurable characteristics, and
- physical forces – including information about several types of hydraulic forces generated by tows moving through a waterway. NAVPAT is best used in primary navigation channels as flows in side channels are significantly more complex and not with in the scope of the present model.

NAVPAT input describes the waterway by cross sections, breaks each cross section into cells having common habitat, and computes a Suitability Index (SI) for each cell for conditions with and without commercial barge traffic. The SI, developed by an interagency team of biologists and engineers, describes habitat quality and varies from 0 (no habitat value) to 1.0 (optimum habitat value). Without traffic habitat quality is determined by habitat relationships that depend on one or more of the following variables:

1) cell depth
2) cell ambient water velocity
3) cell substrate size
4) cell structure (including sunken trees, rocks, old lock walls, wrecked vessels, and other features that provide fish refuge)

Impacts considered in NAVPAT that are induced by tow traffic include:

- propeller entrainment mortality – affecting fish species with pelagic (floating) eggs/larvae in the main channel and channel border (e.g., emerald shiner, paddlefish, freshwater drum eggs/larvae)
- substrate scour – affecting demersal (deposited near the bottom) eggs/larvae in the channel border (e.g., sauger, channel catfish)
- waves/shoreline dewatering – littoral (shallow) or slackwater nest building species (e.g., sunfishes)
- vessel passage events – disrupts feeding efficiency or food availability

The SI recovers between tow events for the substrate scour and velocity effects, but does not recover between tows for propeller entrainment. The duration of the NAVPAT simulation can be important for the propeller entrainment species. NAVPAT evaluates the effects of every tow on habitat quality during the simulation period but does not address cumulative impacts on populations, communities, or trophic dynamics. The SI can be expressed either as bottom area in acres or as volume habitat units in acre-feet. Analyses and conclusions in this report are based on bottom area in acres of habitat units.

The NAVPAT model evaluates six sources of tow-induced velocity that can negatively impact fish habitat: 1) bow wave, 2) displacement flow, 3) return flow, 4) propeller jet, 5) wake flow, and 6) wave-induced velocity in shallow shoreline cells. Wave velocities are calculated only if the minimum depth in a cell is less than or equal to 2.0 ft. Each of the six components is evaluated over a 300-second time history. If two or more velocity sources are occurring simultaneously, their velocities are added together and stored as a 300-second time history of tow-induced velocity from all sources. The time history from these initial steps is then used to compute the depth to which the substrate is disturbed in the cell. A subsequent model step deals with habitat quality and calculates the without traffic SI and the effects of tows on SI. Other tasks important for NAVPAT to run smoothly include random selection of which zone in the channel will be used for simulation, computation of the percentage of the channel that is undisturbed by propeller entrainment, and computation of the percentage of a cell entrained in the propeller jet.

The NAVPAT traffic scenarios are based on five detailed lock-level traffic demand forecasts the Corps has developed for the Ohio River through use of the Ohio River Navigation Investment Model (ORNIM). These are utility coal-based forecasts that reflect the effects of coal source switching by electric utilities to comply with existing or proposed environmental regulations. The five traffic scenarios are:

1) The Bush Administration's Clear Skies Initiative, an amendment to the Clean Air Act – could be expected to have a marked impact on the use of coal by electric utilities, largely because of the proposal's implied mercury emissions restrictions.

2) The Modified Clear Skies Initiative without the severe mercury restrictions included under Clear Skies.

3) The National Ambient Air Quality Standards (NAAQS) Scenario – continues to apply existing air quality policy.

4) The Utility-Based Scenario – uses utility survey information and the Ohio River System (ORS) utility coal model to generate a forecast that reflects the utilities' view of the environmental regulatory future over the next 10 years and extrapolates trends based on projected economic growth.

5) The Utility-Based High Scenario – same as the Utility-Based except that it assumes higher economic growth.

III. Description of Input Files

III. a. Cross Sections

The cross section data files for the Ohio River mainstem were originally organized for an older version of the NAVPAT model. For ORMSS the decision was made to analyze the data with an updated version of NAVPAT, as described in the ERDC technical report TR-05-7 "NAVPAT Application to Winfield Pool, Kanawha River, and Evaluation of NAVPAT Habitat Relationships". Consequently, it was necessary to reformat the cross section data to be compatible with the updated NAVPAT. A programmer was hired to create a software application to automate the reformatting process, which substantially increased the speed at which the conversion was completed.

In addition to data reformatting, several inconsistencies, requiring manual fixes, were discovered in the cross section data and needed to be addressed before the input files could be used. For example, data for a number of pools was organized in reverse order, with the cross sections located at the furthest point upstream placed first and subsequent cross sections recorded in descending order. The order of these files had to be reversed by hand prior to running NAVPAT. In a few cases, the number of cells or bathymetry lines conveyed in the data input did not coincide with the actual number present in the bathymetry profile; or left and right cell limits were not correct. Such errors were found either by randomly scanning the cross section data or when the NAVPAT program could not successfully run. Once errors were found, changes made to NAVPAT computer source codes corrected the data files.

In many analyses of individual cells, values representing the principal substrate size were assigned a value of zero. This presented a problem for those species models requiring analysis of substrate scour (species 5, 7, 9-13, and 15, see text **Table 1**) and was adjusted, accordingly.

Many cross sections, especially in the Belleville and Willow Island Pools, included data that described multiple river channels. Although NAVPAT will run data that include more than one channel, resulting output is only valid for cross sections with a single channel. The problem required the removal of any non-navigable side channels from the cross section files. This was accomplished by raising the elevations describing a non-navigable channel above the maximum water surface elevation. Because NAVPAT does not compute results for cells with elevation values greater than the maximum water surface elevation, no changes were needed for the cells located within a side channel.

Navigation channel location data were often inaccurate and did not reflect the depth or structure of the river channel. Questionable output data is created when the NAVPAT model is asked to examine tows traveling through sections of river too shallow to accommodate barge drafts or even through areas above water level. Most cross sections were compared to navigation charts and then navigation channel data were corrected to allow adequate depth to accommodate the minimum river stage and the maximum draft tow.

A final problem with the cross section data involved points at the terminus of a profile closest to the river banks which did not extend above the maximum water surface elevation. This condition resulted in an error message and termination of the model run.

A separate program (NAVPAT_add_endpts) was written that inserted a point at the maximum water surface elevation. The lateral distance for the new point was based on a 1V:2H slope from an existing point located closest to the river bank.

III. b. Traffic Files

The strength of the NAVPAT model is its flexibility to assess changes in habitat at a variety of scales, from a single stretch of river to numerous pools. Regardless of the size of each section, the NAVPAT model requires the creation of a unique set of batch and input files. The traffic data provided by the Navigation Center was organized in such a way that each cross section was assigned a different traffic level for each of the five forecasts for each of the three years analyzed. Due to the sheer size of the ORMSS project (thousands of cross sections) and time and staffing constraints, running individual cross sections was unrealistic. Instead the data were organized into larger segments.

Although a natural method to divide the Ohio River is by pools, several pools in the mainstem do not have a consistent level of tow traffic from one end to the other. To retain such within-pool variations in tow traffic, the 18 pools were divided into 44 sub-pools. The limits of each sub-pool were established so that each cross section within the unit did not deviate by more than 2.5 million tons (+/-) from the average annual traffic level of the entire unit. To further simplify the run, the units were divided so the same sub-pools could be used on all five forecasts. The sub-pools were then run at the average tow traffic level. The output data from the sub-pools were combined to create one single value representing habitat change for each pool. This method eliminated extreme high and low levels of tow traffic predicted for each pool, but was thought to be the best compromise between limiting the number of model runs and capturing traffic variations in each pool.

The original output from the ORNIM model also had to be adjusted to accommodate the format dictated by NAVPAT. For example, ORNIM described tow speed in miles per hour, whereas NAVPAT requires tow speed in feet per second. ORNIM measurements of tow draft depth (ft) originally included the draft of the tow boat while NAVPAT uses only barge drafts. These discrepancies were identified and corrected.

After corrections were made for the ORNIM model tow speeds, it was observed that tow speeds were far too high to accurately represent actual tow movement on the Ohio River. The speed function used in ORNIM model was based on Howe (1969), which has since been described as inadequate to accurately describe navigation speeds. Consequently, the speed function for the ORNIM model was modified to establish more realistic tow speeds for the NAVPAT traffic input files.

Another inconsistency with the ORNIM model was related to the propeller rotation speed. ORNIM assigned values for propeller size (in.), propeller pitch and propeller speed (RPM). One value was assigned to each category per size class regardless of the size or speed of the tow. Consequently, the assigned propeller speed value was often

inconsistent with the physical attributes of the tow. A code added to ORNIM included formulas to determine more realistic prop speed, size, and pitch.

III. c. Tow Position Frequency Files

Because all tow position frequency files had to be created for the ORMSS data, project time constraints permitted only one frequency distribution to be used. This distribution described a centered sailing line.

III. d. Discharge and Stage Files

The updated version of NAVPAT applied to ORMSS data takes the river stage and discharge data from separate files instead of from the bathymetry file. New stage and discharge files had to be created from the data supplied by the Louisville District.

In several cases, river miles in the stage file were the same as the river mile of the first or last cross section in the bathymetry/cell file and the NAVPAT model could not successfully run. This problem was corrected by slightly increasing or decreasing the stage file river miles to overlap the river miles in the bathymetry/cell file.

Changes to the bathymetry data were made to eliminate multiple channels, but resulted in the total discharge going through the one remaining channel becoming too large. This required a modification of the discharge file to accurately reflect the flow moving through the navigable channel. The discharge files were modified by inserting four new data lines in the discharge file: at a river mile just upstream of the side channel, a new line at the upstream end of the side channel, a new line at the downstream end of the side channel, and a new line just downstream of the side channel.

III. e. Summary of Changes to NAVPAT Program

As mentioned above**,** several changes were made to NAVPAT to successfully apply it to ORMSS. As the input data were analyzed and complications were encountered, checks and safeguards were added to the source codes of the model, as follows:

- The width, depth, and area of cells were checked to make sure that they were not negative values, which would result if the left cell limit was greater than the right cell limit. The original NAVPAT program would have run with the negative cell width and computed negative habitat units for such cells, resulting in a decrease in habitat units for that cross section. The program was revised to terminate the run and create an error message that identified the problem cross section.

- NAVPAT was modified to account for tows with a draft greater than 12 ft.

- A problem related to computation of substrate scour for down-bound tows with large ambient velocities was encountered and corrected.

IV. Methodology

This section describes methods used to collect NAVPAT input data and create input files. Analytical constraints and analytical methods also are described below.

IV. a. Data Collection

Substrate Data

Two methods were used to collect substrate data and were correlated with the date of data collection and location on the river. The lower river (below Meldahl) was surveyed either before or during the early stages of ORMSS. These early data collections were done for site-specific studies conducted by the Louisville District, where the NAVPAT model was originally developed. Substrate samples were collected using a petite ponar dredge with samples taken at standard distances along a cross section. The location of each grab sample was determined using a Global Positioning System (GPS) unit. Subtrate classification involved analysis of grain-size distributions after sieving.

Substrate data in the middle and upper river were collected using modern side-scan sonar (SSS) equipment, which scans a wide bottom swath using high-frequency sound waves. The unit translates signal return strength into a nearly rectilinear, pictographic representation of the scanned area which reveals the presence of submerged objects, as well as patterns of bathymetric relief and substrate character. Advanced equipment was coupled with a differentially corrected, GPS receiver to render a nearly continuous record of river bed composition with spatial accuracy acceptable for translation to a geographic information system (GIS) format.

The sonar images were used to identify substrate “polygons” based on the relationship between sonar images and an extensive series of river bottom samples collected in an upper Ohio River pool (Normandeau Associates, Inc. 1997). These polygons represent areas of similar substrate composition, which can be classified as percentages of grain sizes (e.g., 20% fine sand, 30% gravel, and 50% cobble boulder).

Bathymetry Data

Bathymetry for the Ohio River was provided in three dimensional (XYZ) format with data collected along cross sections approximately 500 ft apart along the entire length of each pool. Each cross section was described by about 150 data points. As a general rule these data correlated with the pool elevation on the day of the survey. Above that elevation, digital terrain data files at 5 ft contour intervals were used to establish bathymetry to the top of bank.

Structure Data

Shoreline conditions above the water level were documented from photographs and field notes and then used to infer the structure and vegetation in the sub-aqueous cells

adjacent to the shoreline. Structure values assigned also considered the surface area of the cell being analyzed.

IV. b. Creation of NAVPAT Input Files

Bathymetry/Cell Files

NAVPAT requires the river to be divided into a series of segments which share common physical and flow characteristics. The bathymetry input files provide data which describe the physical characteristics of the river bottom based on three data lines referred to as X1, GR, and CL.

The description of each river section begins with an X1 line which contains 12 types of data:

1) An X1 header
2) River mile of the representative cross section
3) Number of GR points, as described below
4) The left limit of the navigation channel (ft from the left bank of the river),
5) The right limit of the navigation channel (ft from the right bank of the river),
6) The pool elevation in ft.
7) Number of cells in the river segment,
8) Length of the river segment (ft), and
9-12) Two pairs of XY coordinates.

Left and right navigations channel limits are determined by several factors, including water depth, channel alignment and structures present in the channel such as bridges and locks. The current version of NAVPAT reads the pool elevation from a separate input file so this value in the bathymetry input file simply acts as a place holder. The final four numbers represent two pairs of XY coordinates. Typically, the first XY pair would represent the first point of the bathymetric profile on the left bank while the second XY pair describes a point on the opposite bank and defines the edge of the cross section. However, due to time constraints during ORMSS, accurate coordinate values were not determined and zeros were used as place holders.

Each GR (geometry of the river) line describes a single point used to describe the geometry of the channel. Typically, the point in the first GR line is located at the top of the left bank. After the GR header, the first two values represent the XY coordinates of the point. The first value (Y) is the distance the point is located from the left bank. The second number (X) is the elevation of that point.

The last type of data line in the bathymetry file is the CL (cell limits) line. Each river section is further subdivided into cells parallel to the river bank which are numbered from left to right. Cell limits help maintain constancy of substrate size and minimize depth variations throughout the cell. Each CL line describes an individual cell. The CL header is followed by the cell number, the left and right limits of the cell, principle substrate particle size, the average water velocity (for a point located in the center of the cell), percent of structure in the cell and a roughness value. The current version of

NAVPAT takes the ambient velocity from another input file so the line in the bathymetry file is a place holder. Structure values are utilized in 6 of the 15 biological models and include logs, trees, docks and other features. The roughness parameter is used to calculate ambient velocity using the Manning equation, a common equation for simulating water flows in open channels.

Traffic Files

Traffic input files are produced by the Corps' Navigation Center in Huntington, WV, from the ORNIM computer model. Traffic files describe the commercial tow traffic for a given traffic scenario for a given year. Each line of a traffic input file represents one tow and describes the specific characteristics of the tow, as follows:

1) Julian Day for the time of the tow passage
2) Size class of the tow boat. The NAVPAT model recognizes 8 different size classes based on horsepower.
3) Direction of tow movement, upbound (U) or downbound (D)
4) Empty (E) or loaded (L)
5) Total length of the tow (ft)
6) Total width of the tow (ft)
7) Physical draft of the tow, excluding the push boat (ft)
8) Tow speed relative to land (ft/sec)
9) Propeller size (in)
10) Propeller pitch (in)
11) Propeller speed (rpm)
12) Presence or absence of a Kort nozzle, which enhances tow thrust.

Sailing Lines and Tow Positions

The NAVPAT model uses navigation channel data from the bathymetry files and divides the channel into five sections of equal width. These sections represent five possible positions of a tow in the navigation channel. For each tow in the traffic input file, NAVPAT randomly selects a position from one of the five possibilities. The Tow Position Frequency files consist of frequency distributions laterally across the navigation channel for each tow size class. Larger tows are confined to the center of the channel, while the smaller tows can move more freely within the entire width of the channel.

Stage and Discharge Files

Determination of ambient velocity is made by referring to a spread sheet of river stage or discharge as a function of Julian day and river mile.

IV. c. Analytical Constraints

The NAVPAT model was originally developed to assess navigation impacts to aquatic habitat for site-specific projects. When originally developed, the model strained

the computer processing capabilities and required banks of computers to run for days at a time. The processing time for pool specific runs has been reduced greatly due to the improved speeds of today's computer. Applying the full model to analyze 19 pools, however, was determined to be infeasible given the number of cross-sections, species models, scenarios, and time period of this study. Therefore, to obtain timely results, it was necessary to place some constraints on the analysis.

To put this analysis in perspective, the following variables had to be considered: Each pool was divided into one or more segments that had similar traffic characteristics. The final number of segments used in this analysis was 44. Traffic files were generated for each year within the analysis period (2010-2070). There are 15 species models that have been developed for NAVPAT that were designed to capture the full range of fish habitat types. Fish species were selected to represent three distinct groups (Swift-water Spawning, Swift-water Larval/Fry and Slackwater). Each of these models is analyzed during discrete calendar periods referred to as flow windows. There are three to eight flow windows for each species. The number depends on the species and whether it's in the upper, middle or lower pool. Each window is ten days long. Finally, ORMSS has identified 5 different forecast scenarios based on federal clean air policies that could influence the use of coal over the study period (Utility Based High, Utility Based Medium, National Ambient Air Quality Standards, Clear Skies, and Clear Skies Modified). If all of these variables were run, the total number of output files for ORMSS would have exceeded one million.

Consequently, adjustments had to be made to reduce the computing time and number of output files without sacrificing the significance of the findings. Several adjustments were necessary because NAVPAT was designed for pool-specific studies while it was used in ORMSS to analyze the entire Ohio River mainstem. The first adjustment was to reduce the runs from all 70 forecast years to three. Due to the sensitivity of the model, the decision was made to only use the initial year (2010), the final year (2070) and an intermediate year (2040). Upon completion of the runs, if the model showed large changes in habitat values between these 30 years intervals, additional runs could be made to understand the changes in more detail.

The second adjustment was in the number of species models run. The NAVPAT study conducted for the Winfield Lock Project (USACE 2005) noted that slackwater habitats were not affected by river traffic. Further, the Winfield report found that impacts were limited to species that had a specific seasonal need within the navigation channel. Year-round foragers can move away from adverse conditions and are not generally affected. Eliminating these slackwater species/life stage models from the analysis left only eight models that showed effects.

Representative pools were selected to run all fifteen models to test the hypothesis that species/life stage models behaved similarly in the Ohio River as in the Kanawha River at Winfield. The Willow Island, McAlpine, and Smithland, pools were selected to represent the upper, middle, and lower Ohio River, respectively. If the seven species/life stage models representing slackwater habitat showed changes based on the changes in

traffic, they could be run for more of the remaining pools. Even with these adjustments, the ORMSS NAVPAT runs generated approximately 150,000 output files.

IV. d. Analysis and Interpretation

As described in Section IV.c, NAVPAT model runs were made for all five traffic scenarios. In each scenario, the With Project Condition (WPC) equilibrium traffic projections were compared to the Without Project Condition (WOPC) equilibrium traffic projections. WOPC was defined as the reactive maintenance strategy, which generally includes funding to do inspections, routine maintenance, and occasional component replacements. The WPC includes advance maintenance of lock chamber components, major rehabilitation of lock chambers (wherein individual component replacements are bundled into a single major rehabilitation), and new lock chambers at Emsworth, Dashields, and Montgomery.

NAVPAT does not address the actual response of any of the species but evaluates quality and quantity of habitat for various fleet configurations and traffic levels. The model provides quantitative values of projected environmental effects of various navigation proposals at one or more time intervals in units that are habitat-based and provide a Habitat Suitability Index (HSI). The NAVPAT model outputs are in terms of certain types of aquatic habitats which were defined from river data as described in Section III.a of this report (Cross Sections).

NAVPAT exhibits variability in results that stem primarily from flow window size (defined as the time period in Julian days for which the model is run) and traffic file variability. To reduce variability from flow window size, all flow windows were set at nine days duration. Traffic files were developed by a computer program that generates distributions of tows across the channel cross section. It is important to note that NAVPAT outputs are to be used to examine for trends and compare among alternatives to determine relative degree of impacts rather than using as absolute predictions of actual effects. Finally, because of inherent variability in the model, comparison of small differences was avoided.

For data analyses the Ohio River was divided into 44 reaches to correspond to traffic patterns used in the Ohio River Navigation Investment Model (ORNIM). The boundaries for these reaches were defined by locations where there is a substantial change from one traffic pattern to another. Lock and dam projects were always treated as a boundary between reaches. Results are presented in tabular form for each pool. For any given pool on the river, the data presentation consists of the following:

- Pool name
- Species/life stage habitat type
- Percent of the river-wide total of that species/life stage habitat available in the pool
- Traffic scenario analyzed

- Total HSI Units in the pool under the WOPC and WPC in the years projected (i.e., 2010, 2040, and 2070)
- Difference in the number of HSI Units between the WOPC and WPC
- Percent change in HSI Between WOPC and WPC

Data summaries were graphically displayed with data averaged for the upper, middle, and lower reaches of the Ohio River. For these summaries, there is one graph for each river reach and species/life stage combination. For the years 2010, 2040, and 2070, each graph shows the number of HSI units under the WOPC and WPC. Results are displayed as 1) the mean of all five traffic scenarios 2) the scenario yielding the highest, and 3) the scenario yielding the lowest number of HSI units.

Although many fewer than the possible number of NAVPAT runs were made for this report, the data are available for use in any additional evaluation that may be needed.

V. Results

The results of the NAVPAT application to the ORMSS project are displayed through a series of figures and tables presented at the end of this document, as follows:

- **Figure 1** - a baseline graph of fish habitat availability for the Upper, Middle and Lower Ohio River under Without Project conditions.

- **Table 2** - exemplifying results for an individual pool (Mehdahl Pool) under both Without Project and With Project conditions for all traffic scenarios and all fish life stages.

- **Table 3** - comparing 2010 and 2070 NAVPAT outputs for Meldahl to illustrate long-term fish habitat trends.

- **Tables 4 – 6**: consolidating data (i.e., all scenarios, years, life stages and project conditions) for the Upper, Lower and Middle Ohio River. The Upper segment extends from the Emsworth Pool at Mile 0 to the Greenup Dam at Mile 341. The Middle segment continues from the Greenup Dam to the McAlpine Dam at Mile 607 and the Lower segment continues from McAlpine Dam to the Mississippi confluence at Mile 981.

- **Figures 2 – 16**: summarizing model output for 2010 and 2070 for all traffic scenarios, life stages and both project conditions for the Upper, Lower and Middle Ohio River.

- **Figures 17 – 37**: summarizing model output for 2010 and 2070 for all traffic scenarios, life stages and both project conditions for each pool on the Ohio River.

- **Tables 7 – 27**: presenting complete NAVPAT output for each pool.

VI. Discussion

For purposes of interpretation and evaluation of the results of the Ohio River Mainstem Systems Study application of NAVPAT, it is useful to briefly review the recent application of NAVPAT to the Winfield Pool of the Kanawha River.

VI. a. Kanawa River Study

This application predicted definitive patterns of impacts to different fish habitats from changes in tow configurations and from increased commercial navigation traffic. Generally, this analysis indicated three different responses to navigation traffic that were consistent with known life history patterns of the primary fish assemblages of the Kanawha River: 1) the slackwater fish life stages, 2) the swiftwater larval-fry stages, and 3) swiftwater spawning life stages.

The slackwater group of fish species/life stages showed no effects from navigation at any of the Kanawha River traffic levels evaluated. This indicates that the slackwater fish group is least affected by passing vessels in navigation channels, probably due to their nearshore habitat preferences. This group includes adult and juvenile feeding life stages, and one species/life stage in this group (Freshwater Drum-Adult Feeding) represents a fish not normally considered to be a slackwater species. Feeding behavior in this and other groups of fishes is unlike spawning behaviors, which might be completely abandoned for a season due to tow traffic. While feeding behavior might be temporarily disturbed by tow passage, fish will re-establish feeding behavior once the tow has passed.

The swiftwater larval/fry group showed impacts from increased navigation traffic, but no difference in effects between With Project or Without Project conditions. A model assumption of 100% non-recovery mortality of swiftwater larval/fry stages caused by entrainment through propellers or associated pressure shear and turbulence, however, likely tended to inflate these predicted habitat unit reductions.

Significant negative impacts from navigation to the swiftwater spawning group of fishes in the Winfield Pool of the Kanawha River were obvious. The four swiftwater spawning species/life stages evaluated were Emerald Shiner-Spawning, Paddlefish-Spawning, Sauger-Spawning, and Spotted Bass-Spawning. The corresponding Winfield Pool percent reductions in area habitat units based on one traffic increase scenario were 12%, 11%, 20%, and 34%, respectively. NAVPAT does not use the entrainment modifier in the biological model equations for the swiftwater spawning group. Entrainment only affects the swiftwater larval/fry group. All of the swiftwater spawning group species/life stages instead have a velocity modifier, so habitat loss is due to increases in ambient water velocity. For the Sauger-Spawning species/life stage, NAVPAT also includes a substrate disturbance modifier. These modifiers (water velocity and substrate disturbance) allow for recovery between tow events. It is thought

that the channel geometry of the Kanawha River (narrow and deep) allowed traffic to increase ambient water velocity throughout the entire river cross section.

Since the Kanawha River is a tributary of the Ohio River, with similar commercial navigation traffic characteristics and fish assemblages, it would be reasonable for a NAVPAT application to the Ohio River to produce results similar to those generated for the Kanawha River. A major variable that might be attributed to differences observed between these two recent NAVPAT applications is the larger size (channel width and flow) of the Ohio River relative to the Kanawha River. Vessels using the Ohio River are generally not much larger or more powerful than vessels that navigate the Kanawha River, but the aquatic environment influenced by navigation tows is more compressed along the Kanawha River. The larger system would be better able to absorb navigation impacts with diminished tow effects to its aquatic life resources.

VI. b. Ohio River Study

A clear and consistent pattern evident in the Ohio River Mainstem Study NAVPAT output is that, under either With Project or Without Project conditions, increasing river traffic between the years 2010 and 2070 will result in a loss of habitat units for Emerald Shiner-Spawning and Fry, Paddlefish-Spawning and Larval, Freshwater Drum-Larval, Sauger-Spawning and Larval, and Spotted Bass-Spawning. These loses occur under all five traffic scenarios examined, but are notably greater under the two highest traffic prediction scenarios (Utility Based and Utility Based High). These results are not in anyway surprising since the model intrinsically generates various degrees of non-recovery propeller mortality output for these species/life stages. Except for Paddlefish-Larval, Freshwater Drum-Larval, and Sauger-Larval, these NAVPAT predicted losses of habitat units for the Ohio River will be negligible to slight. The slight to moderate losses in habitat units for Paddlefish-Larval, Freshwater Drum-Larval, and Sauger-Larval are probably balanced by the great abundance of these three types of habitats all along the river. Since they are the most common existing species/life stage habitats within the Ohio River, a modest decline in the availability of these habitats is not likely to be a factor limiting populations of paddlefish, freshwater drum, or sauger in the river.

Beyond these nearly self-evident generalizations, it is very difficult to find consistent and reliable patterns of future predicted navigation influences within the massive outputs of the Ohio River Mainstem Study NAVPAT application. As discussed previously, the failure of such patterns to emerge might be related to the large size and high flows of the Ohio River mainstem, and its ability to absorb predicted additional navigation related impacts, without significantly influencing existing fishery resources within an already highly modified ecosystem.

Some suggestive evidence that system size might be a variable contributing to the differences in Ohio River and Kanawha River NAVPAT results is that the few possibly significant differences (greater than + or – 5.0% delta) observed between With Project or Without Project conditions noted for the Ohio River model application are clustered along the upper and smaller reach of the Ohio River Navigation System. Specifically,

Emerald Shiner-Spawning habitat unit deltas of –5.9% occurred in Dashields Pool in 2010 under the Utility Based and Utility Based High traffic scenarios. Paddlefish-Larval habitat unit deltas of –5.4% occurred in Racine Pool in the same year under the same traffic scenarios, and Freshwater Drum-Larval habitat unit deltas ranging from –5.2% to –8.2% were observed all along the ten uppermost pools in the river from the pool of Emsworth Dam downstream to the pool of Byrd Dam, all again for the year 2010 under Utility Based and Utility Based High traffic scenarios. These impacts to Freshwater Drum-Larval in the upper river over short term, high traffic, and under With Project conditions may be the only non-random habitat unit deltas predicted by the model. With the exception of the Spotted Bass-Spawning species/life stage, no other significant changes were observed for any other species/life stage under any traffic scenario in either 2040 or 2070, in any pool, under either With Project or Without Project conditions. It should be remembered, that while this clustering was clearly exclusive to the upper river, it nonetheless amounted to only a modest portion of the total number of 2520 specific species /life stage events predicted by the NAVPAT model for the Ohio River, and attempts to draw conclusions from this apparent pattern, therefore, should be considered speculative at best.

The Spotted Bass-Spawning species/life stage exception referred to in the preceding paragraph consisted of a total of 35 habitat unit deltas in excess of 5.0%, 15 negative and 20 positive, very randomly distributed throughout the 2010 to 2070 study period, and occurring in a random manner within the five different commercial river traffic scenarios. Of all the NAVPAT quantified fish species/life stage habitats, spawning habitat for spotted bass is by far both the most limited and the most unevenly distributed fish habitat in the Ohio River, especially in the upper and middle reaches (83% of all of the habitat suitable for spotted bass spawning is concentrated in the lower reach of the Ohio River). The very small and rather scattered number of Spotted Bass-Spawning habitat units appears to be very susceptible to random and apparently meaningless model perturbations.

In summary, the Ohio River Mainstem Study NAVPAT application successfully quantified habitat required for various life stages of the primary fish assemblages of the Ohio River, as well as the impacts of future navigation activity scenarios to these habitats. The results of this modeling effort demonstrated that increases in navigation traffic through the year 2070 will negatively, but rather modestly, impact certain groups of fishes, especially swiftwater spawning fishes. While benefits to the fishery might accrue from improvements to navigation under With Project conditions, any such benefits are apparently too small to be measured by the NAVPAT model. In part this might be related to model sensitivity. For instance, NAVPAT programming generalized river cross-sections up to one to two miles in length and normalized traffic input files within the cross-sections. Therefore, this application was not designed to identify reduction in vessel queuing impact benefits to the aquatic resource. However, the failure of the model to demonstrate significant future impacts from navigation are most likely overwhelmingly related to the ability of the Ohio River to absorb the predicted additional navigation impacts, without significantly influencing existing fishery resources within an already highly modified ecosystem.

VII. Recommendations

VII. a. General Improvements to the NAVPAT Model

While the existing edition of the Navigation Predictive Analysis Technique (NAVPAT) provides a useful tool for assessment of the impacts of commercial navigation traffic on various fish species and life stages, a number of improvements to this model would be desirable. ERDC is now in the process of generally upgrading the NAVPAT model, and future applications of NAVPAT will probably find the new ERDC version easier to manage and execute. Also, specific nomenclature should be developed to distinguish between various editions of the model, and the version used in any application should be carefully referenced. A deficiency of both the existing version of NAVPAT and the new edition under development is that neither is able to model conditions nor predict future navigation impacts for the backchannels of river islands. These backchannel reaches are very important habitat components of river ecosystems, and expansion of the model to include this habitat type should be a consideration in future improvement of the NAVPAT model. In addition, during the course of the ORMSS and similar study efforts, such as the modeling of commercial navigation impacts on the Winfield Pool of the Kanawha River, field investigators noted extreme velocity and wave/wake effects from larger V-hulled recreational vessels. At least anecdotally, it appears that the impacts of such vessels might equal or perhaps exceed those of commercial tow traffic. Therefore, it is highly recommended that impacts of recreation traffic be incorporated into future NAVPAT model development.

VII. b. Model Recalibration

As currently calibrated, NAVPAT models navigation impacts to a representative group of fifteen fish species/life stages. These model iterations were selected by an interagency expert group to assess navigation impacts on specific reaches of the navigation system. Resource agencies should be consulted whenever NAVPAT is to be applied in a different region where other species/life stages iterations might be more appropriate. In order to effectively evaluate NAVPAT habitat relationships, the use of guilds should be emphasized to promote a community-level approach to habitat assessment. Consideration should be made of probable spatial distributions of evaluation species within the river so the model can delineate specific areas where evaluation species are most and least susceptible to navigation effects. The variables of importance are depth, velocity, velocity disturbance, substrate composition, substrate disturbance, and structure. From the results of the ORMSS and other applications of NAVPAT, it appears that slackwater species and life stages are the least impacted guilds, and selection of a focused group of main channel species and life stages would be appropriate. Spawning/rearing chronologies need to be identified, and recommendations made on appropriate months to evaluate navigation related impacts. For ORMSS follow-up studies, a recalibration to include impacts to mussels and potentially additional iterations other than fish might also be a very valuable model application.

VII. c. Definition of Significant Impacts

NAVPAT integrates impacts of multiple parameters for various scenarios and produces an output of Habitat Suitability Index (HSI) units. Review and debate by aquatic scientists will be necessary to determine what magnitude of predicted loss or gain of HSI units might amount to a minimal, moderate, or a threshold of substantial impact to the resource for any particular model iteration.

VII. d. GIS Output

In addition to navigation traffic related input, the NAVPAT model requires a tremendous input of physical habitat information. For the ORMSS application, this input includes detailed bathymetry and substrate size data collected along the entire 981-mile length of the Ohio River. Calculated velocities for each model cell under various stage/discharge conditions are also model products. A lack of such comprehensive physical habitat information has long been a critically limiting factor in the characterization and management of the Ohio River ecosystem. Availability of this physical habitat information would be an extremely valuable analysis and management tool. Unfortunately, in its present form, NAVPAT does not easily yield this physical habitat input as a manageable output product. Therefore, it is a very high priority recommendation that the model be expanded to provide physical habitat GIS output.

VIII. References

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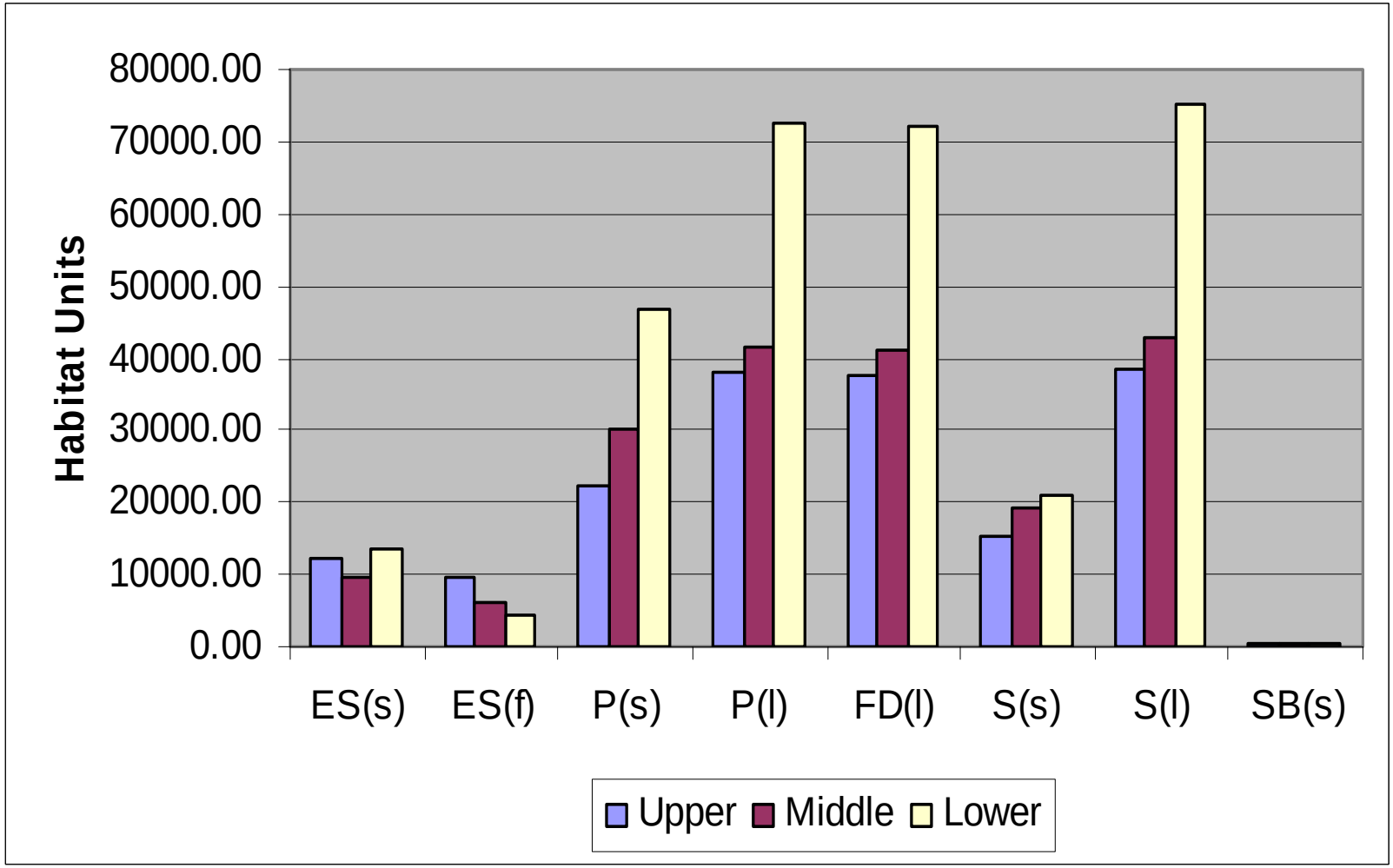
FIGURE 1
Distribution of Without Project Habitat



Note - See pages 4-5 for descriptions of fish species.

TABLE 2
NAVPAT RESULTS
MELDAHL POOL

Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010 Without Project HSI Units	2010 With Project HSI Units	2010 Delta	2010 % Delta	2040 Without Project HSI Units	2040 With Project HSI Units	2040 Delta	2040 % Delta	2070 Without Project HSI Units	2070 With Project HSI Units	2070 Delta	2070 % Delta
ES(s)	Clear Sky w/Hg	7.6	2942.3	2939.6	2.7	0.1	2933.7	2937.8	-4.1	-0.1	2909.7	2909.3	0.4	0.0
1	Clear Sky wo/Hg	7.6	2928.7	2933.7	-5.1	-0.2	2885.5	2920.0	-34.6	-1.2	2850.9	2868.8	-17.9	-0.6
	NAAQS	7.6	2948.9	2926.7	22.2	0.8	2905.5	2918.3	-12.8	-0.4	2849.6	2878.2	-28.6	-1.0
	Utility Based (Coal)	7.6	2948.9	2888.5	60.4	2.0	2878.6	2889.6	-11.0	-0.4	2879.5	2848.3	31.2	1.1
	Utility Based High	7.6	2948.9	2888.5	60.4	2.0	2878.8	2873.8	5.0	0.2	2859.3	2878.8	-19.5	-0.7
ES(f)	Clear Sky w/Hg	8.7	1727.9	1728.3	-0.5	0.0	1717.4	1718.5	-1.1	-0.1	1706.9	1697.6	9.3	0.5
2	Clear Sky wo/Hg	8.7	1745.9	1767.6	-21.7	-1.2	1674.5	1702.3	-27.7	-1.7	1641.0	1648.5	-7.5	-0.5
	NAAQS	8.7	1727.3	1714.6	12.7	0.7	1672.5	1668.5	3.9	0.2	1652.5	1670.5	-17.9	-1.1
	Utility Based (Coal)	8.7	1703.4	1677.7	25.7	1.5	1622.6	1636.7	-14.1	-0.9	1591.7	1582.4	9.2	0.6
	Utility Based High	8.7	1703.4	1677.7	25.7	1.5	1622.4	1623.7	-1.3	-0.1	1554.9	1551.1	3.8	0.2
P(s)	Clear Sky w/Hg	9.2	9039.6	9061.4	-21.8	-0.2	9000.5	8994.6	5.9	0.1	8957.4	8963.3	-5.9	-0.1
3	Clear Sky wo/Hg	9.2	9040.4	8980.3	60.1	0.7	8984.0	8990.8	-6.8	-0.1	8899.9	8947.3	-47.5	-0.5
	NAAQS	9.2	9038.1	9081.6	-43.5	-0.5	8976.0	8938.2	37.8	0.4	8897.8	8863.2	34.6	0.4
	Utility Based (Coal)	9.2	9055.3	9046.1	9.3	0.1	8977.5	8968.3	9.3	0.1	8898.5	8883.0	15.5	0.2
	Utility Based High	9.2	9055.3	9046.1	9.3	0.1	8915.4	8893.9	21.5	0.2	8900.3	8924.7	-24.4	-0.3
P(l)	Clear Sky w/Hg	9.2	13494.4	13721.2	-226.7	-1.7	13525.3	13505.7	19.6	0.1	13057.2	12911.2	146.0	1.1
4	Clear Sky wo/Hg	9.2	13604.1	13363.5	240.6	1.8	13070.2	13055.1	15.1	0.1	12538.2	12610.8	-72.6	-0.6
	NAAQS	9.2	13595.5	13750.1	-154.6	-1.1	13253.5	13194.9	58.7	0.4	12529.2	12449.5	79.7	0.6
	Utility Based (Coal)	9.2	12734.3	12795.4	-61.1	-0.5	12163.0	12066.8	96.2	0.8	11708.3	11626.0	82.3	0.7
	Utility Based High	9.2	12734.3	12795.4	-61.1	-0.5	12016.4	12006.3	10.1	0.1	11206.1	11015.5	190.5	1.7
FD(l)	Clear Sky w/Hg	9.3	13811.6	13631.6	179.9	1.3	13574.3	13705.2	-130.9	-1.0	12930.0	13056.9	-126.9	-1.0
6	Clear Sky wo/Hg	9.3	13213.0	13639.4	-426.4	-3.2	13055.2	13059.9	-4.7	0.0	12531.2	12597.4	-66.2	-0.5
	NAAQS	9.3	13526.2	13256.3	270.0	2.0	13216.2	13275.7	-59.5	-0.5	12502.4	12708.5	-206.2	-1.6
	Utility Based (Coal)	9.3	12933.0	12554.8	378.2	2.9	12043.5	12048.0	-4.5	0.0	11421.2	11429.0	-7.8	-0.1
	Utility Based High	9.3	12933.0	12554.8	378.2	2.9	11991.4	11881.1	110.3	0.9	11269.8	10982.6	287.3	2.5
S(s)	Clear Sky w/Hg	8.5	5144.0	5129.3	14.8	0.3	5103.5	5089.7	13.9	0.3	5067.0	5045.1	21.9	0.4
7	Clear Sky wo/Hg	8.5	5069.2	5078.0	-8.8	-0.2	5077.1	5066.8	10.3	0.2	5014.4	4993.5	20.8	0.4
	NAAQS	8.5	5108.4	5153.2	-44.8	-0.9	5061.9	5056.1	5.8	0.1	5037.3	4983.7	53.6	1.1
	Utility Based (Coal)	8.5	5125.8	5140.1	-14.4	-0.3	5033.6	5034.0	-0.4	0.0	4955.3	4957.4	-2.1	0.0
	Utility Based High	8.5	5125.8	5140.1	-14.4	-0.3	4968.6	4950.1	18.4	0.4	4947.9	4931.4	16.4	0.3
S(l)	Clear Sky w/Hg	9.3	14052.0	13890.8	161.2	1.1	14027.3	14050.0	-22.7	-0.2	13365.1	13359.2	5.9	0.0
8	Clear Sky wo/Hg	9.3	13870.4	13850.1	20.3	0.1	13471.0	13405.3	65.7	0.5	12995.9	12993.5	2.5	0.0
	NAAQS	9.3	13984.6	13986.2	-1.6	0.0	13559.6	13387.3	172.3	1.3	12910.0	12887.8	22.2	0.2
	Utility Based (Coal)	9.3	13314.3	13087.2	227.1	1.7	12729.1	12553.4	175.7	1.4	11953.3	11871.8	81.5	0.7
	Utility Based High	9.3	13314.3	13087.2	227.1	1.7	12283.8	12281.8	2.0	0.0	11659.6	11642.7	16.8	0.1
SB(s)	Clear Sky w/Hg	2.3	53.9	52.4	1.4	2.7	52.8	53.5	-0.7	-1.3	53.2	53.6	-0.4	-0.8
14	Clear Sky wo/Hg	2.3	51.7	52.6	-0.8	-1.6	49.1	48.7	0.4	0.8	45.7	47.0	-1.3	-2.8
	NAAQS	2.3	50.8	50.9	-0.2	-0.4	49.2	49.4	-0.2	-0.4	46.6	48.1	-1.4	-3.1
	Utility Based (Coal)	2.3	49.2	47.6	1.6	3.3	46.4	46.6	-0.2	-0.5	43.9	43.8	0.1	0.2
	Utility Based High	2.3	49.2	47.6	1.6	3.3	45.8	46.5	-0.7	-1.5	44.2	43.4	0.8	1.8

[1]ES(s)=Emerald Shiner (spawning); ES(f)=Emerald Shiner (fry); P(s)=Paddlefish (spawning); P(l)=Paddlefish (larval); FD(l)=Freshwater Drum (larval); S(s)=Sauger (spawning); S(l)=Sauger (larval); SB(s)=Spotted Bass (spawning)

TABLE 3
NAVPAT RESULTS
MELDAHL POOL

Fish Species/ Life Stage[1]	Traffic Forecast Scenario	Without Project 2010	Without Project 2070	Delta	% Delta	With Project 2010	With Project 2070	Delta	% Delta
ES(s)	Clear Sky w/Hg	2942.27	2909.69	32.57	1.11	2939.56	2909.31	30.26	1.03
1	Clear Sky wo/Hg	2928.66	2850.90	77.75	2.65	2933.75	2868.76	64.99	2.22
	NAAQS	2948.88	2849.60	99.29	3.37	2926.68	2878.17	48.50	1.66
	Utility Based (Coal)	2948.88	2879.50	69.38	2.35	2888.45	2848.30	40.15	1.39
	Utility Based High	2948.88	2859.30	89.59	3.04	2888.45	2878.80	9.65	0.33
ES(f)	Clear Sky w/Hg	1727.86	1706.89	20.97	1.21	1728.31	1697.59	30.72	1.78
2	Clear Sky wo/Hg	1745.86	1640.97	104.89	6.01	1767.55	1648.51	119.05	6.74
	NAAQS	1727.34	1652.52	74.81	4.33	1714.59	1670.45	44.14	2.57
	Utility Based (Coal)	1703.42	1591.67	111.75	6.56	1677.70	1582.45	95.26	5.68
	Utility Based High	1703.42	1554.88	148.54	8.72	1677.70	1551.12	126.58	7.54
P(s)	Clear Sky w/Hg	9039.58	8957.40	82.18	0.91	9061.41	8963.29	98.12	1.08
3	Clear Sky wo/Hg	9040.40	8899.86	140.54	1.55	8980.29	8947.33	32.96	0.37
	NAAQS	9038.07	8897.82	140.25	1.55	9081.56	8863.17	218.39	2.40
	Utility Based (Coal)	9055.35	8898.52	156.82	1.73	9046.06	8883.02	163.05	1.80
	Utility Based High	9055.35	8900.28	155.07	1.71	9046.06	8924.67	121.40	1.34
P(l)	Clear Sky w/Hg	13494.43	13057.20	437.24	3.24	13721.17	12911.21	809.96	5.90
4	Clear Sky wo/Hg	13604.14	12538.17	1065.97	7.84	13363.53	12610.81	752.72	5.63
	NAAQS	13595.48	12529.18	1066.30	7.84	13750.10	12449.52	1300.59	9.46
	Utility Based (Coal)	12734.32	11708.32	1026.00	8.06	12795.44	11626.03	1169.41	9.14
	Utility Based High	12734.32	11206.08	1528.24	12.00	12795.44	11015.54	1779.91	13.91
FD(l)	Clear Sky w/Hg	13811.57	12930.00	881.57	6.38	13631.64	13056.90	574.74	4.22
6	Clear Sky wo/Hg	13212.96	12531.19	681.77	5.16	13639.39	12597.38	1042.01	7.64
	NAAQS	13526.22	12502.38	1023.83	7.57	13256.26	12708.54	547.73	4.13
	Utility Based (Coal)	12933.01	11421.24	1511.77	11.69	12554.77	11429.04	1125.74	8.97
	Utility Based High	12933.01	11269.82	1663.19	12.86	12554.77	10982.55	1572.22	12.52
S(s)	Clear Sky w/Hg	5144.03	5066.99	77.04	1.50	5129.27	5045.10	84.16	1.64
7	Clear Sky wo/Hg	5069.20	5014.36	54.84	1.08	5077.96	4993.53	84.43	1.66
	NAAQS	5108.42	5037.32	71.11	1.39	5153.18	4983.74	169.44	3.29
	Utility Based (Coal)	5125.78	4955.29	170.49	3.33	5140.15	4957.35	182.80	3.56
	Utility Based High	5125.78	4947.85	177.93	3.47	5140.15	4931.42	208.73	4.06
S(l)	Clear Sky w/Hg	14051.98	13365.09	686.90	4.89	13890.80	13359.23	531.57	3.83
8	Clear Sky wo/Hg	13870.40	12995.93	874.47	6.30	13850.09	12993.47	856.62	6.18
	NAAQS	13984.63	12909.96	1074.67	7.68	13986.19	12887.78	1098.41	7.85
	Utility Based (Coal)	13314.29	11953.31	1360.98	10.22	13087.17	11871.78	1215.39	9.29
	Utility Based High	13314.29	11659.56	1654.73	12.43	13087.17	11642.71	1444.46	11.04
SB(s)	Clear Sky w/Hg	53.88	53.20	0.69	1.28	52.44	53.60	-1.17	-2.23
14	Clear Sky wo/Hg	51.74	45.69	6.05	11.70	52.58	46.95	5.63	10.70
	NAAQS	50.77	46.63	4.14	8.15	50.95	48.06	2.89	5.68
	Utility Based (Coal)	49.22	43.88	5.35	10.86	47.61	43.78	3.83	8.04
	Utility Based High	49.22	44.20	5.02	10.20	47.61	43.39	4.22	8.86

TABLE 4
NAVPAT Traffic Impacts
Upper Ohio River

				2010				2040				2070				2010-2070			2010-2070		
Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Upper River	ES(s)	Clear Sky w/Hg	16980.01	12272.56	12240.45	-32.1	-0.26%	12076.2	12111.11	34.9	0.29%	11977.06	11958.25	-18.8	-0.16%	12272.56	11977.06	-2.41%	12240.45	11958.25	-2.31%
	1	Clear Sky wo/Hg	16980.01	11979.55	12076.59	97.0	0.81%	11828.6	11860.23	31.6	0.27%	11721.05	11715.82	-5.2	-0.04%	11979.55	11721.05	-2.16%	12076.59	11715.82	-2.99%
		NAAQS	16980.01	12078.60	12057.58	-21.0	-0.17%	11760.9	11784.29	23.4	0.20%	11657.51	11680.62	23.1	0.20%	12078.60	11657.51	-3.49%	12057.58	11680.62	-3.13%
		Utility Based (Coal)	16980.01	12194.56	11898.47	-296.1	-2.43%	11853.4	11888.72	35.4	0.30%	11712.96	11668.38	-44.6	-0.38%	12194.56	11712.96	-3.95%	11898.47	11668.38	-1.93%
		Utility Based High	16980.01	12194.56	11898.47	-296.1	-2.43%	11742.6	11755.55	12.9	0.11%	11619.91	11562.96	-56.9	-0.49%	12194.56	11619.91	-4.71%	11898.47	11562.96	-2.82%
	ES(f)	Clear Sky w/Hg	11559.97	9769.41	9769.73	0.3	0.00%	9441.0	9472.74	31.7	0.34%	9367.06	9342.03	-25.0	-0.27%	9769.41	9367.06	-4.12%	9769.73	9342.03	-4.38%
	2	Clear Sky wo/Hg	11559.97	9357.79	9538.40	180.6	1.93%	9269.2	9243.68	-25.5	-0.27%	8967.24	8964.67	-2.6	-0.03%	9357.79	8967.24	-4.17%	9538.40	8964.67	-6.01%
		NAAQS	11559.97	9529.03	9462.67	-66.4	-0.70%	9120.7	9105.95	-14.7	-0.16%	8933.65	8858.50	-75.2	-0.84%	9529.03	8933.65	-6.25%	9462.67	8858.50	-6.38%
		Utility Based (Coal)	11559.97	9731.31	9359.69	-371.6	-3.82%	9314.1	9350.43	36.4	0.39%	9017.18	8997.97	-19.2	-0.21%	9731.31	9017.18	-7.34%	9359.69	8997.97	-3.86%
		Utility Based High	11559.97	9731.31	9359.69	-371.6	-3.82%	9107.9	9118.18	10.3	0.11%	8876.71	8877.61	0.9	0.01%	9731.31	8876.71	-8.78%	9359.69	8877.61	-5.15%
	P(s)	Clear Sky w/Hg	28296.32	22806.87	22491.29	-315.6	-1.38%	22342.5	22283.83	-58.7	-0.26%	22344.07	22351.69	7.6	0.03%	22806.87	22344.07	-2.03%	22491.29	22351.69	-0.62%
	3	Clear Sky wo/Hg	28296.32	22119.31	22159.45	40.1	0.18%	22162.7	22066.27	-96.5	-0.44%	21869.02	22047.77	178.8	0.82%	22119.31	21869.02	-1.13%	22159.45	22047.77	-0.50%
		NAAQS	28296.32	22271.25	22383.45	112.2	0.50%	22271.2	22213.87	-57.4	-0.26%	22042.46	22026.19	-16.3	-0.07%	22271.25	22042.46	-1.03%	22383.45	22026.19	-1.60%
		Utility Based (Coal)	28296.32	22210.03	22270.08	60.0	0.27%	21954.9	22020.78	65.9	0.30%	21878.24	21833.21	-45.0	-0.21%	22210.03	21878.24	-1.49%	22270.08	21833.21	-1.96%
		Utility Based High	28296.32	22210.03	22270.08	60.0	0.27%	21910.8	21917.27	6.5	0.03%	21844.70	21738.84	-105.9	-0.48%	22210.03	21844.70	-1.64%	22270.08	21738.84	-2.39%
	P(l)	Clear Sky w/Hg	53908.67	40019.14	39609.24	-409.9	-1.02%	37932.7	37988.67	56.0	0.15%	37322.97	37502.49	179.5	0.48%	40019.14	37322.97	-6.74%	39609.24	37502.49	-5.32%
	4	Clear Sky wo/Hg	53908.67	37277.97	37984.95	707.0	1.90%	36074.7	36375.24	300.5	0.83%	35038.74	35098.77	60.0	0.17%	37277.97	35038.74	-6.01%	37984.95	35098.77	-7.60%
		NAAQS	53908.67	38035.08	37834.37	-200.7	-0.53%	36007.4	36114.31	106.9	0.30%	34766.22	34955.97	189.8	0.55%	38035.08	34766.22	-8.59%	37834.37	34955.97	-7.61%
		Utility Based (Coal)	53908.67	38925.22	37364.69	-1560.5	-4.01%	36593.4	36875.42	282.0	0.77%	35174.80	34825.12	-349.7	-0.99%	38925.22	35174.80	-9.63%	37364.69	34825.12	-6.80%
		Utility Based High	53908.67	38925.22	37364.69	-1560.5	-4.01%	35699.1	35756.37	57.2	0.16%	34099.13	33889.70	-209.4	-0.61%	38925.22	34099.13	-12.40%	37364.69	33889.70	-9.30%
	FD(l)	Clear Sky w/Hg	53768.14	39187.47	38982.95	-204.5	-0.52%	37321.5	37579.47	257.9	0.69%	36368.16	36400.04	31.9	0.09%	39187.47	36368.16	-7.19%	38982.95	36400.04	-6.63%
	6	Clear Sky wo/Hg	53768.14	36866.71	38105.86	1239.1	3.36%	35930.3	36315.65	385.3	1.07%	34111.63	33831.66	-280.0	-0.82%	36866.71	34111.63	-7.47%	38105.86	33831.66	-11.22%
		NAAQS	53768.14	37434.41	37174.71	-259.7	-0.69%	35280.3	35284.27	4.0	0.01%	33812.43	33824.93	12.5	0.04%	37434.41	33812.43	-9.68%	37174.71	33824.93	-9.01%
		Utility Based (Coal)	53768.14	38972.77	36708.83	-2263.9	-5.81%	35641.4	36275.93	634.5	1.78%	34018.50	33501.55	-517.0	-1.52%	38972.77	34018.50	-12.71%	36708.83	33501.55	-8.74%
		Utility Based High	53768.14	38972.77	36708.83	-2263.9	-5.81%	34862.9	34962.54	99.7	0.29%	32945.65	32844.08	-101.6	-0.31%	38972.77	32945.65	-15.46%	36708.83	32844.08	-10.53%
	S(s)	Clear Sky w/Hg	25427.15	15708.68	15662.91	-45.8	-0.29%	15263.3	15217.38	-45.9	-0.30%	15234.51	15183.88	-50.6	-0.33%	15708.68	15234.51	-3.02%	15662.91	15183.88	-3.06%
	7	Clear Sky wo/Hg	25427.15	14913.27	15073.02	159.7	1.07%	14995.6	14949.79	-45.8	-0.31%	14701.46	14757.59	56.1	0.38%	14913.27	14701.46	-1.42%	15073.02	14757.59	-2.09%
		NAAQS	25427.15	15292.36	15244.76	-47.6	-0.31%	14919.1	14943.34	24.3	0.16%	14930.54	14755.79	-174.7	-1.17%	15292.36	14930.54	-2.37%	15244.76	14755.79	-3.21%
		Utility Based (Coal)	25427.15	15368.98	15369.14	0.2	0.00%	14948.5	15067.31	118.8	0.79%	14830.27	14646.25	-184.0	-1.24%	15368.98	14830.27	-3.51%	15369.14	14646.25	-4.70%
		Utility Based High	25427.15	15368.98	15369.14	0.2	0.00%	14701.9	14889.04	187.2	1.27%	14706.62	14699.75	-6.9	-0.05%	15368.98	14706.62	-4.31%	15369.14	14699.75	-4.36%
	S(l)	Clear Sky w/Hg	54041.38	40626.31	39708.11	-918.2	-2.26%	39325.9	39301.92	-24.0	-0.06%	38473.62	38786.44	312.8	0.81%	40626.31	38473.62	-5.30%	39708.11	38786.44	-2.32%
	8	Clear Sky wo/Hg	54041.38	38432.39	38305.26	-127.1	-0.33%	37297.0	37150.01	-147.0	-0.39%	35648.17	35841.24	193.1	0.54%	38432.39	35648.17	-7.24%	38305.26	35841.24	-6.43%
		NAAQS	54041.38	38608.03	38844.22	236.2	0.61%	37302.5	37067.13	-235.4	-0.63%	35572.22	35495.75	-76.5	-0.21%	38608.03	35572.22	-7.86%	38844.22	35495.75	-8.62%
		Utility Based (Coal)	54041.38	38914.43	38921.29	6.9	0.02%	37819.4	37976.95	157.6	0.42%	36090.98	35870.30	-220.7	-0.61%	38914.43	36090.98	-7.26%	38921.29	35870.30	-7.84%
		Utility Based High	54041.38	38914.43	38921.29	6.9	0.02%	36912.9	37181.24	268.4	0.73%	35798.58	35118.93	-679.6	-1.90%	38914.43	35798.58	-8.01%	38921.29	35118.93	-9.77%
	SB(s)	Clear Sky w/Hg	2514.335	586.51	586.59	0.1	0.01%	528.9	531.54	2.7	0.50%	538.35	545.22	6.9	1.28%	586.51	538.35	-8.21%	586.59	545.22	-7.05%
	14	Clear Sky wo/Hg	2514.335	522.04	514.93	-7.1	-1.36%	475.3	469.22	-6.1	-1.28%	441.24	441.27	0.0	0.01%	522.04	441.24	-15.48%	514.93	441.27	-14.31%
		NAAQS	2514.335	539.86	540.45	0.6	0.11%	460.6	467.18	6.6	1.43%	441.59	436.28	-5.3	-1.20%	539.86	441.59	-18.20%	540.45	436.28	-19.27%
		Utility Based (Coal)	2514.335	572.74	554.97	-17.8	-3.10%	514.6	516.13	1.6	0.30%	478.36	469.55	-8.8	-1.84%	572.74	478.36	-16.48%	554.97	469.55	-15.39%
		Utility Based High	2514.335	572.74	554.97	-17.8	-3.10%	503.9	501.25	-2.6	-0.52%	436.93	453.34	16.4	3.76%	572.74	436.93	-23.71%	554.97	453.34	-18.31%

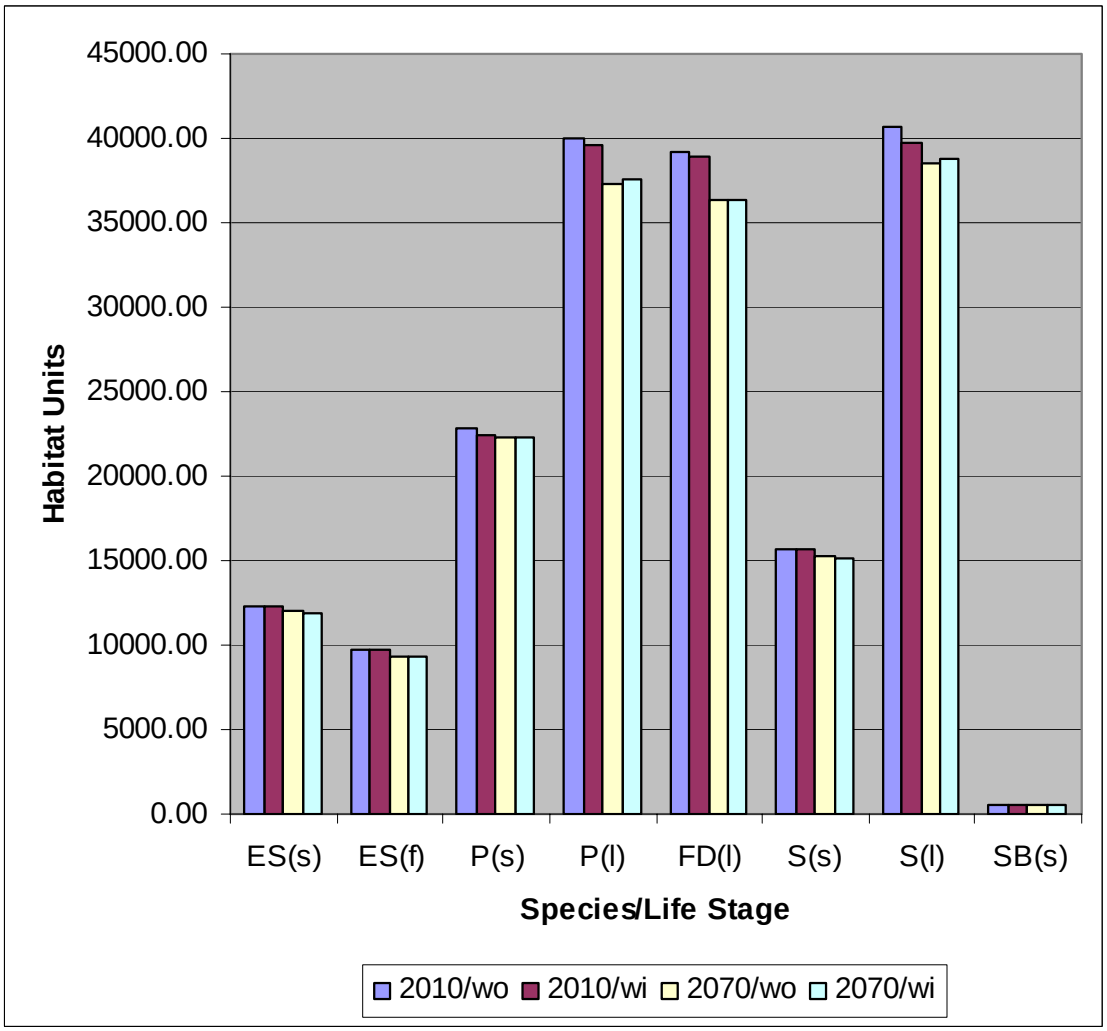
TABLE 5
NAVPAT Traffic Impacts
Middle Ohio River

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Middle River	ES(s)	Clear Sky w/Hg	11200.42	9445.39	9432.28	-13.1	-0.14%	9380.2	9404.34	24.2	0.26%	9321.78	9292.59	-29.2	-0.31%	9445.39	9321.78	-1.31%	9432.28	9292.59	-1.48%
	1	Clear Sky wo/Hg	11200.42	9408.03	9407.90	-0.1	0.00%	9278.6	9364.97	86.4	0.93%	9171.98	9196.66	24.7	0.27%	9408.03	9171.98	-2.51%	9407.90	9196.66	-2.25%
		NAAQS	11200.42	9419.25	9396.92	-22.3	-0.24%	9302.9	9342.72	39.8	0.43%	9164.65	9207.01	42.4	0.46%	9419.25	9164.65	-2.70%	9396.92	9207.01	-2.02%
		Utility Based (Coal)	11200.42	9423.80	9271.68	-152.1	-1.61%	9251.3	9253.74	2.5	0.03%	9229.99	9137.48	-92.5	-1.00%	9423.80	9229.99	-2.06%	9271.68	9137.48	-1.45%
		Utility Based High	11200.42	9423.80	9271.68	-152.1	-1.61%	9260.5	9223.90	-36.6	-0.40%	9173.47	9232.71	59.2	0.65%	9423.80	9173.47	-2.66%	9271.68	9232.71	-0.42%
	ES(f)	Clear Sky w/Hg	6667.675	5897.70	5897.65	-0.1	0.00%	5812.9	5812.00	-0.9	-0.02%	5750.76	5740.36	-10.4	-0.18%	5897.70	5750.76	-2.49%	5897.65	5740.36	-2.67%
	2	Clear Sky wo/Hg	6667.675	5882.98	5979.36	96.4	1.64%	5679.4	5796.38	117.0	2.06%	5624.24	5661.09	36.8	0.66%	5882.98	5624.24	-4.40%	5979.36	5661.09	-5.32%
		NAAQS	6667.675	5907.47	5858.14	-49.3	-0.84%	5699.1	5712.94	13.9	0.24%	5656.10	5715.37	59.3	1.05%	5907.47	5656.10	-4.26%	5858.14	5715.37	-2.44%
		Utility Based (Coal)	6667.675	5847.57	5765.88	-81.7	-1.40%	5585.6	5660.22	74.6	1.34%	5533.11	5484.33	-48.8	-0.88%	5847.57	5533.11	-5.38%	5765.88	5484.33	-4.88%
		Utility Based High	6667.675	5847.57	5765.88	-81.7	-1.40%	5611.9	5652.49	40.6	0.72%	5429.38	5488.38	59.0	1.09%	5847.57	5429.38	-7.15%	5765.88	5488.38	-4.81%
	P(s)	Clear Sky w/Hg	34629.74	30348.12	30292.82	-55.3	-0.18%	30075.8	30061.83	-13.9	-0.05%	29989.64	30022.26	32.6	0.11%	30348.12	29989.64	-1.18%	30292.82	30022.26	-0.89%
	3	Clear Sky wo/Hg	34629.74	30260.06	30164.57	-95.5	-0.32%	30139.2	30124.45	-14.8	-0.05%	29803.24	29959.62	156.4	0.52%	30260.06	29803.24	-1.51%	30164.57	29959.62	-0.68%
		NAAQS	34629.74	30300.24	30420.70	120.5	0.40%	30120.3	29989.29	-131.0	-0.44%	29884.29	29746.39	-137.9	-0.46%	30300.24	29884.29	-1.37%	30420.70	29746.39	-2.22%
		Utility Based (Coal)	34629.74	30349.91	30312.24	-37.7	-0.12%	30090.3	30134.62	44.3	0.15%	29896.55	29870.07	-26.5	-0.09%	30349.91	29896.55	-1.49%	30312.24	29870.07	-1.46%
		Utility Based High	34629.74	30349.91	30312.24	-37.7	-0.12%	30003.1	29887.75	-115.4	-0.38%	29861.22	29894.18	33.0	0.11%	30349.91	29861.22	-1.61%	30312.24	29894.18	-1.38%
	P(l)	Clear Sky w/Hg	54228.63	41590.71	42118.65	527.9	1.27%	40981.3	40949.45	-31.9	-0.08%	39686.43	39229.54	-456.9	-1.15%	41590.71	39686.43	-4.58%	42118.65	39229.54	-6.86%
	4	Clear Sky wo/Hg	54228.63	41582.14	41093.11	-489.0	-1.18%	40067.6	40181.18	113.6	0.28%	38764.39	38959.85	195.5	0.50%	41582.14	38764.39	-6.78%	41093.11	38959.85	-5.19%
		NAAQS	54228.63	41611.60	42110.21	498.6	1.20%	40731.9	40380.89	-351.0	-0.86%	38624.05	38212.16	-411.9	-1.07%	41611.60	38624.05	-7.18%	42110.21	38212.16	-9.26%
		Utility Based (Coal)	54228.63	39765.03	40143.97	378.9	0.95%	38513.3	38274.70	-238.6	-0.62%	37244.57	37233.41	-11.2	-0.03%	39765.03	37244.57	-6.34%	40143.97	37233.41	-7.25%
		Utility Based High	54228.63	39765.03	40143.97	378.9	0.95%	38054.9	38138.15	83.3	0.22%	35979.48	35607.77	-371.7	-1.03%	39765.03	35979.48	-9.52%	40143.97	35607.77	-11.30%
	FD(l)	Clear Sky w/Hg	54045.49	41942.72	42009.99	67.3	0.16%	40860.9	41248.45	387.6	0.95%	39274.06	39288.84	14.8	0.04%	41942.72	39274.06	-6.36%	42009.99	39288.84	-6.48%
	6	Clear Sky wo/Hg	54045.49	40555.75	41766.71	1211.0	2.99%	40126.9	40287.97	161.1	0.40%	38668.11	38931.99	263.9	0.68%	40555.75	38668.11	-4.65%	41766.71	38931.99	-6.79%
		NAAQS	54045.49	41300.32	41011.83	-288.5	-0.70%	40396.2	40672.78	276.6	0.68%	38378.24	38555.44	177.2	0.46%	41300.32	38378.24	-7.08%	41011.83	38555.44	-5.99%
		Utility Based (Coal)	54045.49	40330.99	39274.34	-1056.7	-2.62%	38183.7	38205.81	22.1	0.06%	36680.68	36720.24	39.6	0.11%	40330.99	36680.68	-9.05%	39274.34	36720.24	-6.50%
		Utility Based High	54045.49	40330.99	39274.34	-1056.7	-2.62%	38189.3	38095.74	-93.5	-0.24%	36305.65	35641.71	-663.9	-1.83%	40330.99	36305.65	-9.98%	39274.34	35641.71	-9.25%
	S(s)	Clear Sky w/Hg	28044.77	19292.95	19262.54	-30.4	-0.16%	19040.9	18991.37	-49.5	-0.26%	18874.55	18786.44	-88.1	-0.47%	19292.95	18874.55	-2.17%	19262.54	18786.44	-2.47%
	7	Clear Sky wo/Hg	28044.77	18977.04	19025.54	48.5	0.26%	18919.7	18800.88	-118.8	-0.63%	18704.14	18666.37	-37.8	-0.20%	18977.04	18704.14	-1.44%	19025.54	18666.37	-1.89%
		NAAQS	28044.77	19153.90	19345.47	191.6	1.00%	18947.4	18893.42	-54.0	-0.28%	18790.28	18643.51	-146.8	-0.78%	19153.90	18790.28	-1.90%	19345.47	18643.51	-3.63%
		Utility Based (Coal)	28044.77	19198.57	19254.71	56.1	0.29%	18812.2	18842.48	30.3	0.16%	18607.61	18593.61	-14.0	-0.08%	19198.57	18607.61	-3.08%	19254.71	18593.61	-3.43%
		Utility Based High	28044.77	19198.57	19254.71	56.1	0.29%	18622.6	18570.24	-52.3	-0.28%	18503.75	18510.23	6.5	0.04%	19198.57	18503.75	-3.62%	19254.71	18510.23	-3.87%
	S(l)	Clear Sky w/Hg	54492.33	43248.68	43014.87	-233.8	-0.54%	42207.2	42237.80	30.6	0.07%	40541.25	40631.77	90.5	0.22%	43248.68	40541.25	-6.26%	43014.87	40631.77	-5.54%
	8	Clear Sky wo/Hg	54492.33	42641.91	42792.98	151.1	0.35%	41348.4	41445.95	97.6	0.24%	39813.73	40096.31	282.6	0.71%	42641.91	39813.73	-6.63%	42792.98	40096.31	-6.30%
		NAAQS	54492.33	42874.43	43123.03	248.6	0.58%	41398.4	40954.83	-443.5	-1.07%	39412.16	39610.26	198.1	0.50%	42874.43	39412.16	-8.08%	43123.03	39610.26	-8.15%
		Utility Based (Coal)	54492.33	41614.14	40845.95	-768.2	-1.85%	39799.7	39474.05	-325.7	-0.82%	38100.03	37950.46	-149.6	-0.39%	41614.14	38100.03	-8.44%	40845.95	37950.46	-7.09%
		Utility Based High	54492.33	41614.14	40845.95	-768.2	-1.85%	38956.4	38990.67	34.2	0.09%	37472.09	37519.03	46.9	0.13%	41614.14	37472.09	-9.95%	40845.95	37519.03	-8.15%
	SB(s)	Clear Sky w/Hg	1020.18	294.84	296.04	1.2	0.41%	294.9	298.39	3.4	1.17%	289.72	293.77	4.1	1.40%	294.84	289.72	-1.74%	296.04	293.77	-0.77%
	14	Clear Sky wo/Hg	1020.18	294.27	299.25	5.0	1.69%	283.5	281.64	-1.9	-0.66%	266.27	273.41	7.1	2.68%	294.27	266.27	-9.51%	299.25	273.41	-8.63%
		NAAQS	1020.18	294.03	298.24	4.2	1.43%	274.9	277.56	2.6	0.96%	268.07	275.02	7.0	2.59%	294.03	268.07	-8.83%	298.24	275.02	-7.79%
		Utility Based (Coal)	1020.18	279.69	266.07	-13.6	-4.87%	266.3	272.82	6.6	2.46%	256.41	256.72	0.3	0.12%	279.69	256.41	-8.32%	266.07	256.72	-3.51%
		Utility Based High	1020.18	279.69	266.07	-13.6	-4.87%	265.2	266.50	1.3	0.49%	258.72	256.90	-1.8	-0.71%	279.69	258.72	-7.50%	266.07	256.90	-3.45%

TABLE 6
NAVPAT Traffic Impacts
Lower Ohio River

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Lower River	ES(s)	Clear Sky w/Hg	17224.82	13789.33	13811.36	22.0	0.16%	13669.6	13675.12	5.5	0.04%	13659.20	13632.06	-27.1	-0.20%	13789.33	13659.20	-0.94%	13811.36	13632.06	-1.30%
	1	Clear Sky wo/Hg	17224.82	13711.34	13704.29	-7.0	-0.05%	13619.3	13669.16	49.9	0.37%	13423.51	13532.62	109.1	0.81%	13711.34	13423.51	-2.10%	13704.29	13532.62	-1.25%
		NAAQS	17224.82	13728.88	13810.35	81.5	0.59%	13673.5	13663.62	-9.8	-0.07%	13402.17	13392.87	-9.3	-0.07%	13728.88	13402.17	-2.38%	13810.35	13392.87	-3.02%
		Utility Based (Coal)	17224.82	13704.74	13645.82	-58.9	-0.43%	13597.7	13627.68	30.0	0.22%	13494.10	13461.94	-32.2	-0.24%	13704.74	13494.10	-1.54%	13645.82	13461.94	-1.35%
		Utility Based High	17224.82	13704.74	13645.82	-58.9	-0.43%	13665.4	13682.90	17.5	0.13%	13464.79	13495.49	30.7	0.23%	13704.74	13464.79	-1.75%	13645.82	13495.49	-1.10%
	ES(f)	Clear Sky w/Hg	4445.69	4275.85	4260.41	-15.4	-0.36%	4239.0	4242.81	3.8	0.09%	4213.30	4209.83	-3.5	-0.08%	4275.85	4213.30	-1.46%	4260.41	4209.83	-1.19%
	2	Clear Sky wo/Hg	4445.69	4248.13	4264.12	16.0	0.38%	4217.5	4238.81	21.3	0.51%	4204.15	4186.58	-17.6	-0.42%	4248.13	4204.15	-1.04%	4264.12	4186.58	-1.82%
		NAAQS	4445.69	4266.73	4258.19	-8.5	-0.20%	4233.7	4249.39	15.7	0.37%	4196.21	4191.65	-4.6	-0.11%	4266.73	4196.21	-1.65%	4258.19	4191.65	-1.56%
		Utility Based (Coal)	4445.69	4241.13	4254.30	13.2	0.31%	4219.4	4210.36	-9.0	-0.21%	4200.07	4192.43	-7.6	-0.18%	4241.13	4200.07	-0.97%	4254.30	4192.43	-1.45%
		Utility Based High	4445.69	4241.13	4254.30	13.2	0.31%	4231.6	4234.98	3.4	0.08%	4200.00	4167.42	-32.6	-0.78%	4241.13	4200.00	-0.97%	4254.30	4167.42	-2.04%
	P(s)	Clear Sky w/Hg	52839.54	46966.72	46970.01	3.3	0.01%	46611.5	46621.96	10.5	0.02%	46466.77	46438.07	-28.7	-0.06%	46966.72	46466.77	-1.06%	46970.01	46438.07	-1.13%
	3	Clear Sky wo/Hg	52839.54	46796.24	46829.98	33.7	0.07%	46552.0	46600.16	48.1	0.10%	46163.38	46330.59	167.2	0.36%	46796.24	46163.38	-1.35%	46829.98	46330.59	-1.07%
		NAAQS	52839.54	46787.74	47059.89	272.2	0.58%	46522.9	46514.73	-8.2	-0.02%	46215.89	46151.66	-64.2	-0.14%	46787.74	46215.89	-1.22%	47059.89	46151.66	-1.93%
		Utility Based (Coal)	52839.54	46929.00	46886.69	-42.3	-0.09%	46614.7	46604.54	-10.1	-0.02%	46389.96	46320.73	-69.2	-0.15%	46929.00	46389.96	-1.15%	46886.69	46320.73	-1.21%
		Utility Based High	52839.54	46929.00	46886.69	-42.3	-0.09%	46551.7	46410.39	-141.3	-0.30%	46330.65	46289.99	-40.7	-0.09%	46929.00	46330.65	-1.28%	46886.69	46289.99	-1.27%
	P(l)	Clear Sky w/Hg	88704.49	72767.94	72542.39	-225.5	-0.31%	70723.4	70635.58	-87.9	-0.12%	69014.94	68984.78	-30.2	-0.04%	72767.94	69014.94	-5.16%	72542.39	68984.78	-4.90%
	4	Clear Sky wo/Hg	88704.49	72330.22	72452.03	121.8	0.17%	69855.0	70063.77	208.7	0.30%	68119.98	68622.47	502.5	0.74%	72330.22	68119.98	-5.82%	72452.03	68622.47	-5.29%
		NAAQS	88704.49	72546.06	72177.48	-368.6	-0.51%	69710.1	70394.64	684.5	0.98%	67562.65	67966.07	403.4	0.60%	72546.06	67562.65	-6.87%	72177.48	67966.07	-5.83%
		Utility Based (Coal)	88704.49	72139.04	72208.35	69.3	0.10%	69423.1	70082.96	659.9	0.95%	68395.08	67296.81	-1098.3	-1.61%	72139.04	68395.08	-5.19%	72208.35	67296.81	-6.80%
		Utility Based High	88704.49	72139.04	72208.35	69.3	0.10%	69999.0	69908.04	-90.9	-0.13%	67227.67	67770.06	542.4	0.81%	72139.04	67227.67	-6.81%	72208.35	67770.06	-6.15%
	FD(l)	Clear Sky w/Hg	88612.29	71694.64	72641.02	946.4	1.32%	70624.3	70727.51	103.3	0.15%	68743.38	68050.03	-693.3	-1.01%	71694.64	68743.38	-4.12%	72641.02	68050.03	-6.32%
	6	Clear Sky wo/Hg	88612.29	72023.30	72174.41	151.1	0.21%	70271.6	70289.80	18.2	0.03%	67538.95	69032.97	1494.0	2.21%	72023.30	67538.95	-6.23%	72174.41	69032.97	-4.35%
		NAAQS	88612.29	72043.46	72864.84	821.4	1.14%	70639.7	70373.59	-266.1	-0.38%	67950.74	68359.17	408.4	0.60%	72043.46	67950.74	-5.68%	72864.84	68359.17	-6.18%
		Utility Based (Coal)	88612.29	72818.65	72540.64	-278.0	-0.38%	70498.8	69890.31	-608.5	-0.86%	69534.96	68294.17	-1240.8	-1.78%	72818.65	69534.96	-4.51%	72540.64	68294.17	-5.85%
		Utility Based High	88612.29	72818.65	72540.64	-278.0	-0.38%	69276.4	69939.02	662.6	0.96%	68203.98	67301.66	-902.3	-1.32%	72818.65	68203.98	-6.34%	72540.64	67301.66	-7.22%
	S(s)	Clear Sky w/Hg	32092.98	21210.17	21218.70	8.5	0.04%	21141.0	21161.42	20.5	0.10%	20720.63	20753.36	32.7	0.16%	21210.17	20720.63	-2.31%	21218.70	20753.36	-2.19%
	7	Clear Sky wo/Hg	32092.98	20968.05	21103.40	135.3	0.65%	20895.0	20843.88	-51.1	-0.24%	20644.11	20688.67	44.6	0.22%	20968.05	20644.11	-1.54%	21103.40	20688.67	-1.97%
		NAAQS	32092.98	21051.79	21286.10	234.3	1.11%	20817.0	20760.92	-56.1	-0.27%	20769.90	20648.15	-121.7	-0.59%	21051.79	20769.90	-1.34%	21286.10	20648.15	-3.00%
		Utility Based (Coal)	32092.98	21107.31	21266.13	158.8	0.75%	20857.9	21079.80	221.8	1.06%	20690.78	20671.43	-19.4	-0.09%	21107.31	20690.78	-1.97%	21266.13	20671.43	-2.80%
		Utility Based High	32092.98	21107.31	21266.13	158.8	0.75%	20863.7	20934.87	71.1	0.34%	20667.05	20772.10	105.1	0.51%	21107.31	20667.05	-2.09%	21266.13	20772.10	-2.32%
	S(l)	Clear Sky w/Hg	90076.21	75394.46	75643.94	249.5	0.33%	73841.6	73748.88	-92.7	-0.13%	71976.38	72242.62	266.2	0.37%	75394.46	71976.38	-4.53%	75643.94	72242.62	-4.50%
	8	Clear Sky wo/Hg	90076.21	74897.72	75320.95	423.2	0.57%	73581.0	73369.57	-211.5	-0.29%	71300.20	72329.28	1029.1	1.44%	74897.72	71300.20	-4.80%	75320.95	72329.28	-3.97%
		NAAQS	90076.21	75373.25	76575.37	1202.1	1.59%	73314.8	73179.28	-135.5	-0.18%	70576.46	71337.94	761.5	1.08%	75373.25	70576.46	-6.36%	76575.37	71337.94	-6.84%
		Utility Based (Coal)	90076.21	75446.10	75333.55	-112.6	-0.15%	72733.4	72877.47	144.1	0.20%	71274.24	71017.74	-256.5	-0.36%	75446.10	71274.24	-5.53%	75333.55	71017.74	-5.73%
		Utility Based High	90076.21	75446.10	75333.55	-112.6	-0.15%	72749.6	72630.35	-119.3	-0.16%	71188.34	71259.64	71.3	0.10%	75446.10	71188.34	-5.64%	75333.55	71259.64	-5.41%
	SB(s)	Clear Sky w/Hg	1016.283	286.85	295.43	8.6	2.99%	293.5	292.56	-0.9	-0.31%	278.76	274.75	-4.0	-1.44%	286.85	278.76	-2.82%	295.43	274.75	-7.00%
	14	Clear Sky wo/Hg	1016.283	289.43	279.64	-9.8	-3.38%	281.7	286.22	4.5	1.59%	267.60	271.78	4.2	1.56%	289.43	267.60	-7.54%	279.64	271.78	-2.81%
		NAAQS	1016.283	287.40	290.33	2.9	1.02%	277.9	274.74	-3.2	-1.15%	263.89	277.06	13.2	4.99%	287.40	263.89	-8.18%	290.33	277.06	-4.57%
		Utility Based (Coal)	1016.283	296.70	287.71	-9.0	-3.03%	281.2	270.73	-10.5	-3.73%	273.56	271.28	-2.3	-0.84%	296.70	273.56	-7.80%	287.71	271.28	-5.71%
		Utility Based High	1016.283	296.70	287.71	-9.0	-3.03%	269.5	269.79	0.3	0.11%	266.13	268.08	1.9	0.73%	296.70	266.13	-10.30%	287.71	268.08	-6.82%

FIGURE 2
Clear Skies w/Hg - Upper River



Species/Life Stage: ES(s)=Emerald Shiner (spawning); ES(f)= Emerald Shiner (fry); P(s)=Paddlefish (spawning); P(l)= Paddlefish (larval); FD(l)=Freshwater Drum (larval); S(s)=Sauger (spawning); S(l)= Sauger (larval); SB(s)=Spotted Bass (spawning)

FIGURE 3
Clear Skies w/o Hg - Upper River

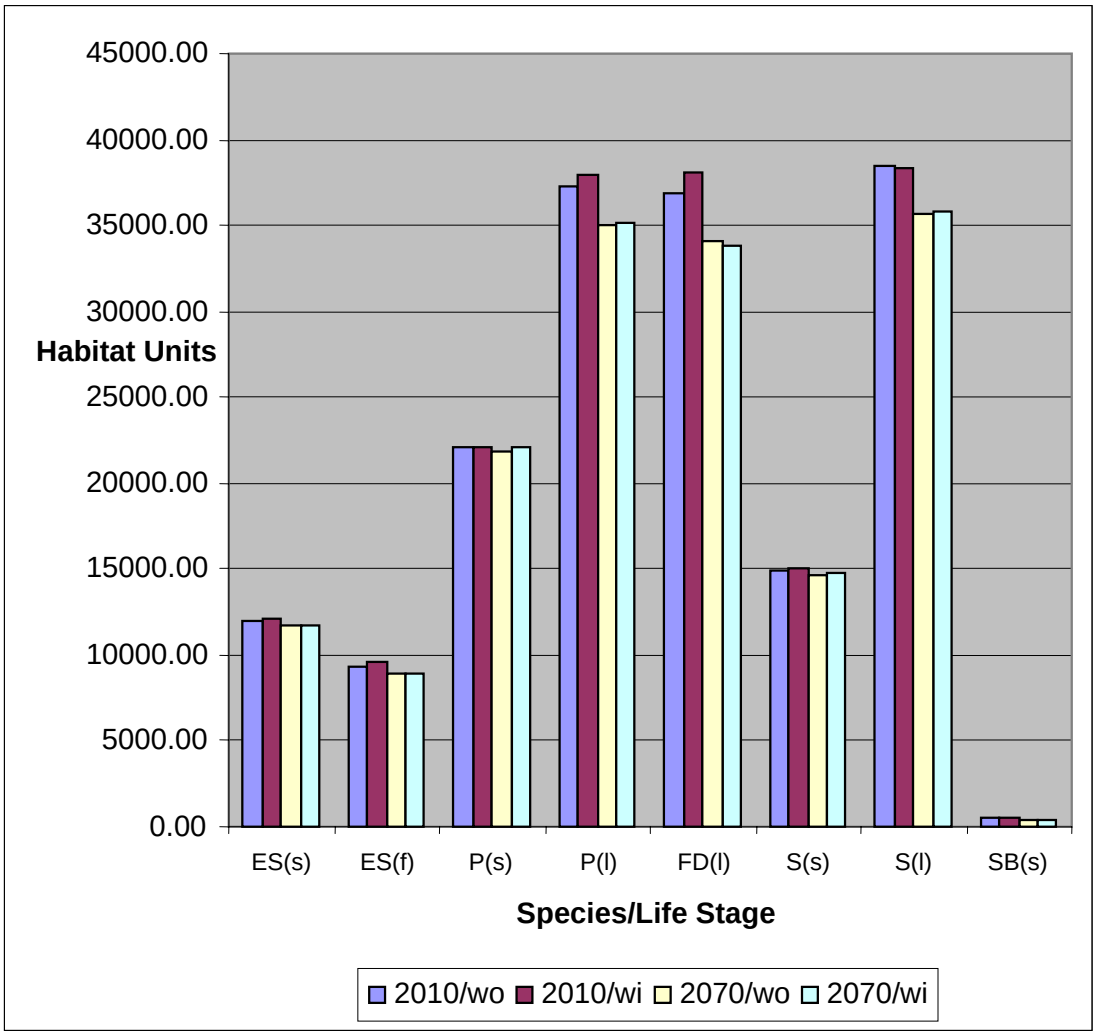


FIGURE 4
NAAQS- Upper River

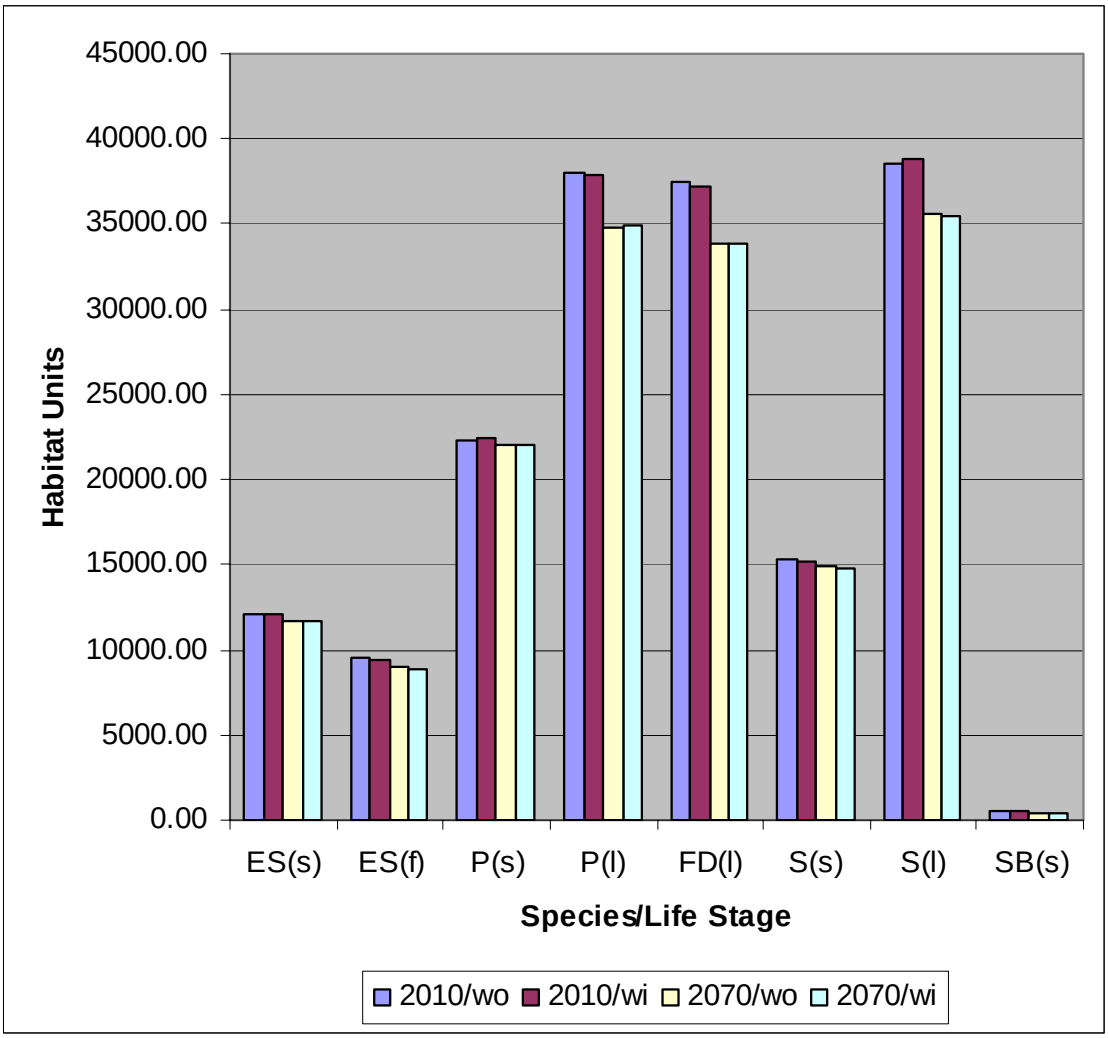


FIGURE 5
Utility Based (coal) - Upper River

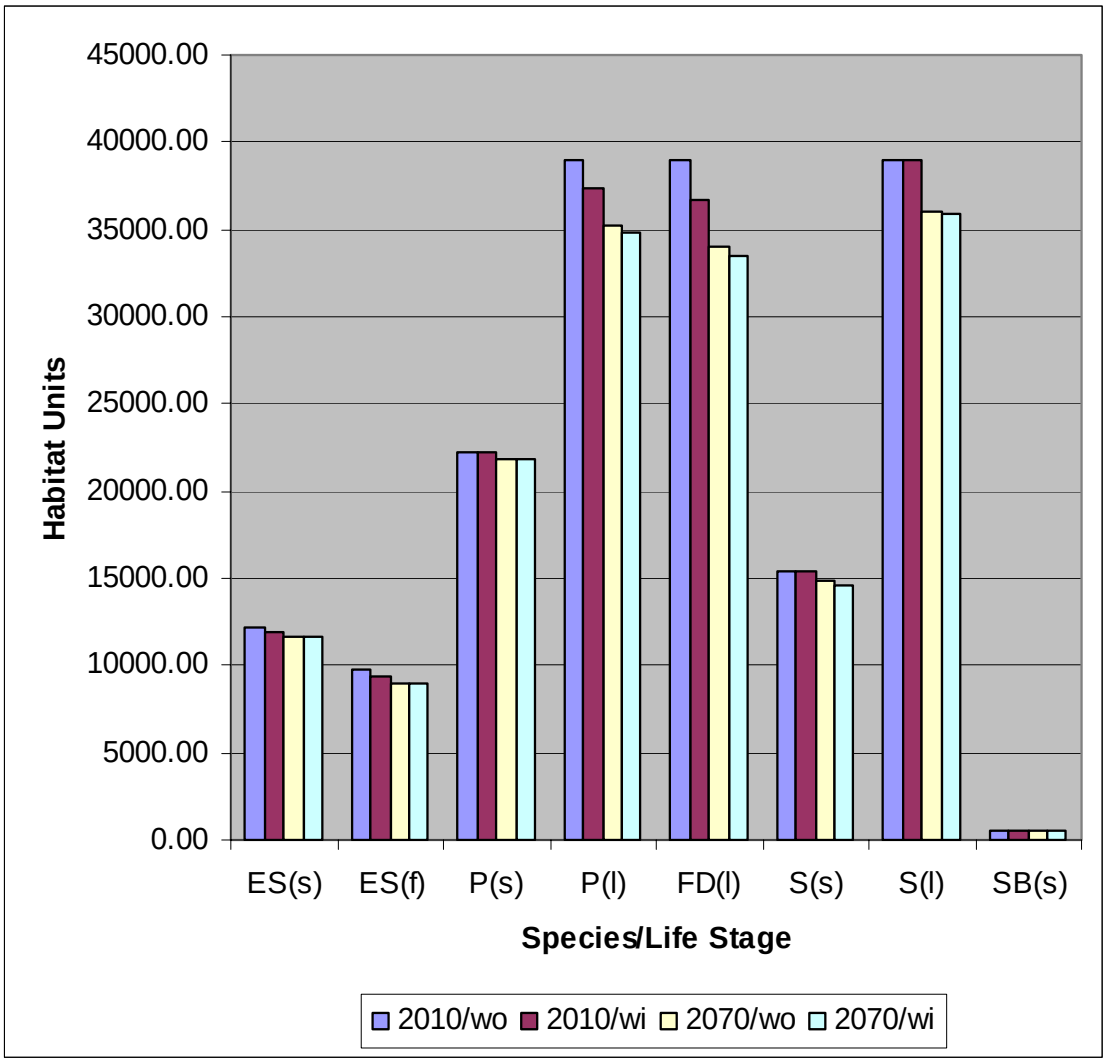


FIGURE 6
Utility Based High - Upper River

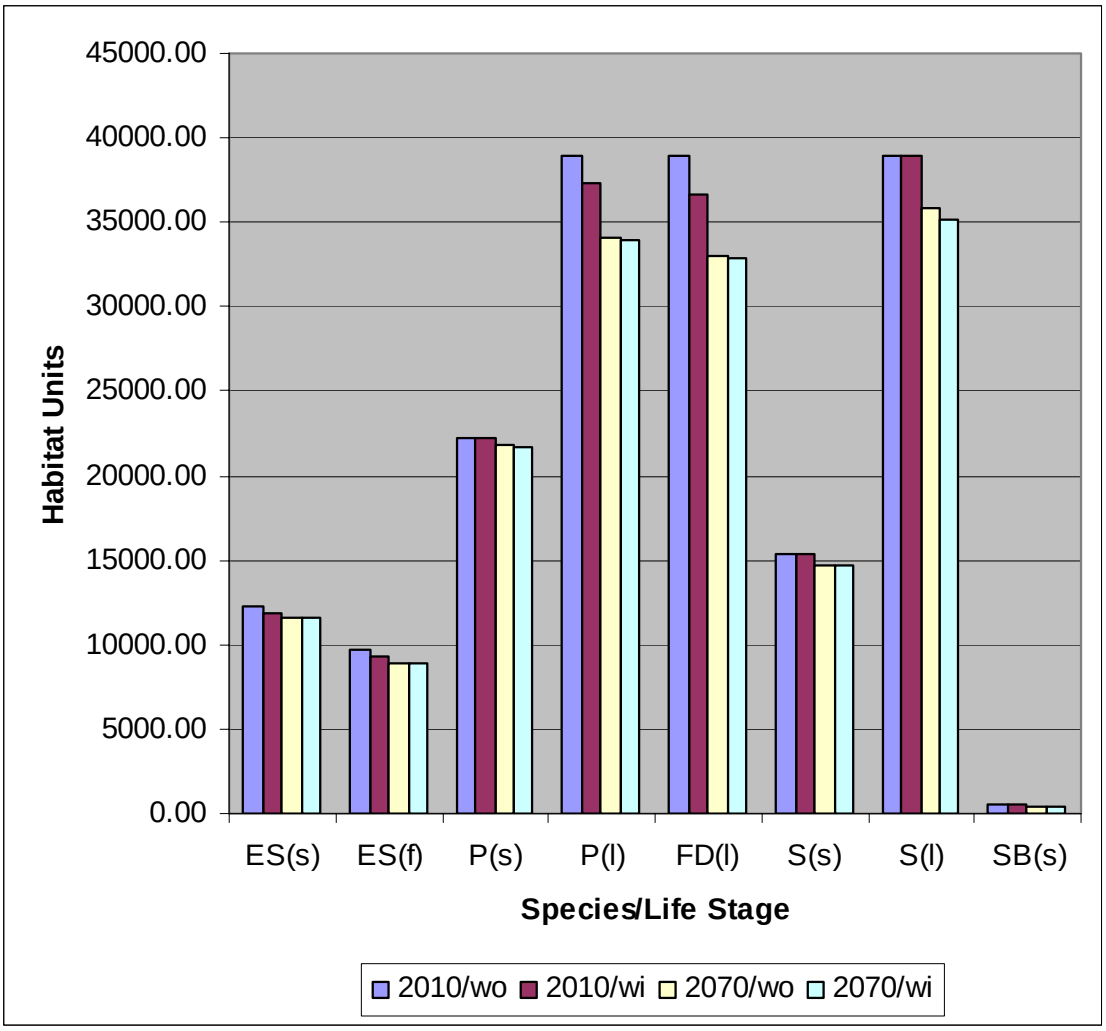


FIGURE 7
Clear Skies w/Hg - Middle River

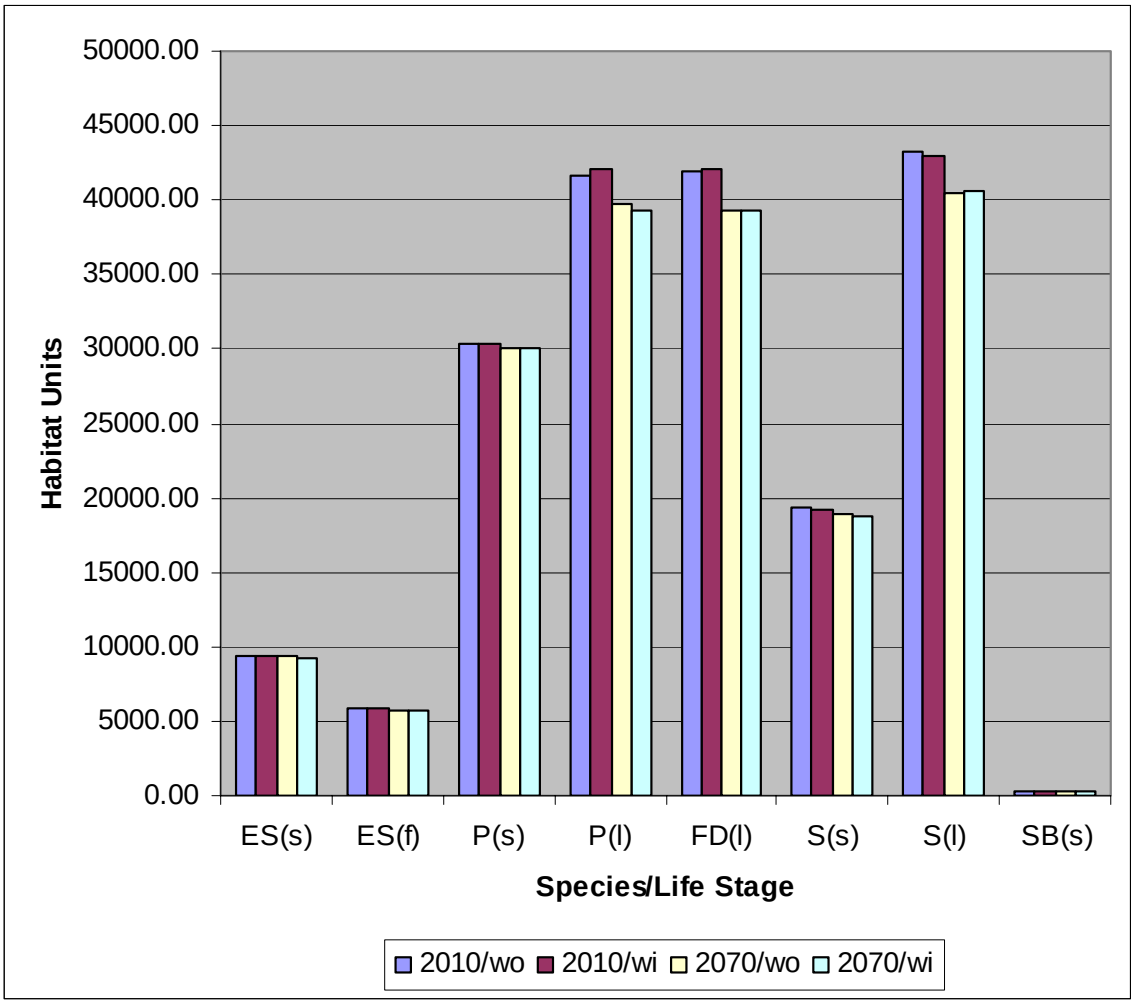


FIGURE 8
Clear Skies w/o Hg - Middle River

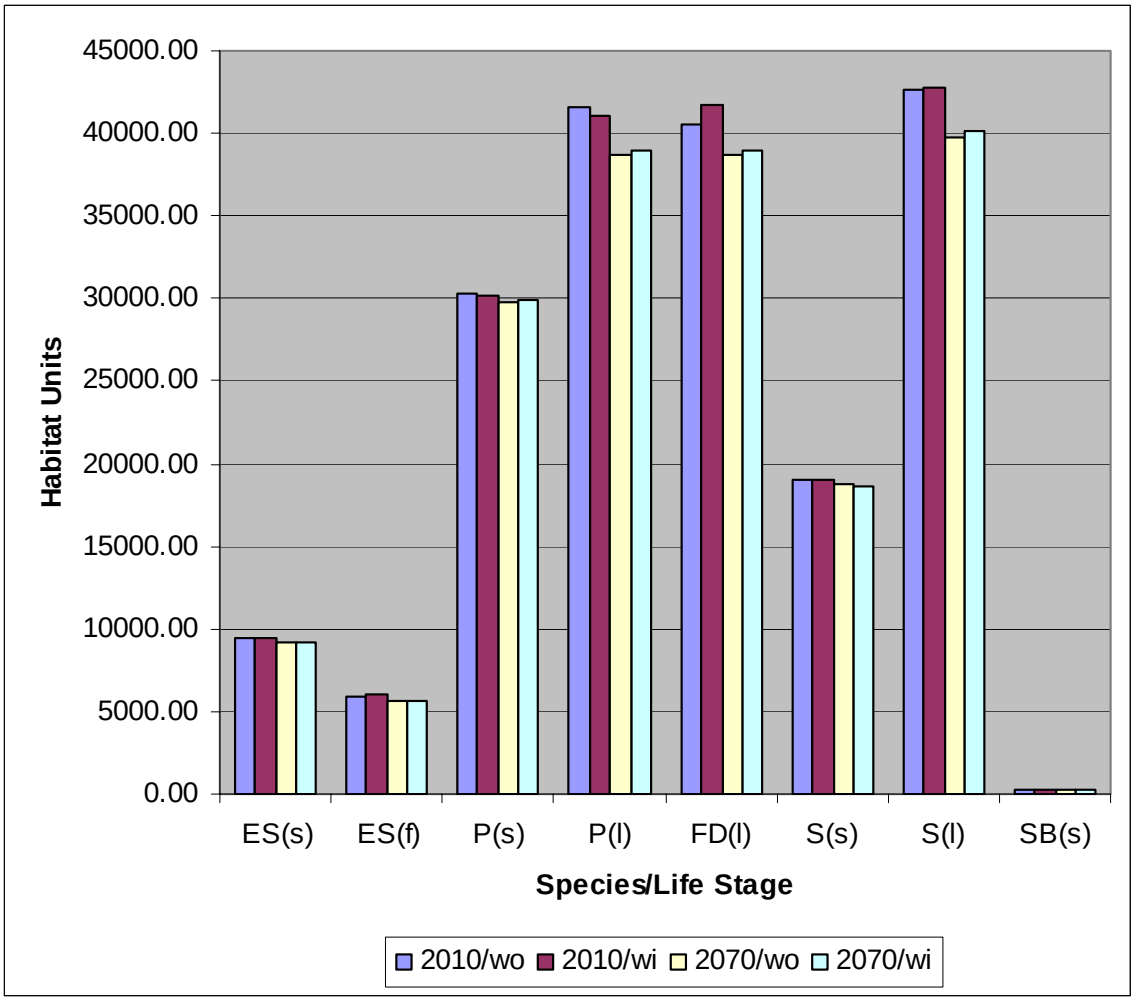


FIGURE 9
NAAQS - Middle River

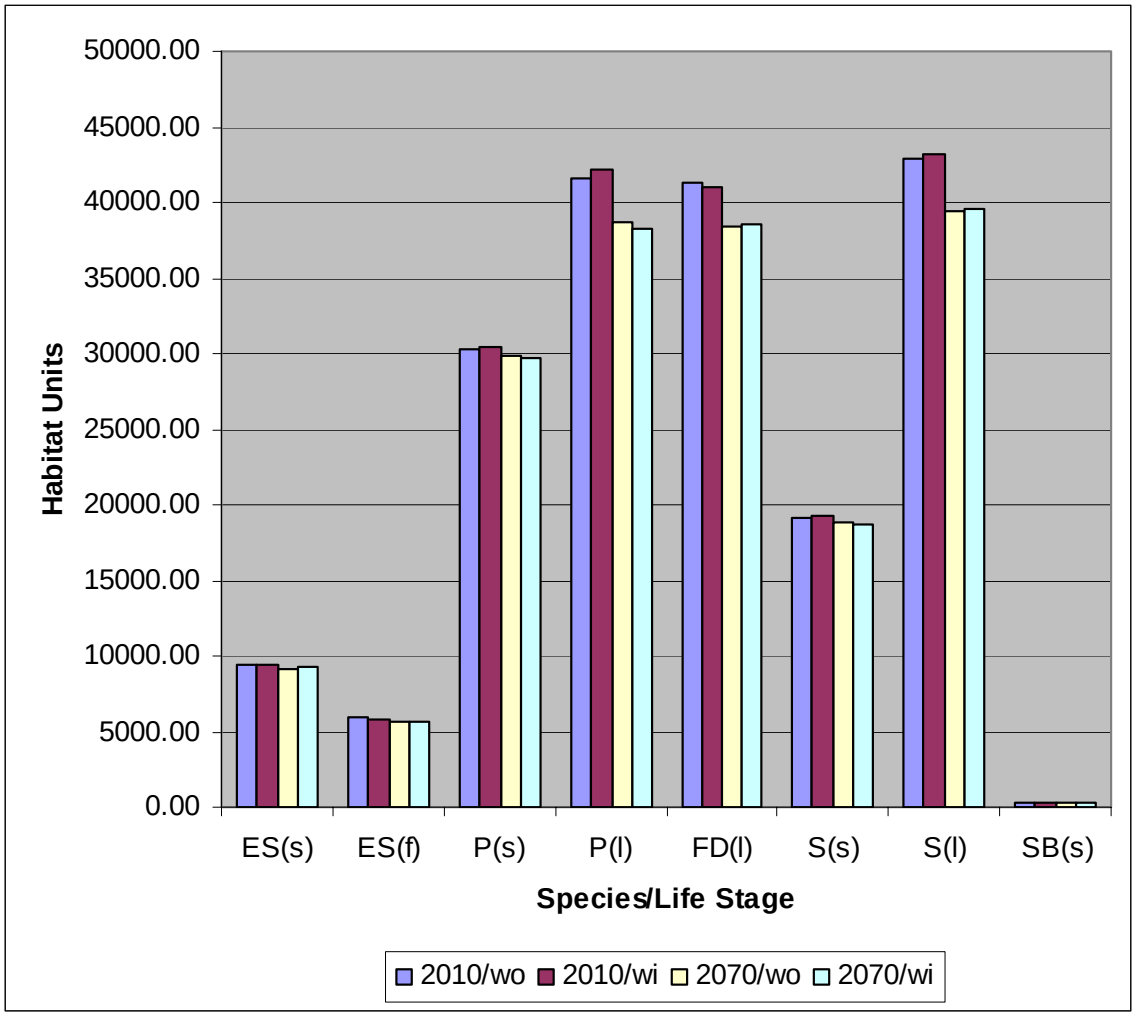


FIGURE 10
Utility Based (coal) - Middle River

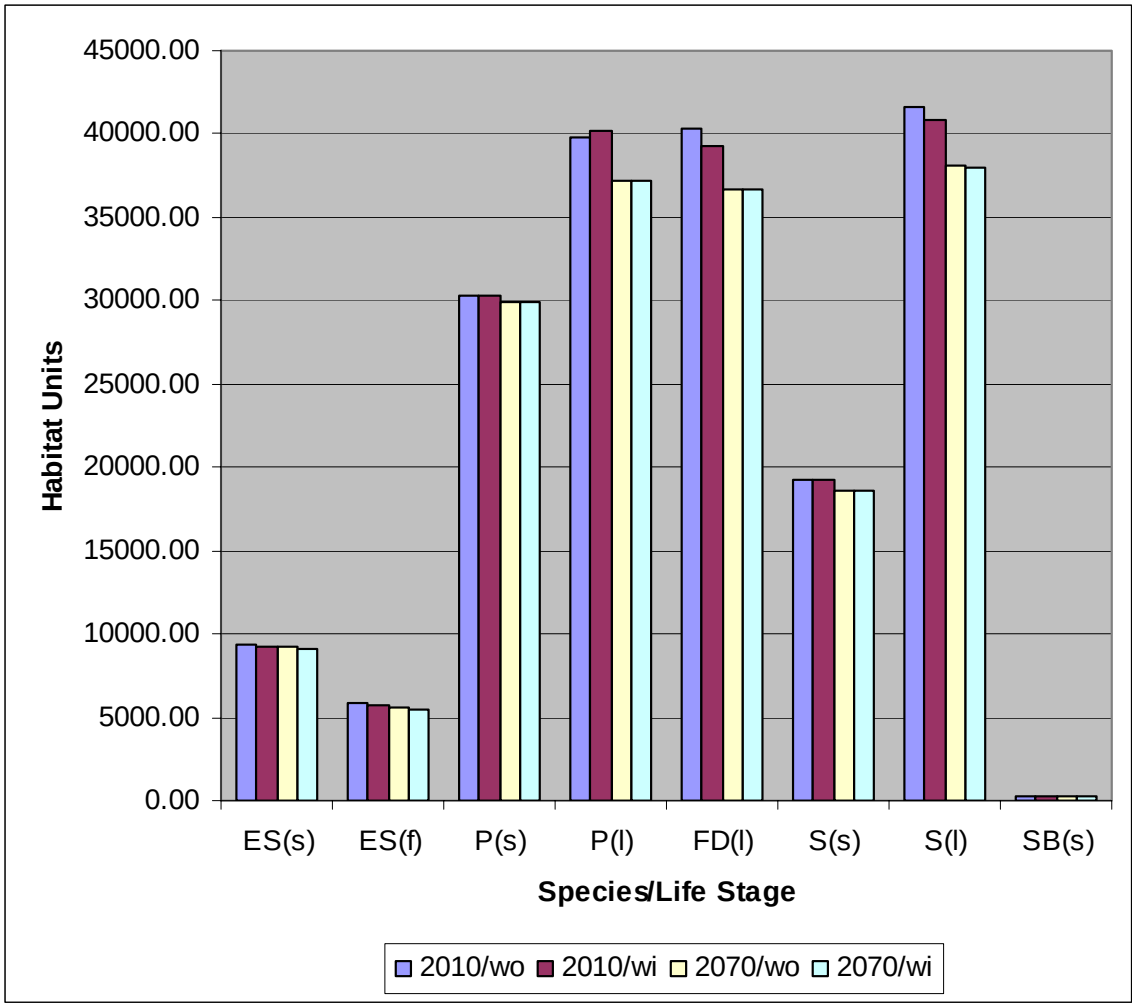


FIGURE11
Utility Based High - Middle River

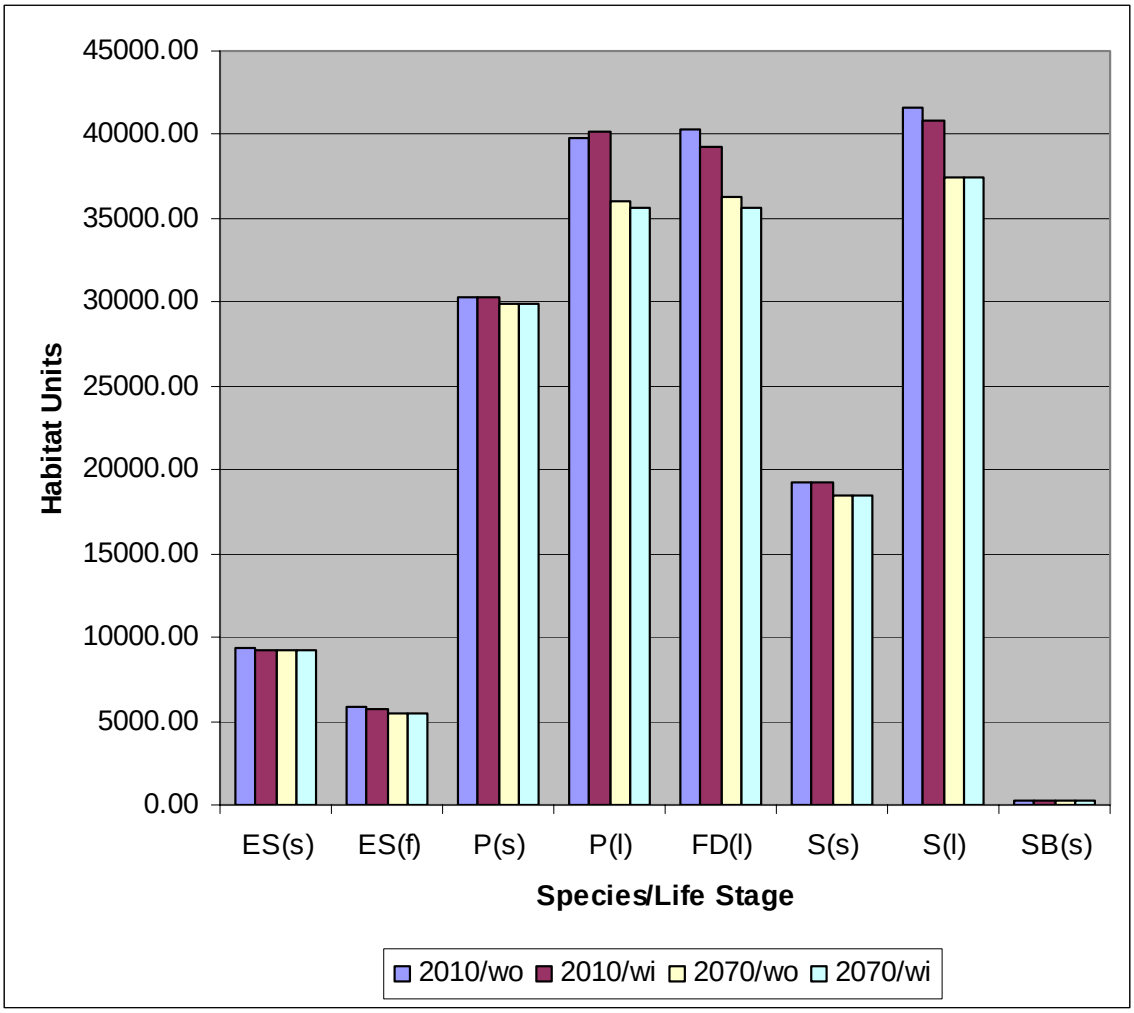


FIGURE 12
Clear Skies w/Hg - Lower River

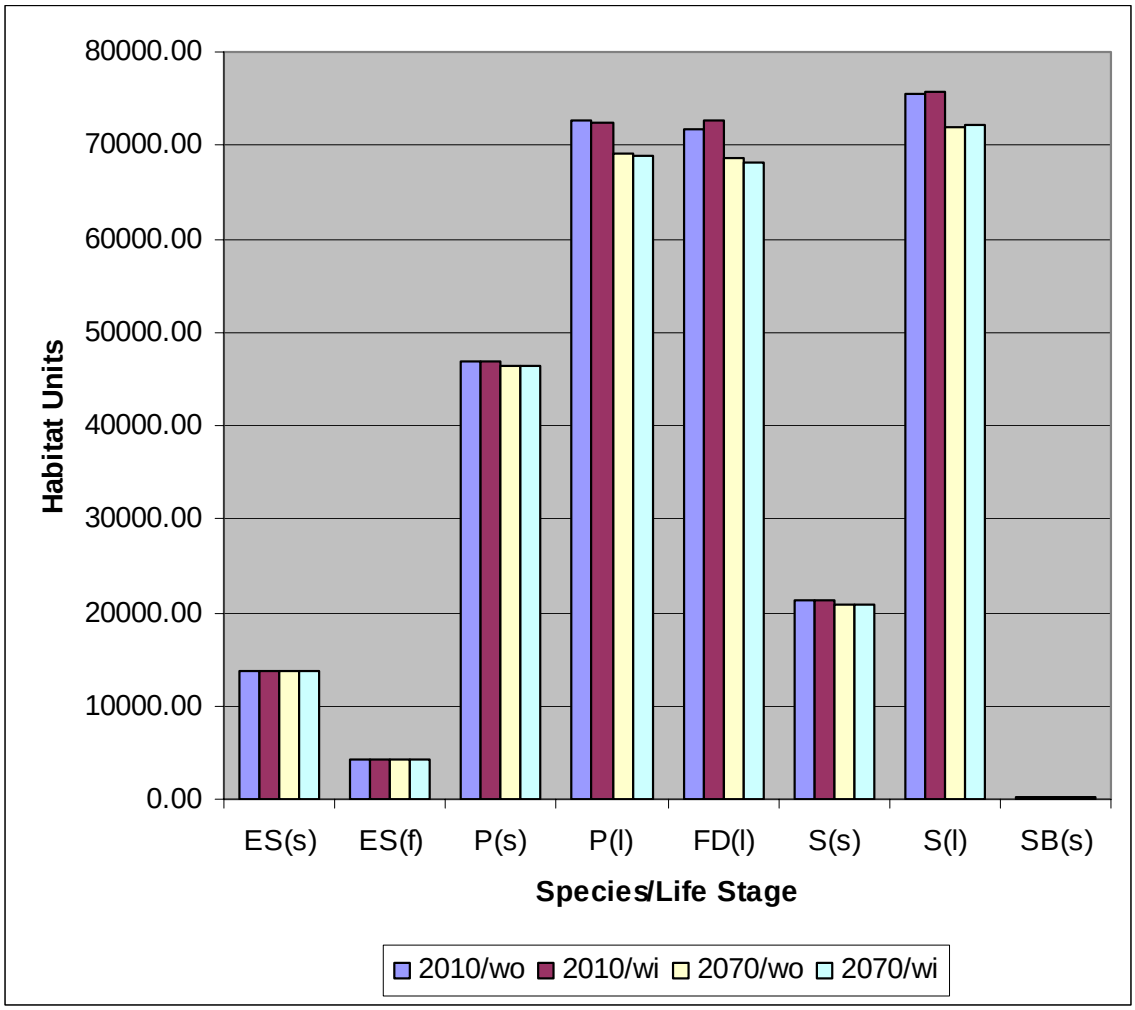


FIGURE 13
Clear Skies w/o Hg - Lower River

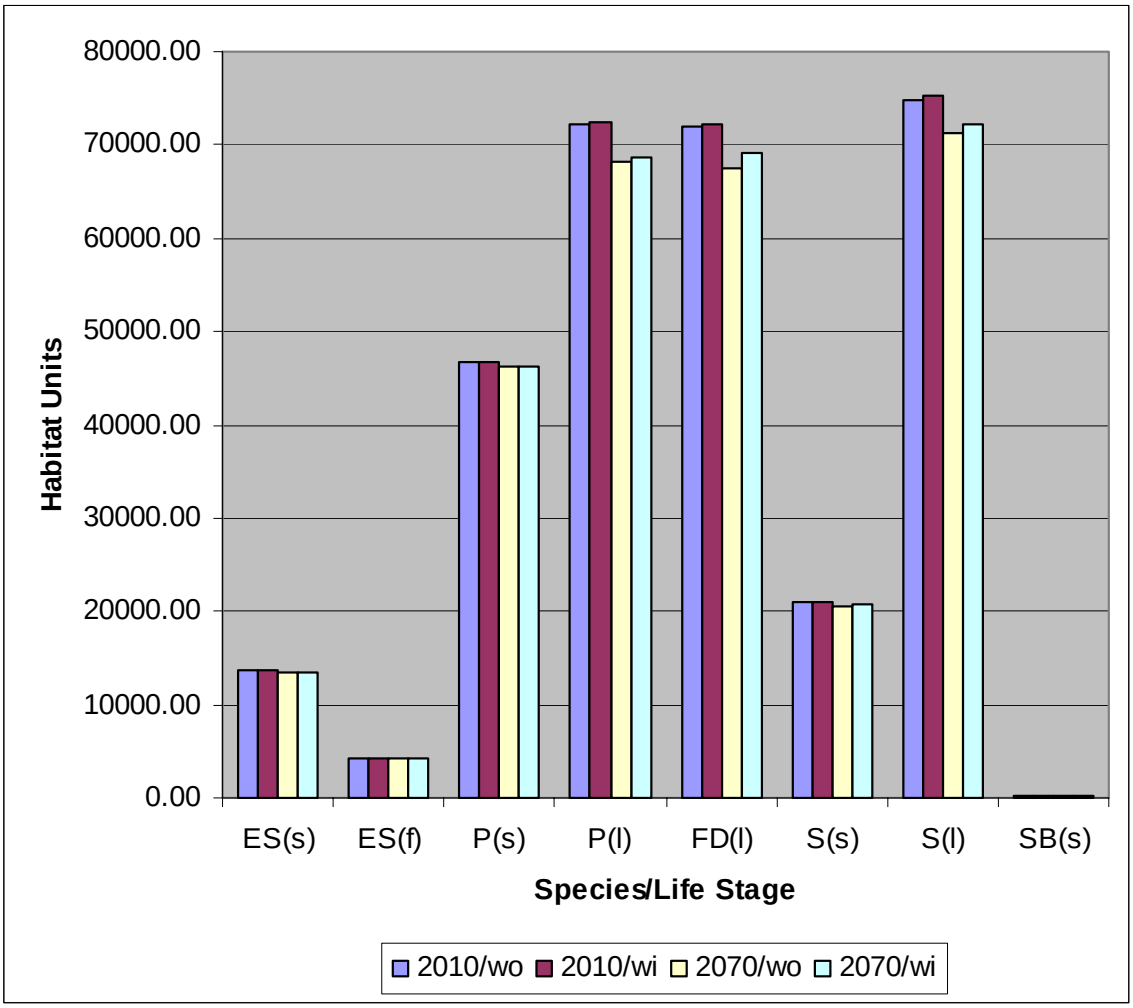


FIGURE 14
NAAQS - Lower River

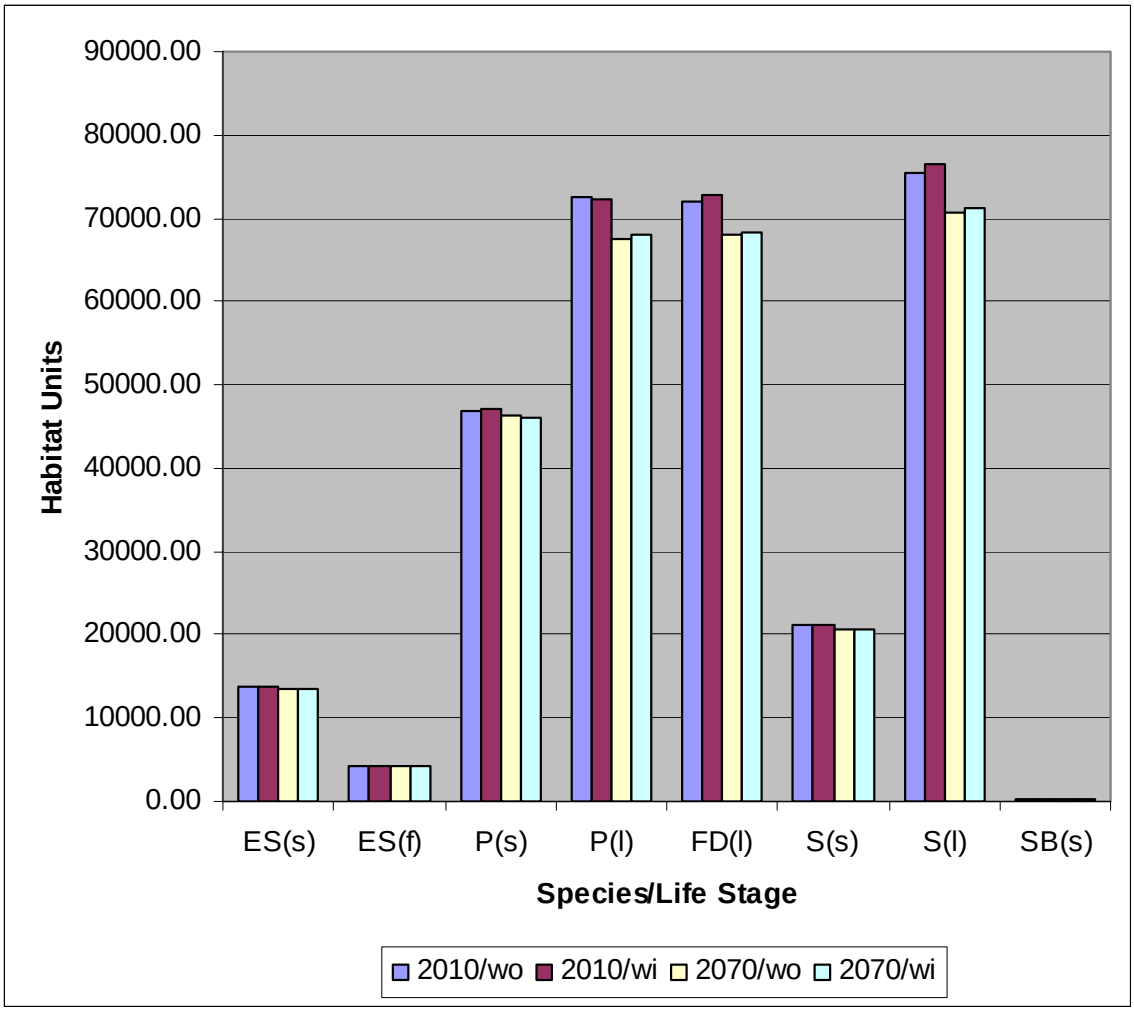


FIGURE 15
Utility Based (coal) - Lower River

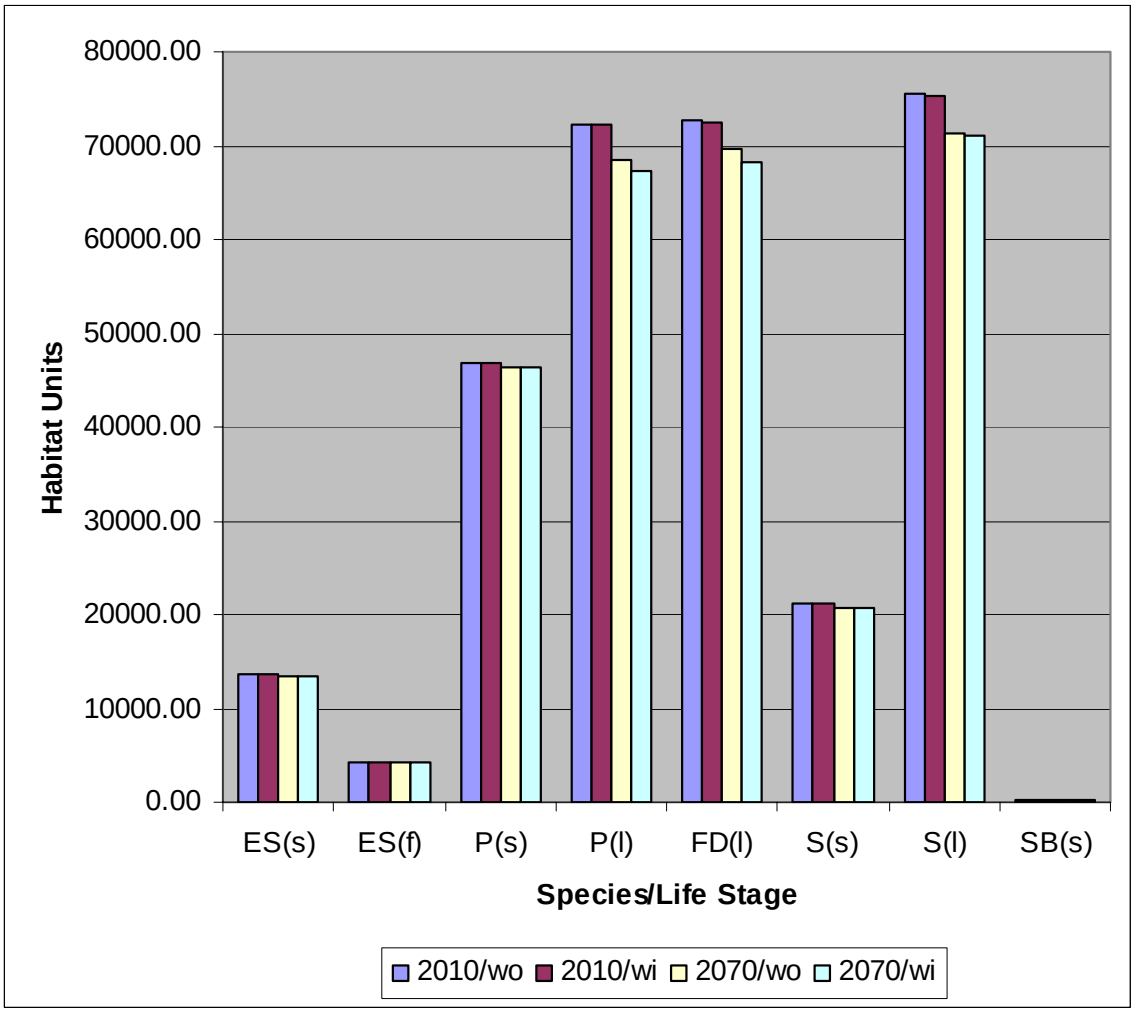


FIGURE 16
Utility Based High - Lower River

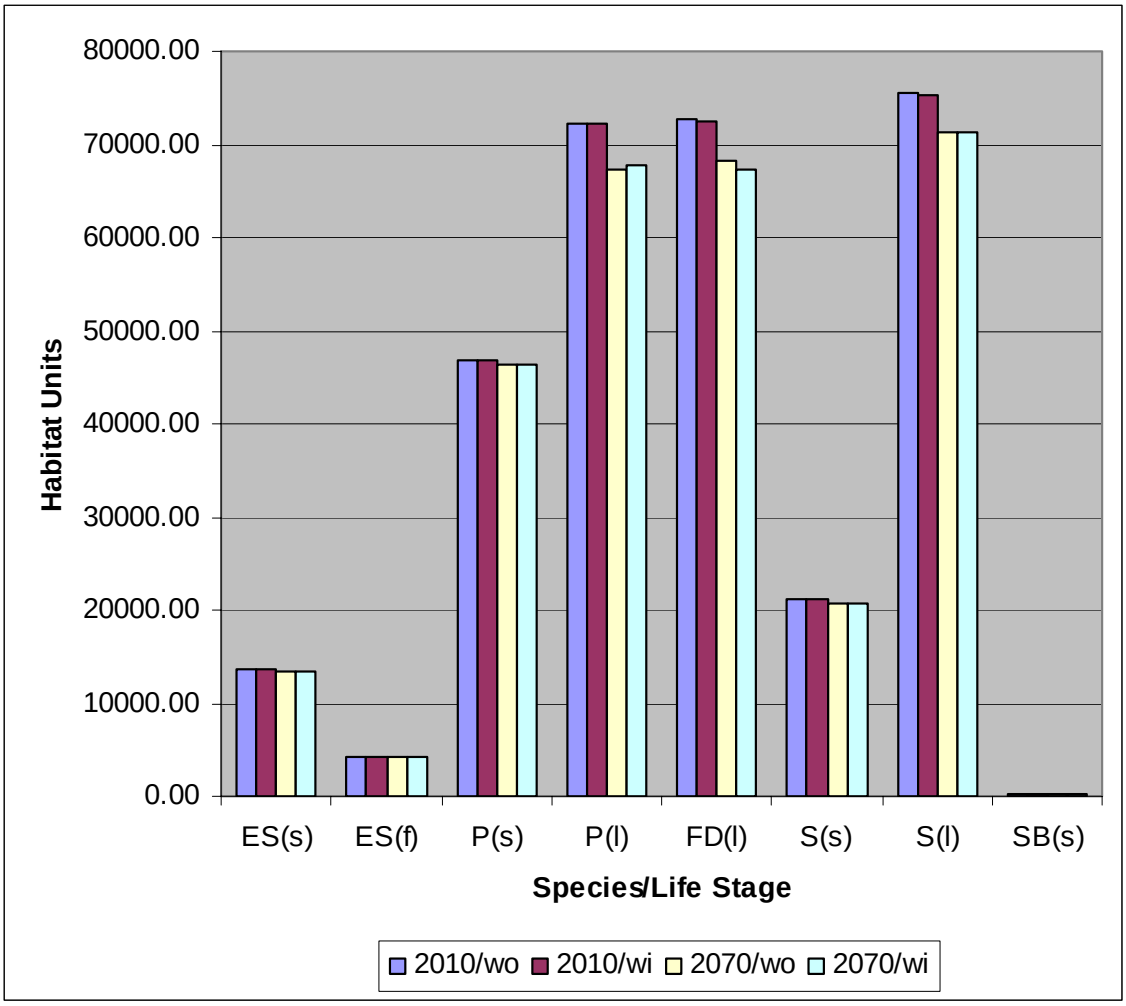
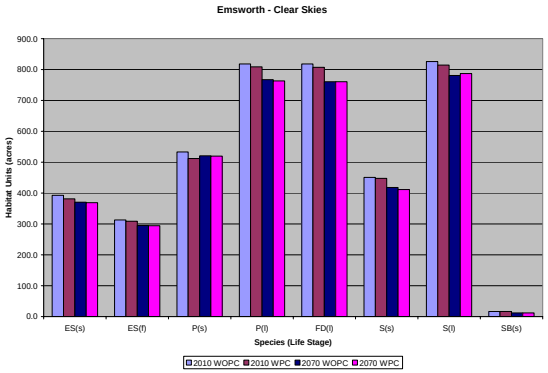
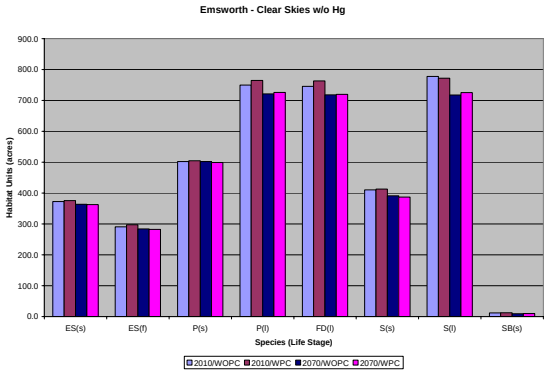
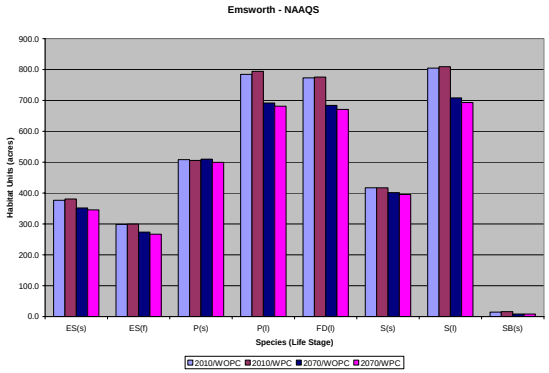
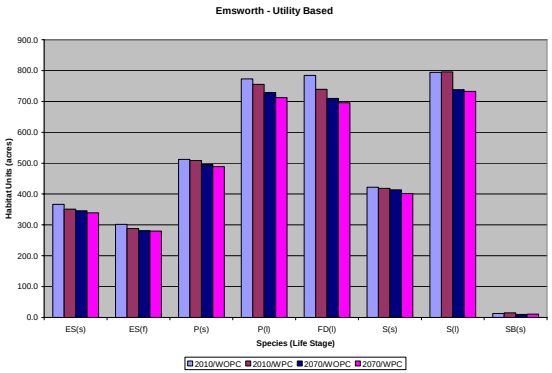


FIGURE 17
Emsworth Pool Long Term Comparisons









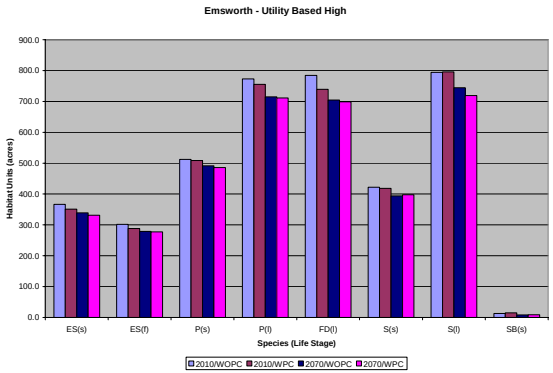
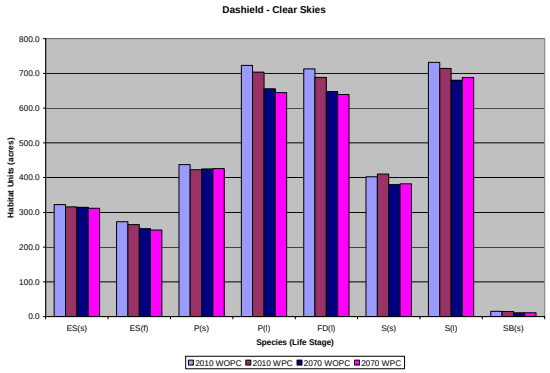
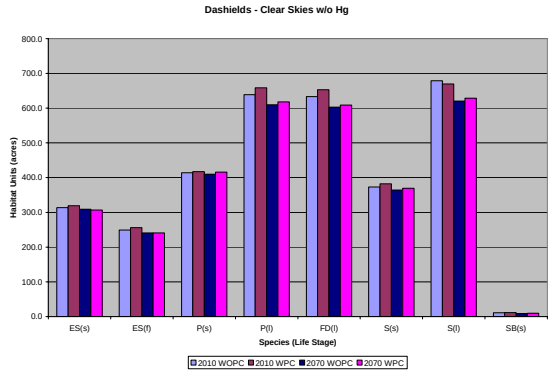
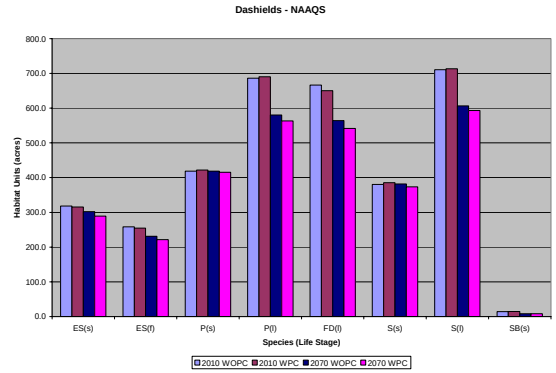
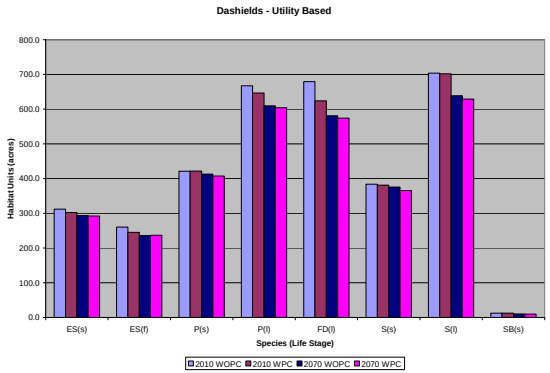


FIGURE 18
Dashields Pool Long Term Comparisons









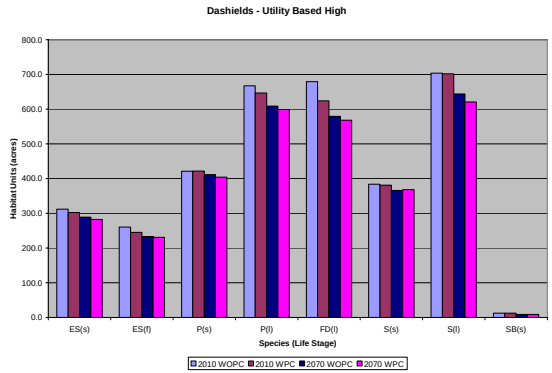
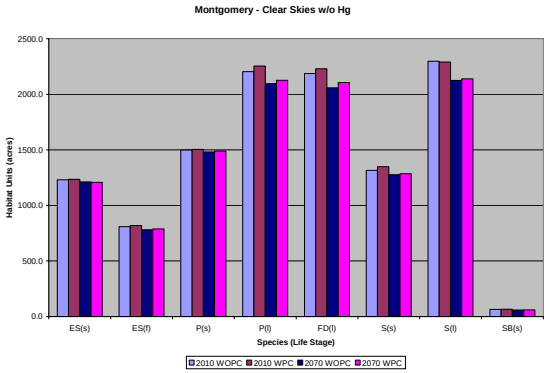
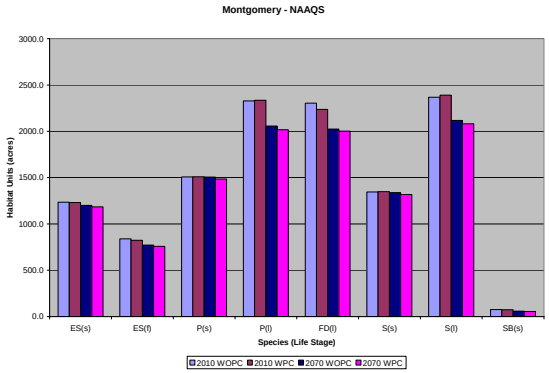
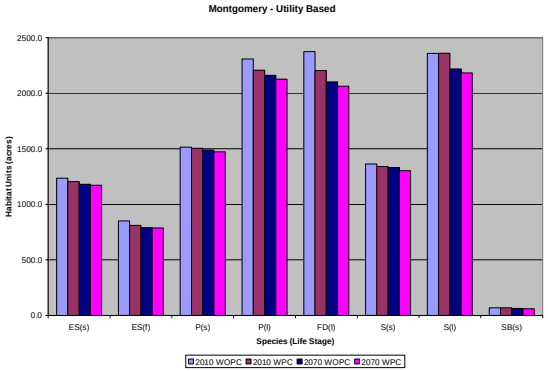


FIGURE 19
Montgomery Pool Long Term Comparisons







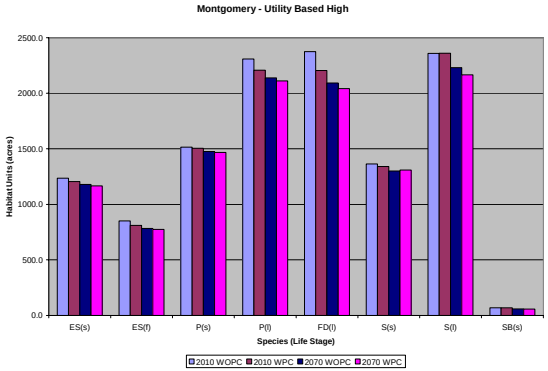
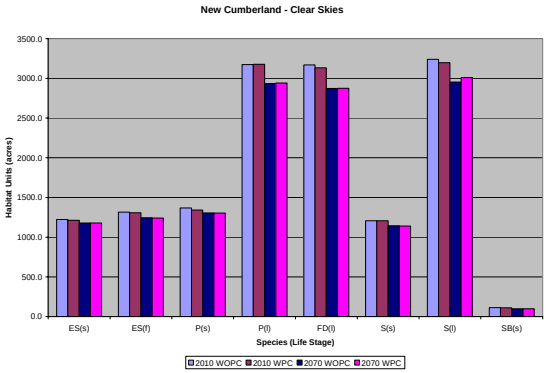
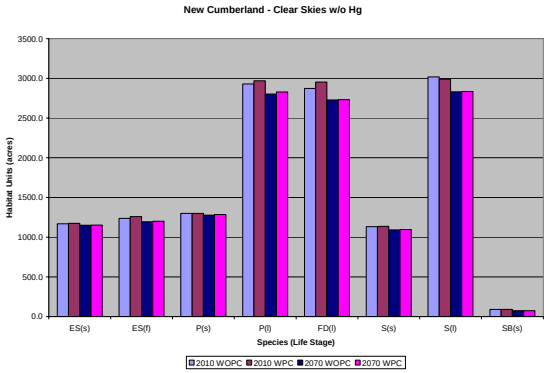
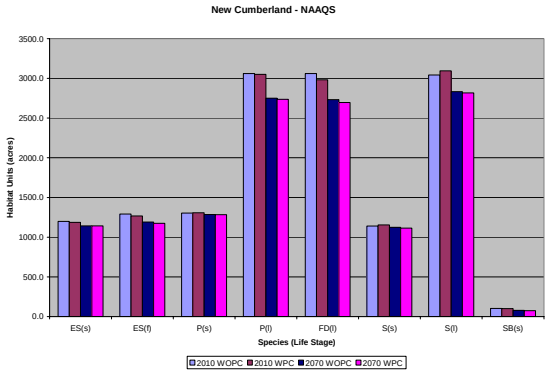
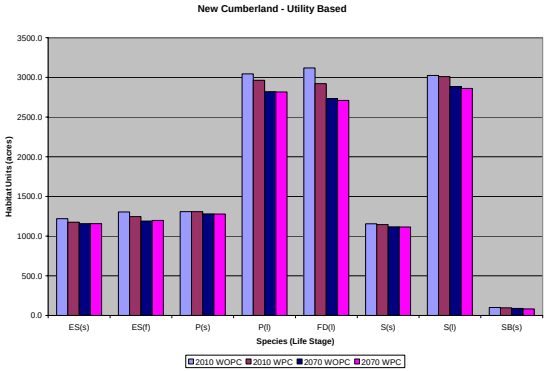


FIGURE 20
New Cumberland Pool Long Term Comparisons









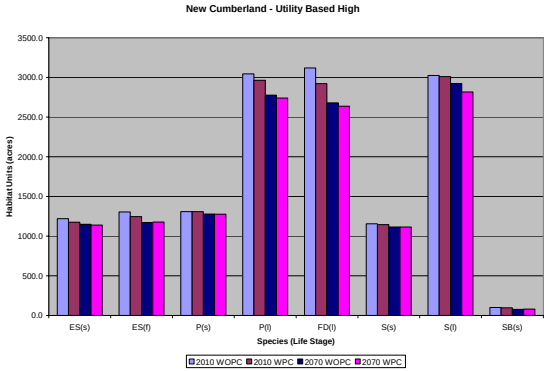
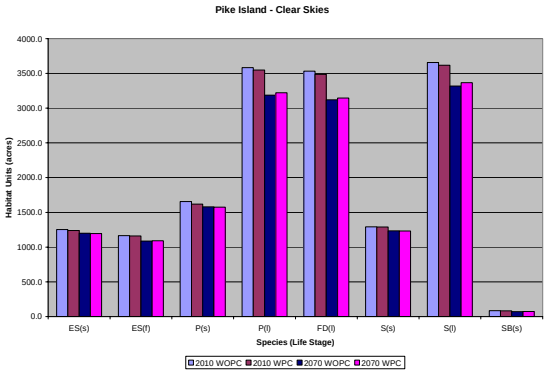
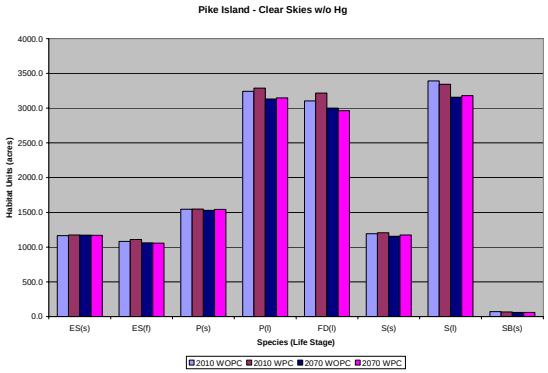
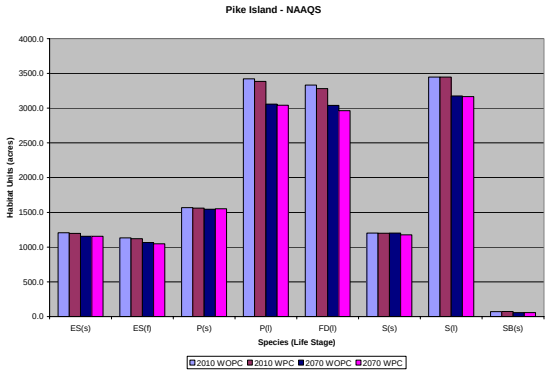
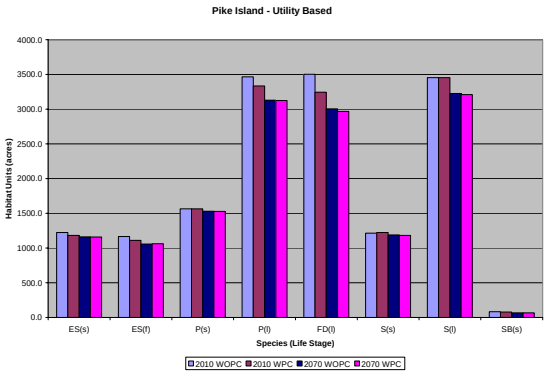


FIGURE 21
Pike Island Pool Long Term Comparisons









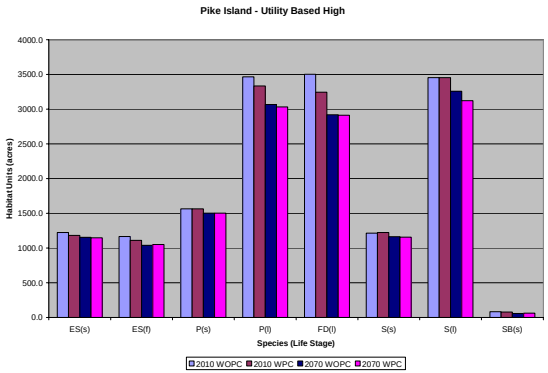
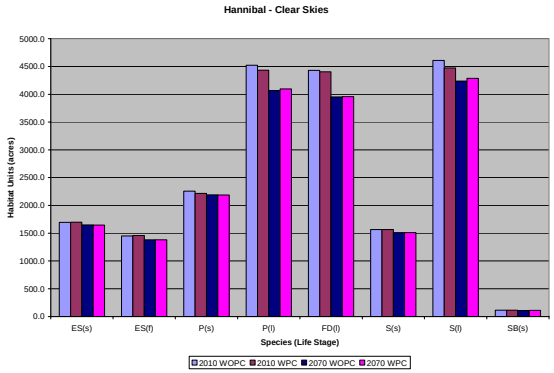
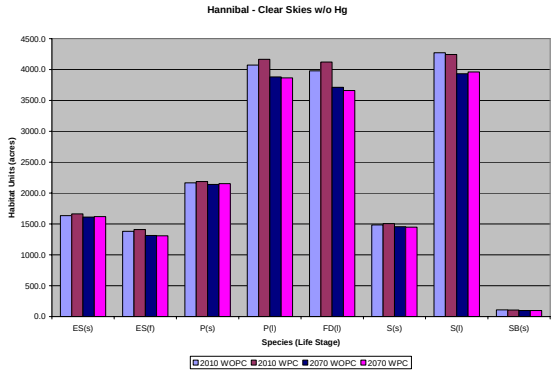
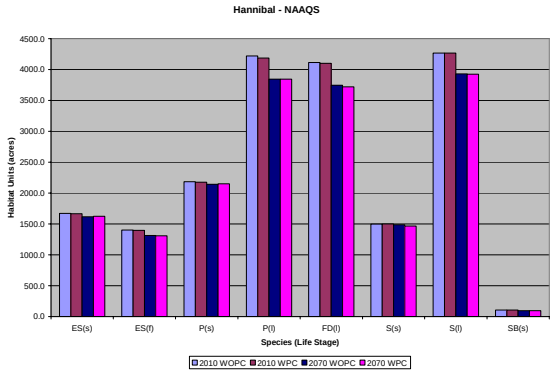
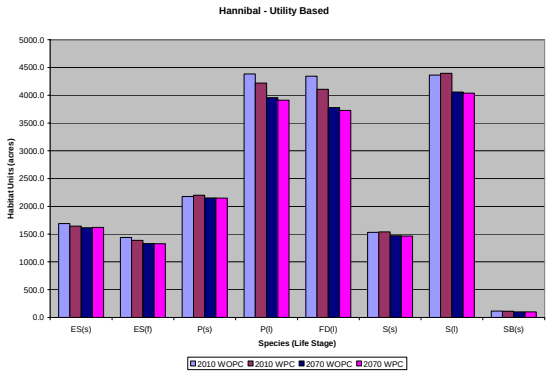


FIGURE 22
Hannibal Pool Long Term Comparisons









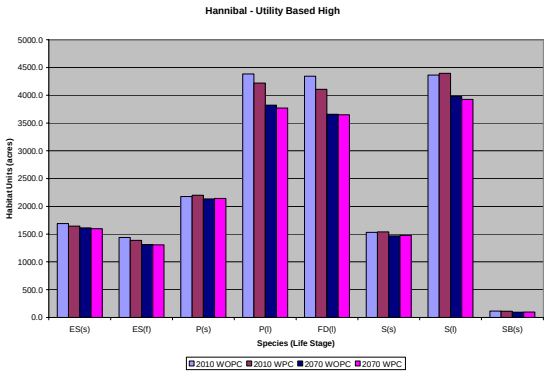
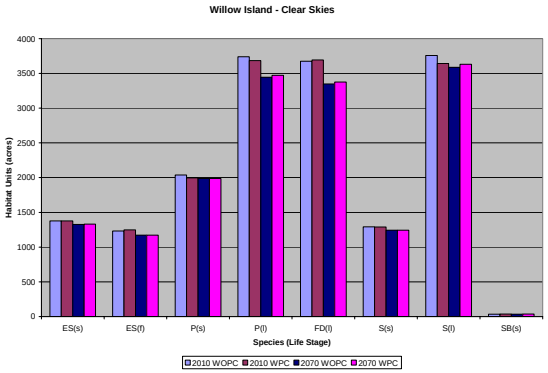
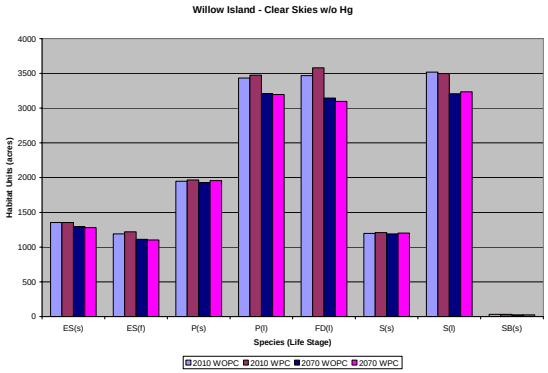
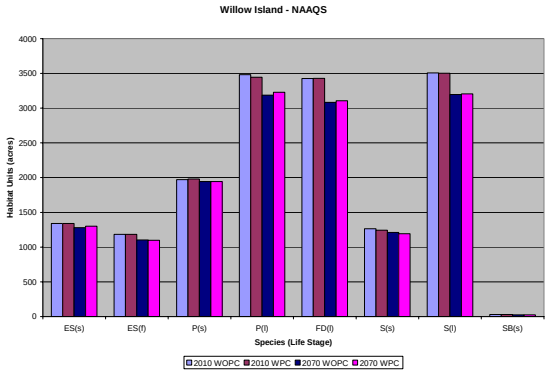
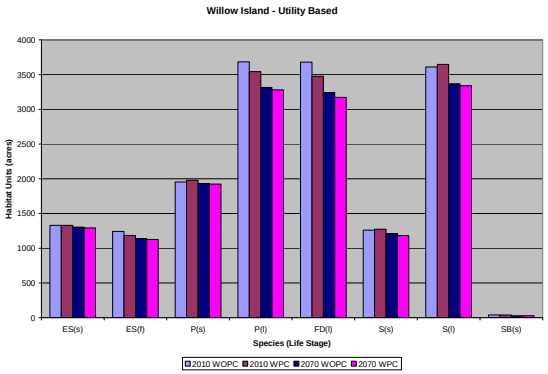


FIGURE 23
Willow Island Pool Long Term Comparisons









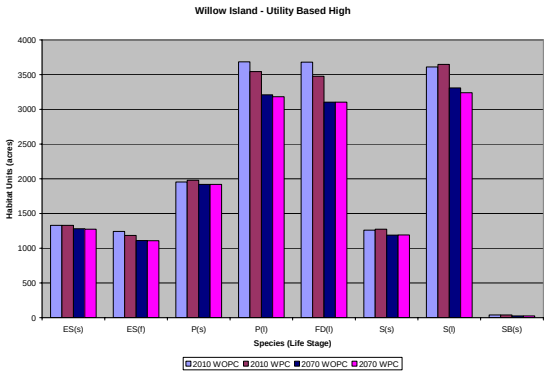
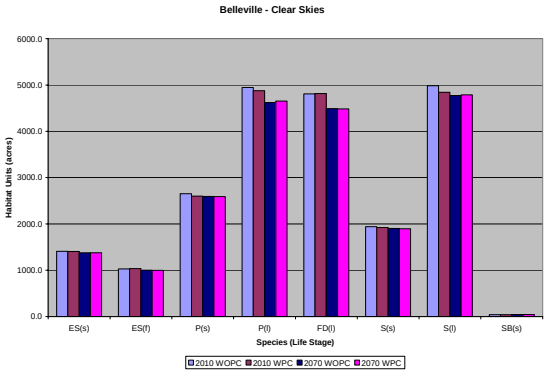
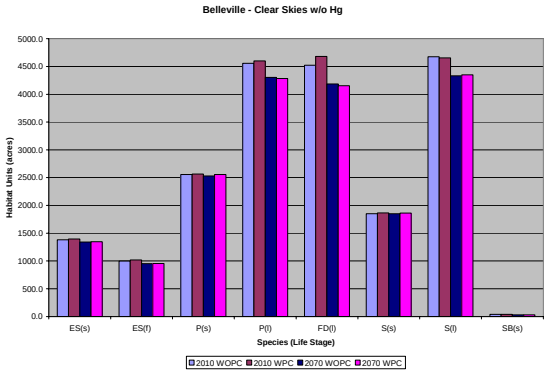
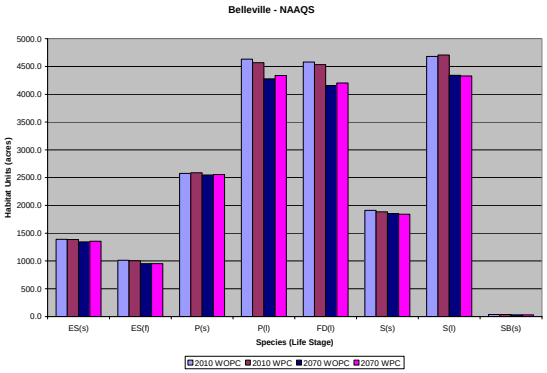
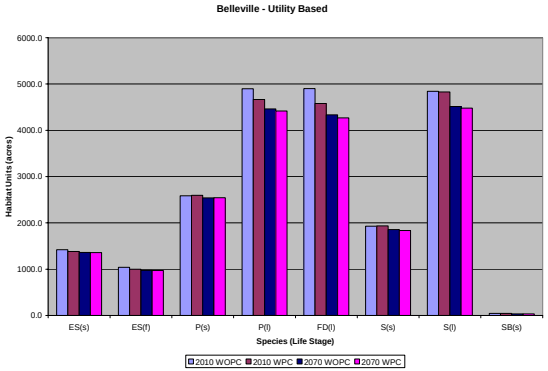


FIGURE 24
Belleville Pool Long Term Comparisons









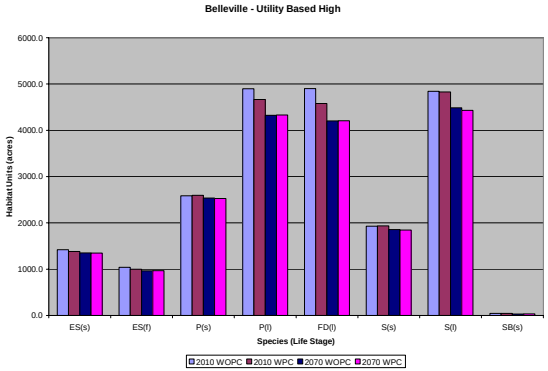
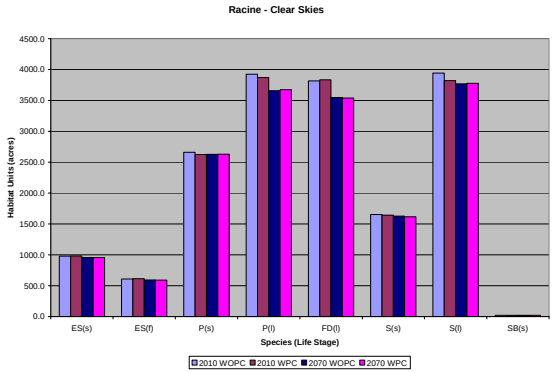
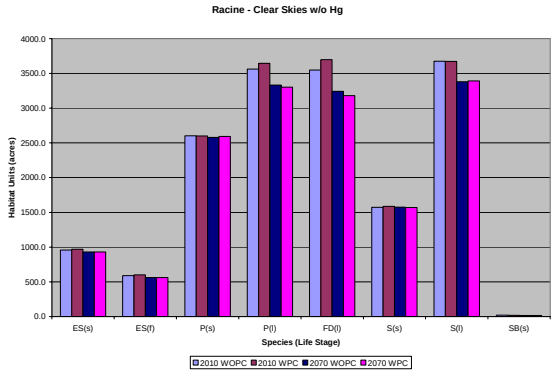
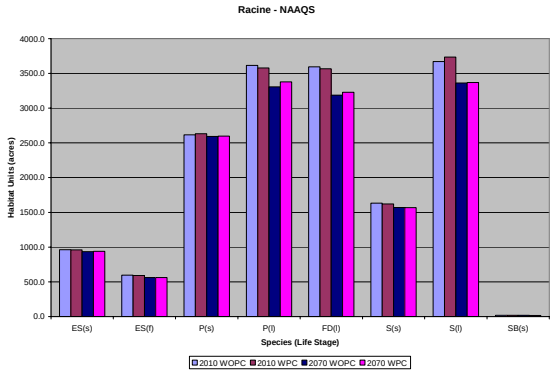
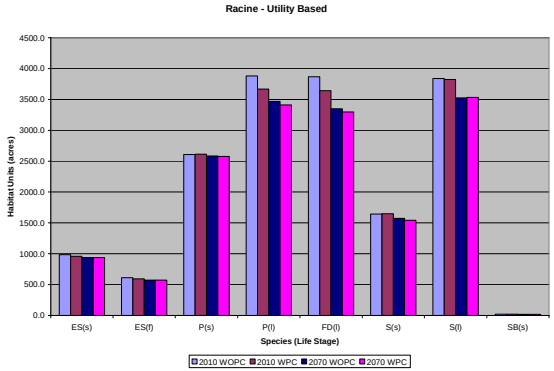


FIGURE 25
Racine Pool Long Term Comparisons









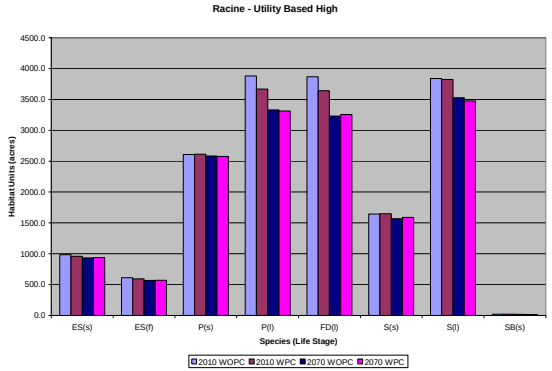
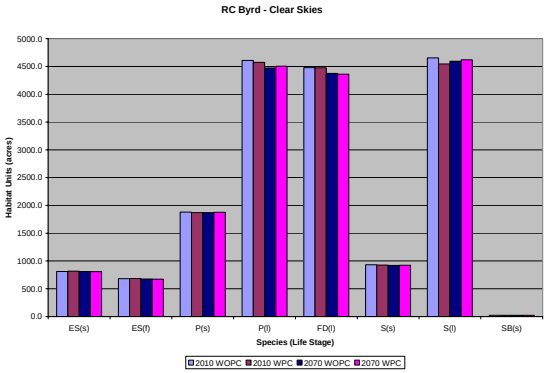
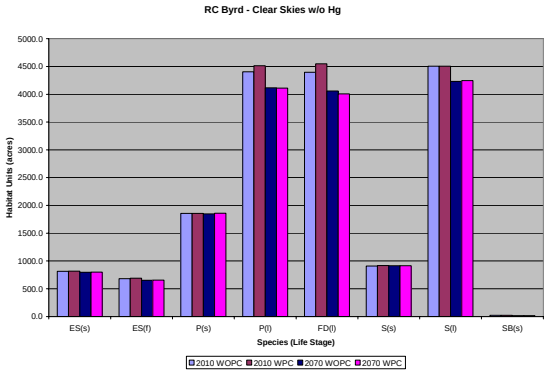
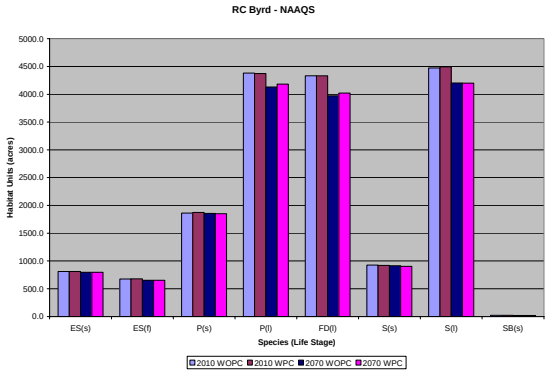
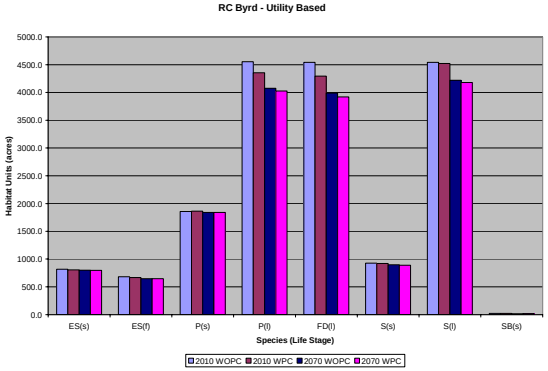


FIGURE 26
R C Byrd Pool Long Term Comparisons









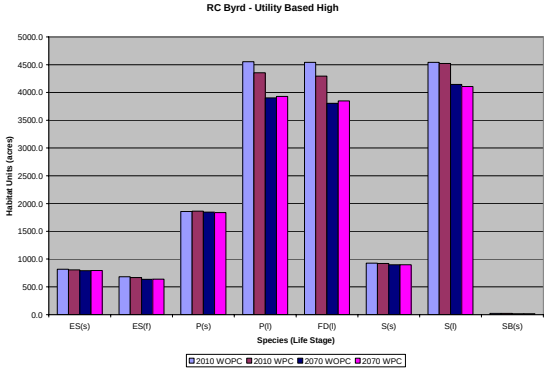
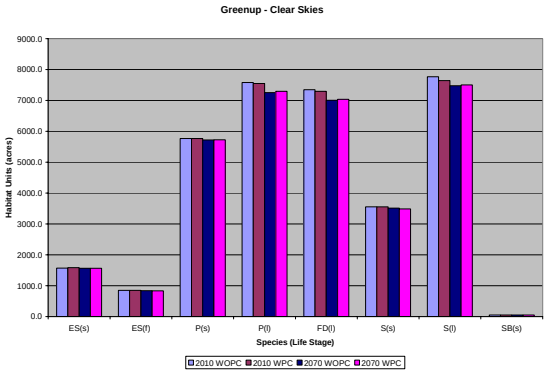
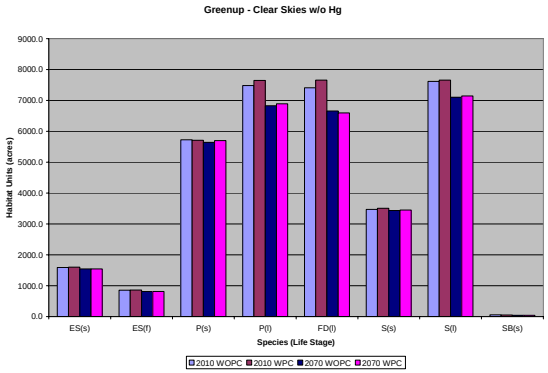
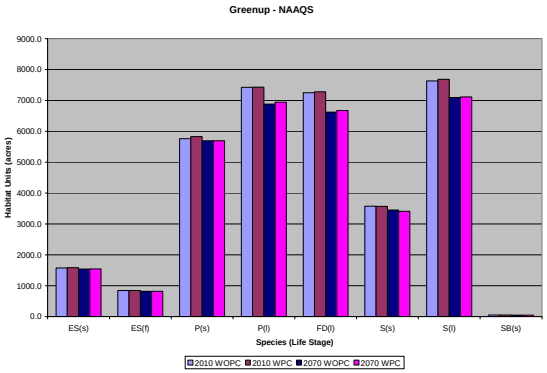
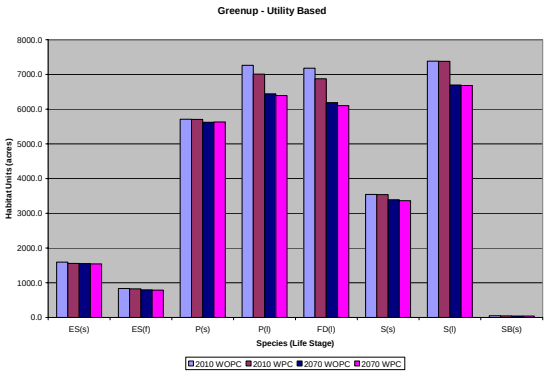


FIGURE 27
Greenup Pool Long Term Comparisons









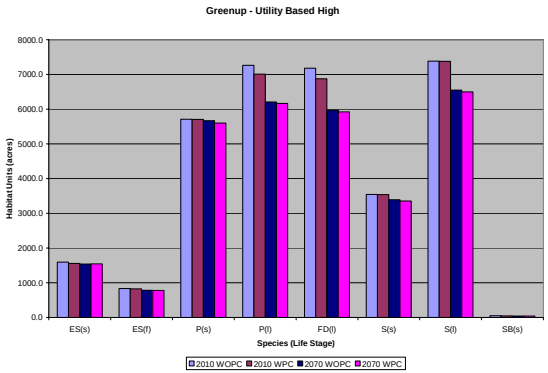
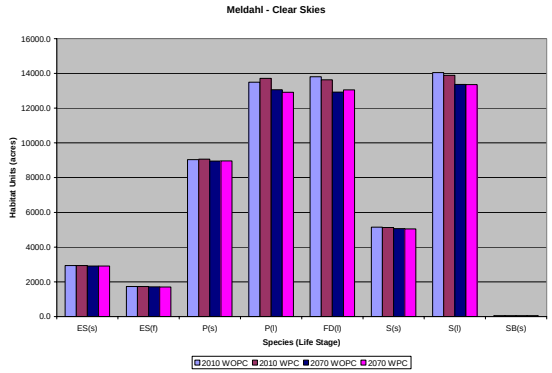
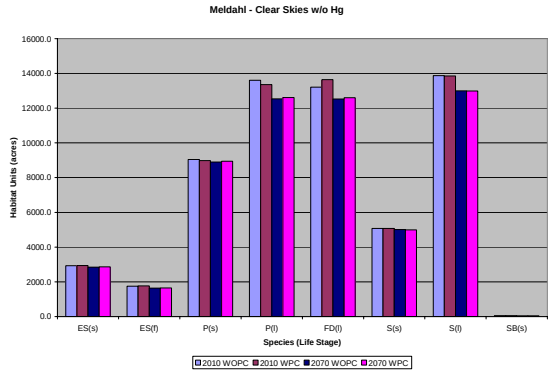
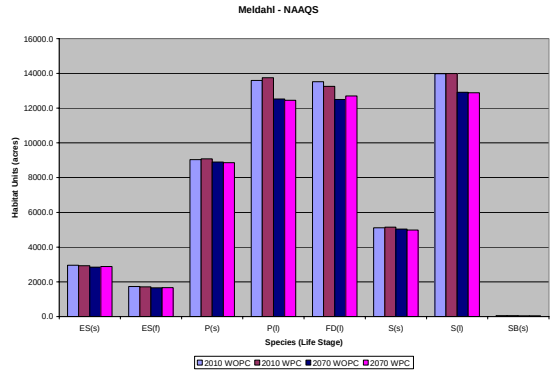
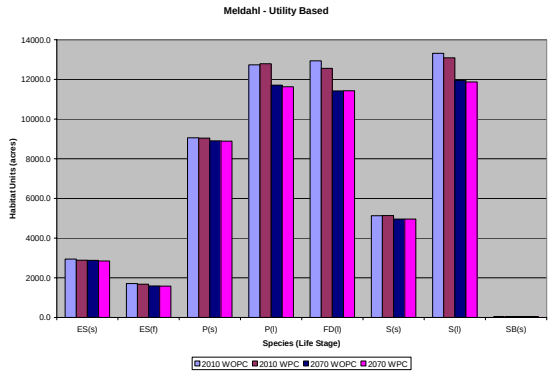


FIGURE 28
Meldahl Pool Long Term Comparisons









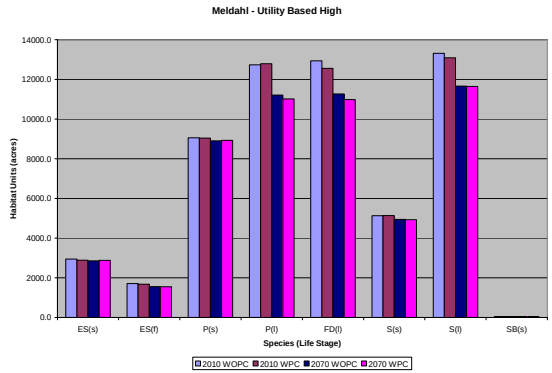
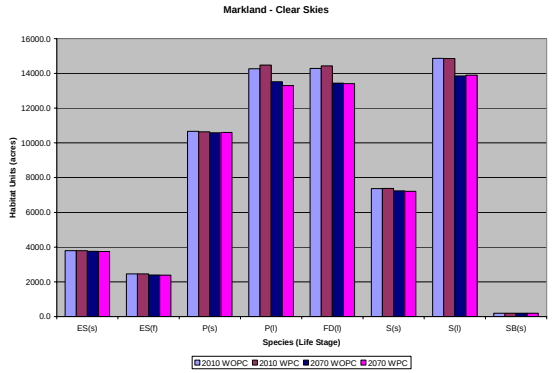
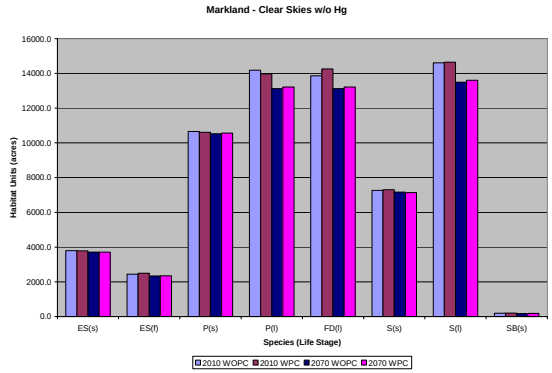
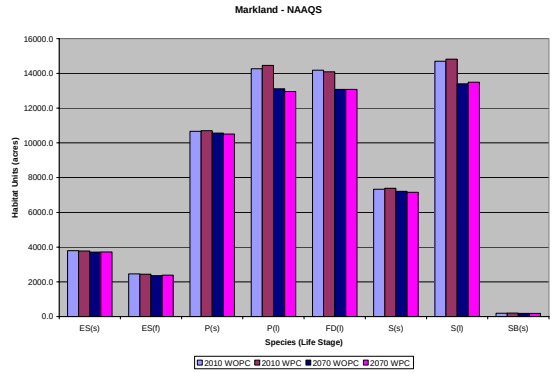
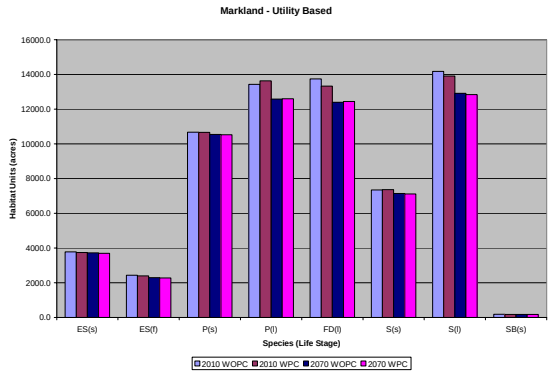


FIGURE 29
Markland Pool Long Term Comparisons









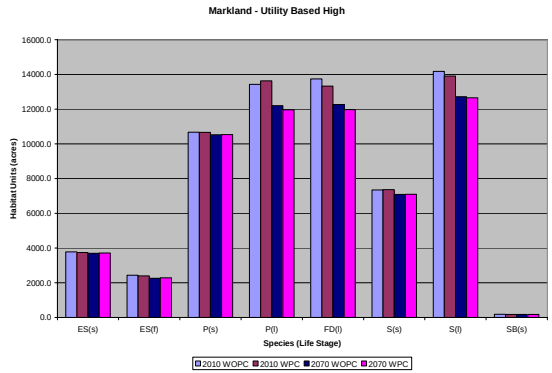
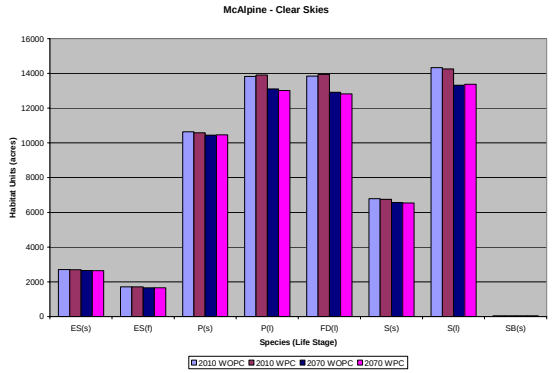
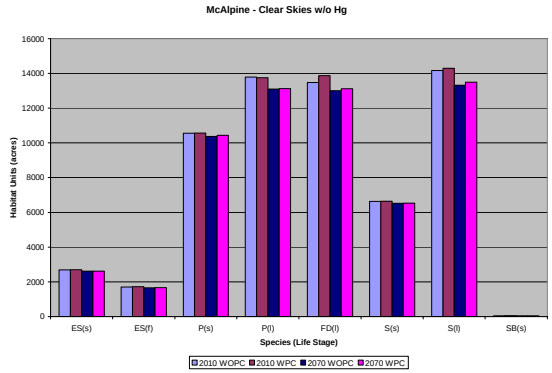
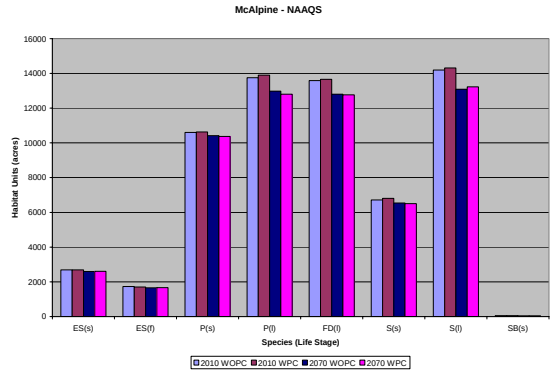
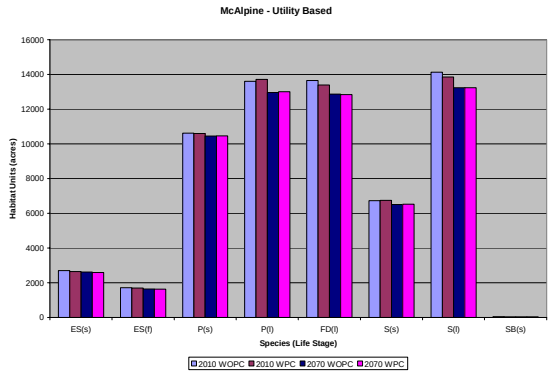


FIGURE 30
McAlpine Pool Long Term Comparisons









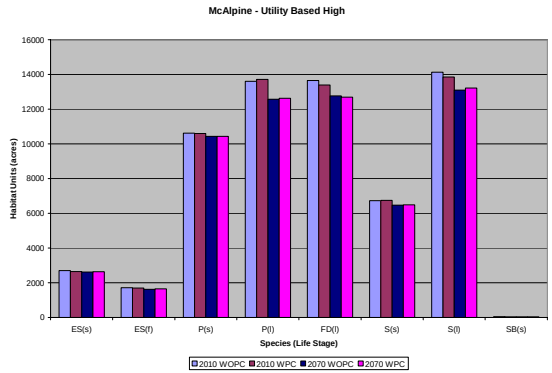
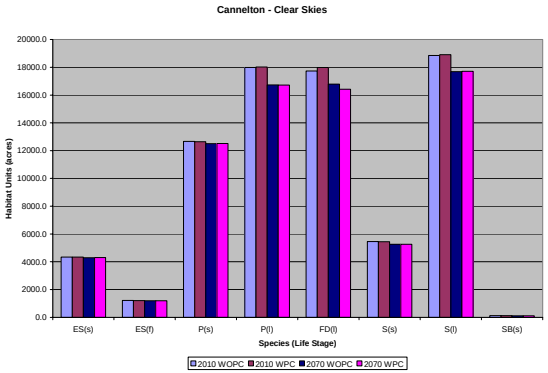
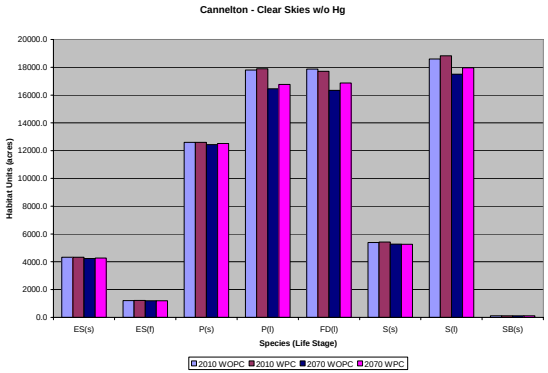
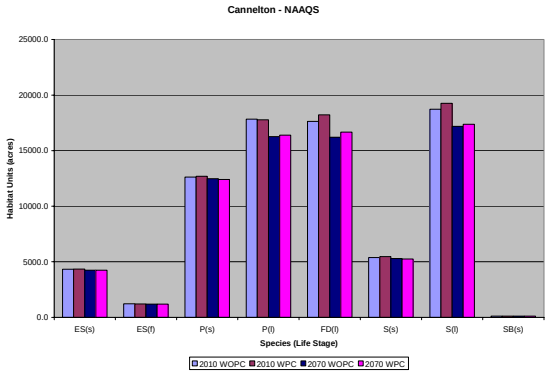
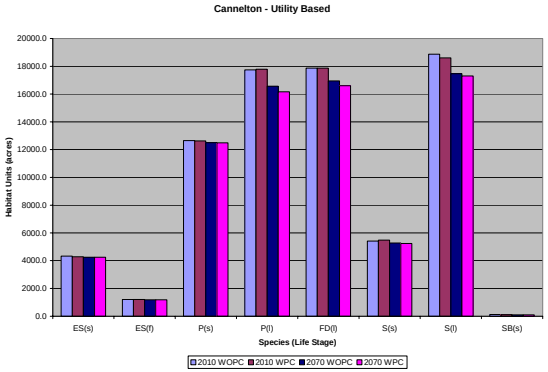


FIGURE 31
Cannelton Pool Long Term Comparisons









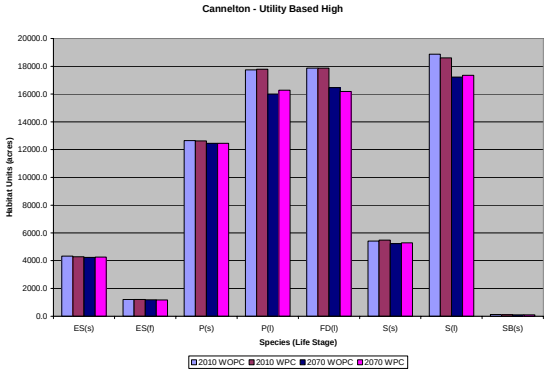
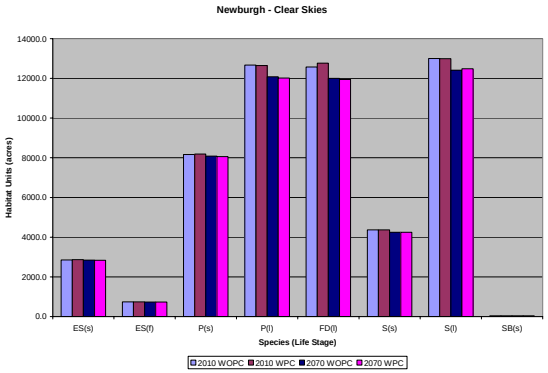
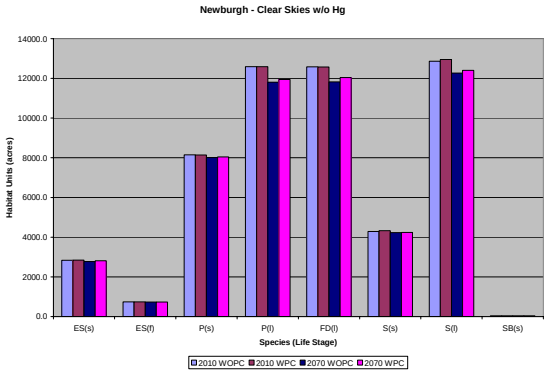
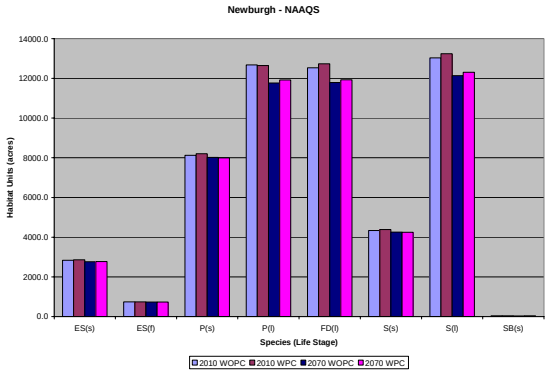
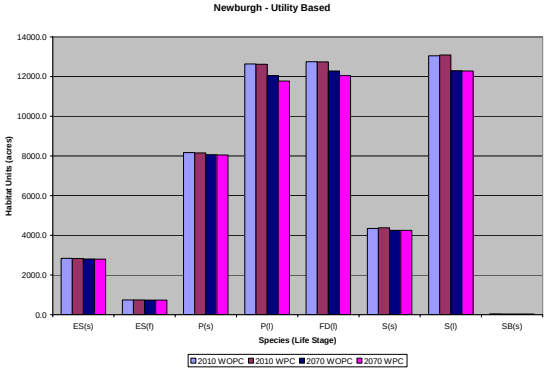


FIGURE 32
Newburgh Pool Long Term Comparisons









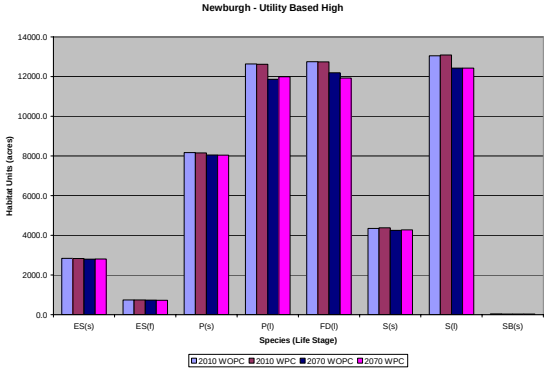
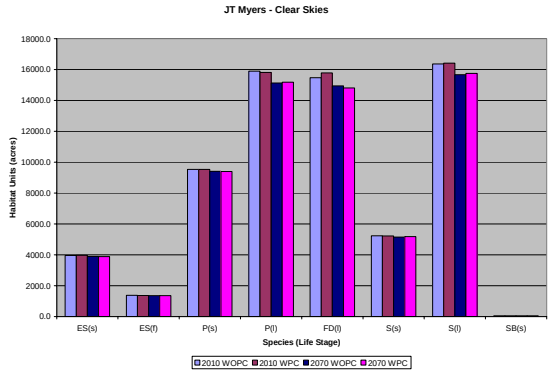
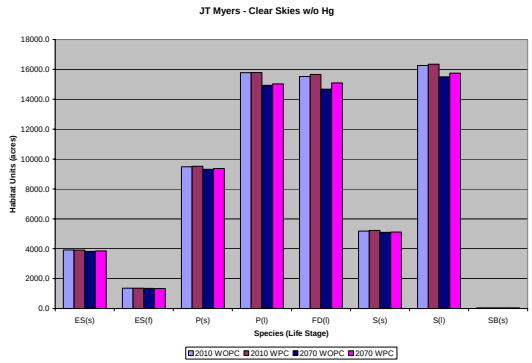
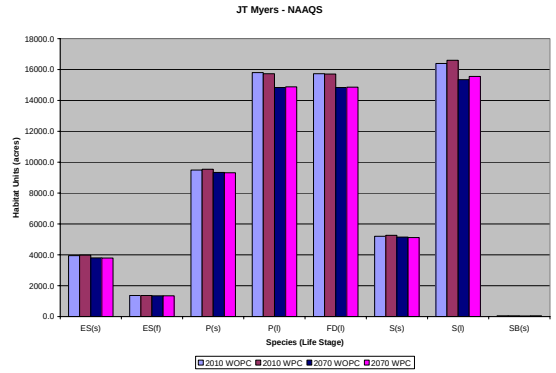
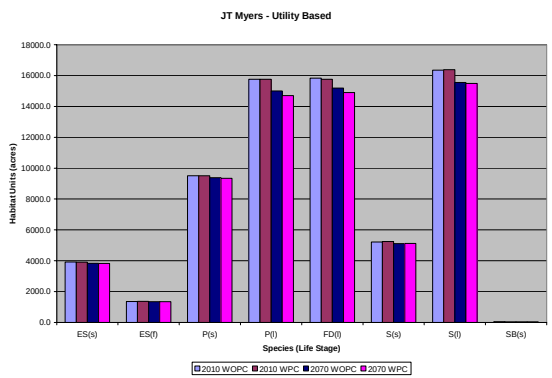


FIGURE 33
J T Myers Pool Long Term Comparisons









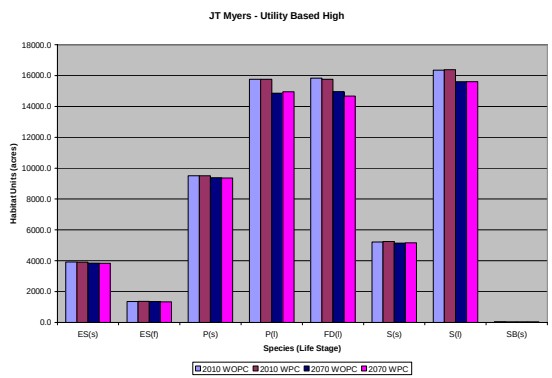
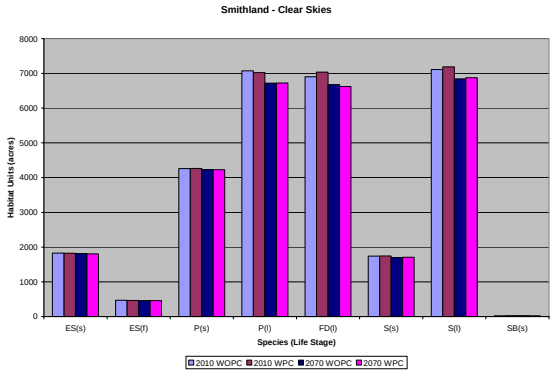
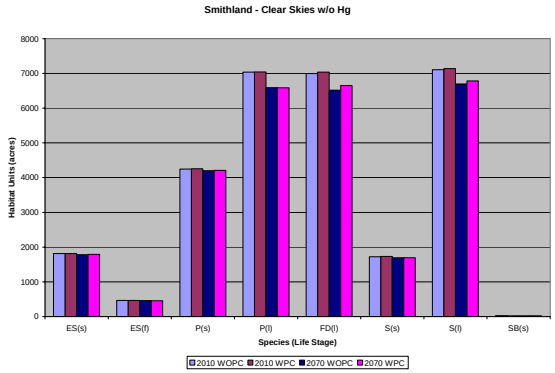
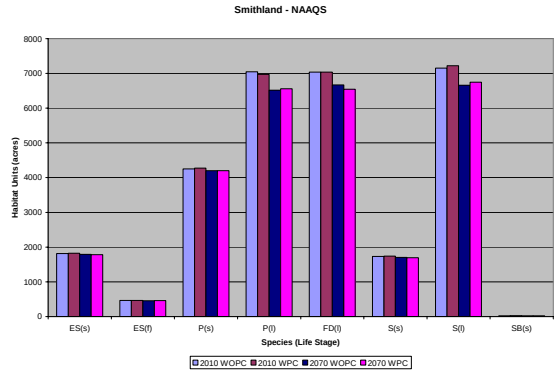
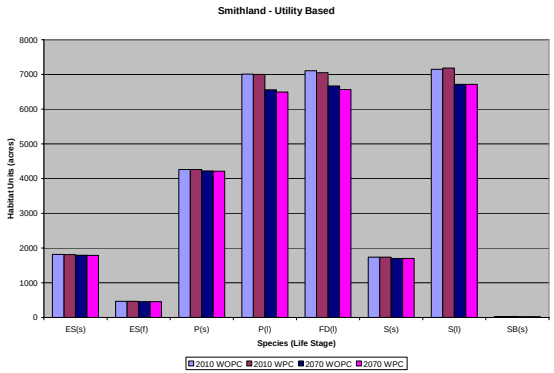


FIGURE 34
Smithland Pool Long Term Comparisons









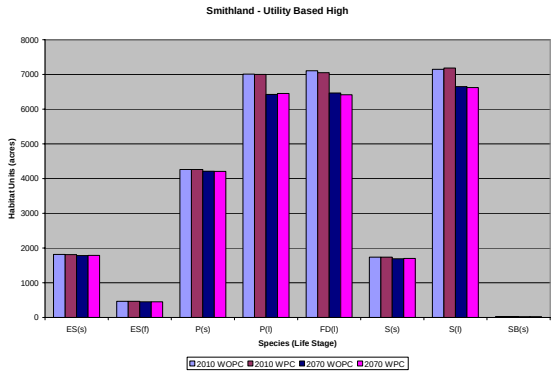
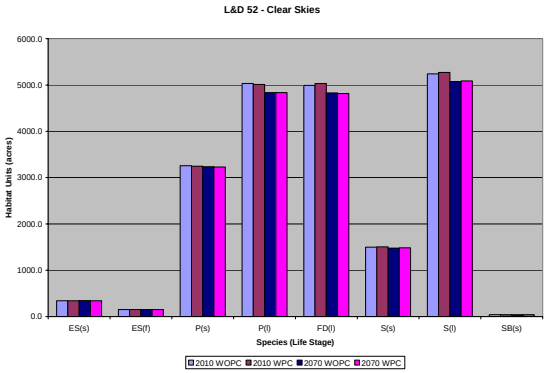
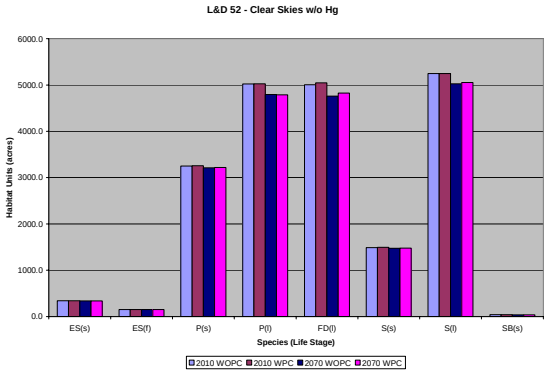
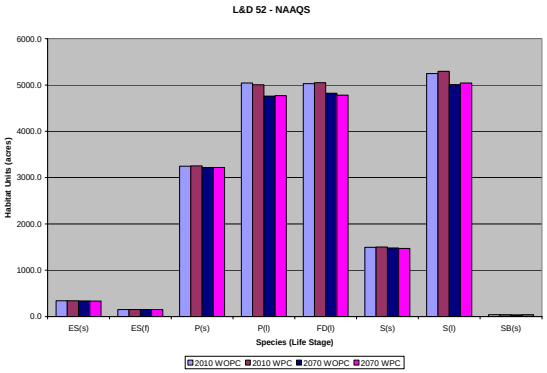
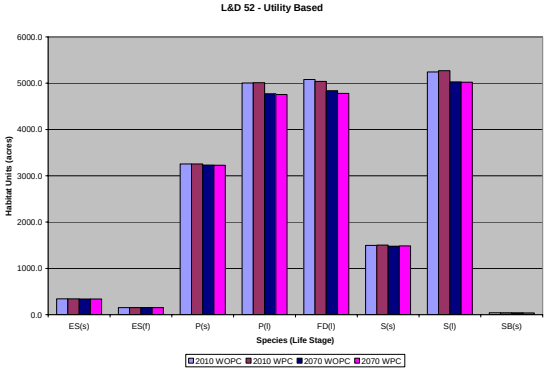


FIGURE 35
L&D#52 Pool Long Term Comparisons









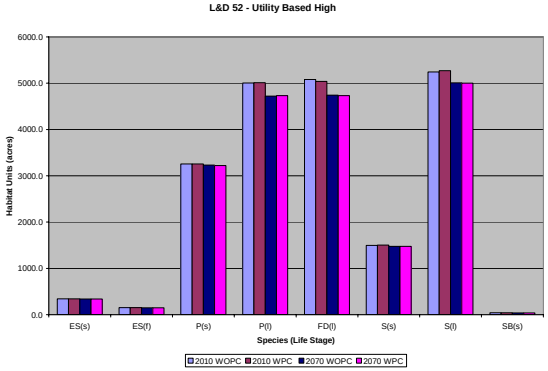
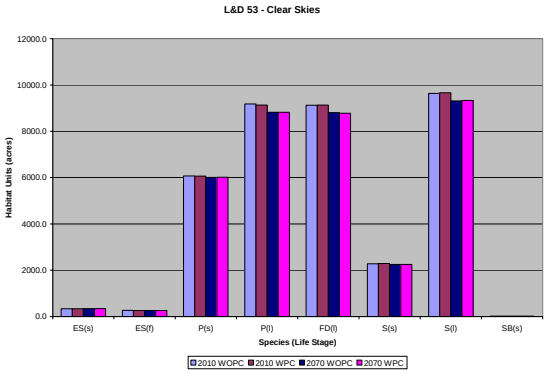
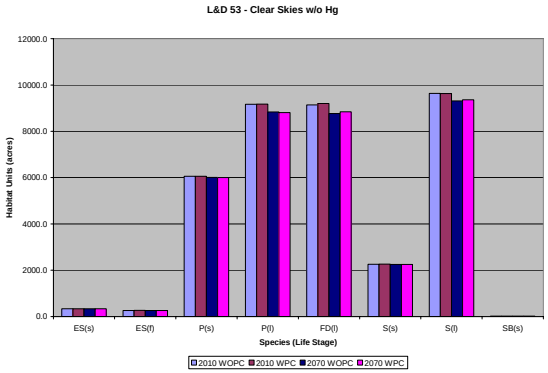
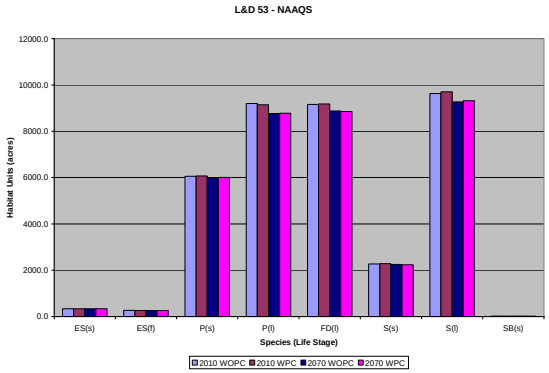
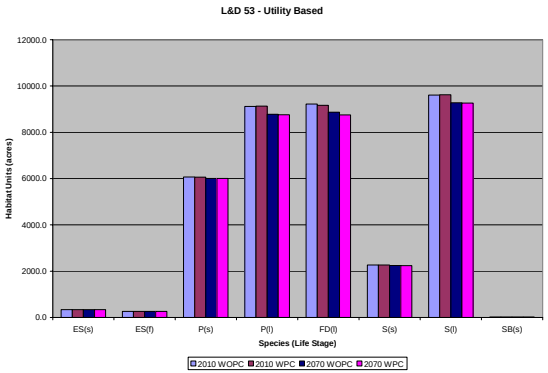


FIGURE 36
L&D#53 Pool Long Term Comparisons









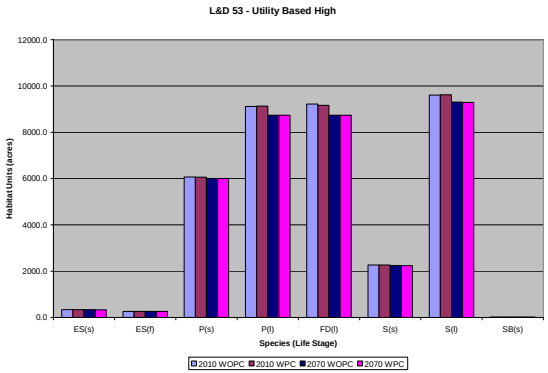


TABLE 7
Emsworth Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Emsworth	ES(s)	Clear Sky w/Hg	1.34	392.9	381.5	-11.4	-2.91%	364.6	365.6	1.1	0.29%	370.3	368.9	-1.4	-0.38%	392.90	370.30	-5.75%	381.48	368.90	-3.30%
	1	Clear Sky wo/Hg	1.34	372.7	375.7	3.0	0.80%	369.0	367.6	-1.4	-0.38%	363.9	362.6	-1.3	-0.37%	372.71	363.93	-2.36%	375.69	362.60	-3.48%
		NAAQS	1.34	376.5	380.8	4.3	1.13%	350.1	351.4	1.4	0.39%	351.6	345.4	-6.3	-1.78%	376.52	351.61	-6.62%	380.79	345.36	-9.30%
		Utility Based (Coal)	1.34	366.2	351.0	-15.2	-4.14%	351.0	346.1	-4.9	-1.39%	345.4	339.2	-6.2	-1.78%	366.20	345.37	-5.69%	351.04	339.21	-3.37%
		Utility Based High	1.34	366.2	351.0	-15.2	-4.14%	347.5	344.4	-3.1	-0.89%	338.7	331.4	-7.3	-2.17%	366.20	338.70	-7.51%	351.04	331.36	-5.60%
	ES(f)	Clear Sky w/Hg	1.59	312.9	308.5	-4.4	-1.39%	287.9	290.1	2.2	0.78%	294.7	294.4	-0.3	-0.10%	312.91	294.66	-5.83%	308.55	294.36	-4.60%
	2	Clear Sky wo/Hg	1.59	290.8	297.0	6.2	2.13%	294.2	294.2	0.0	-0.01%	284.0	282.4	-1.6	-0.58%	290.77	284.02	-2.32%	296.97	282.38	-4.91%
		NAAQS	1.59	298.4	299.6	1.2	0.39%	286.5	282.3	-4.2	-1.47%	273.6	266.9	-6.6	-2.43%	298.40	273.58	-8.32%	299.56	266.94	-10.89%
		Utility Based (Coal)	1.59	301.9	288.0	-13.9	-4.60%	293.3	291.4	-1.9	-0.65%	281.7	280.2	-1.5	-0.52%	301.90	281.71	-6.69%	288.01	280.25	-2.69%
		Utility Based High	1.59	301.9	288.0	-13.9	-4.60%	282.4	286.8	4.4	1.57%	278.8	277.2	-1.5	-0.55%	301.90	278.79	-7.65%	288.01	277.25	-3.74%
	P(s)	Clear Sky w/Hg	0.56	533.1	511.8	-21.3	-3.99%	516.2	509.0	-7.2	-1.40%	520.9	519.5	-1.4	-0.26%	533.06	520.89	-2.28%	511.80	519.51	1.51%
	3	Clear Sky wo/Hg	0.56	502.3	504.8	2.4	0.48%	509.6	508.1	-1.4	-0.28%	502.1	498.6	-3.5	-0.70%	502.35	502.15	-0.04%	504.78	498.65	-1.21%
		NAAQS	0.56	508.3	505.5	-2.8	-0.55%	513.9	516.7	2.8	0.55%	509.6	499.4	-10.2	-2.00%	508.28	509.59	0.26%	505.49	499.38	-1.21%
		Utility Based (Coal)	0.56	512.0	508.2	-3.8	-0.75%	495.4	501.6	6.2	1.25%	495.8	489.0	-6.8	-1.37%	512.04	495.80	-3.17%	508.21	489.03	-3.77%
		Utility Based High	0.56	512.0	508.2	-3.8	-0.75%	497.4	495.6	-1.8	-0.35%	491.7	486.0	-5.7	-1.16%	512.04	491.74	-3.97%	508.21	486.04	-4.36%
	P(l)	Clear Sky w/Hg	0.50	818.4	808.6	-9.9	-1.20%	757.7	758.9	1.3	0.17%	767.2	763.6	-3.5	-0.46%	818.43	767.16	-6.26%	808.57	763.61	-5.56%
	4	Clear Sky wo/Hg	0.50	749.9	764.8	14.9	1.99%	734.3	745.2	10.9	1.48%	721.3	725.8	4.5	0.63%	749.90	721.27	-3.82%	764.81	725.80	-5.10%
		NAAQS	0.50	784.3	794.4	10.1	1.29%	719.6	718.9	-0.7	-0.09%	691.9	681.4	-10.5	-1.52%	784.29	691.91	-11.78%	794.39	681.36	-14.23%
		Utility Based (Coal)	0.50	772.7	755.5	-17.2	-2.22%	762.2	752.9	-9.2	-1.21%	729.1	712.1	-17.0	-2.33%	772.67	729.09	-5.64%	755.50	712.08	-5.75%
		Utility Based High	0.50	772.7	755.5	-17.2	-2.22%	745.4	743.9	-1.5	-0.20%	715.1	711.5	-3.6	-0.50%	772.67	715.06	-7.46%	755.50	711.46	-5.83%
	FD(l)	Clear Sky w/Hg	0.51	818.2	807.3	-10.9	-1.33%	747.4	754.3	6.9	0.93%	760.7	760.4	-0.2	-0.03%	818.20	760.65	-7.03%	807.30	760.44	-5.80%
	6	Clear Sky wo/Hg	0.51	745.9	763.0	17.1	2.30%	760.9	766.1	5.3	0.69%	718.3	719.5	1.2	0.16%	745.87	718.30	-3.70%	763.01	719.45	-5.71%
		NAAQS	0.51	773.1	775.8	2.7	0.35%	732.1	719.3	-12.8	-1.75%	684.0	670.9	-13.1	-1.92%	773.10	683.99	-11.53%	775.79	670.88	-13.52%
		Utility Based (Coal)	0.51	784.6	739.4	-45.3	-5.77%	754.2	742.8	-11.4	-1.52%	709.8	695.5	-14.3	-2.01%	784.63	709.82	-9.54%	739.36	695.54	-5.93%
		Utility Based High	0.51	784.6	739.4	-45.3	-5.77%	715.9	729.8	13.9	1.94%	704.4	698.6	-5.8	-0.82%	784.63	704.44	-10.22%	739.36	698.63	-5.51%
	S(s)	Clear Sky w/Hg	0.86	450.8	447.7	-3.1	-0.70%	414.3	412.3	-2.0	-0.49%	418.2	411.7	-6.5	-1.56%	450.84	418.19	-7.24%	447.69	411.68	-8.04%
	7	Clear Sky wo/Hg	0.86	410.7	413.1	2.5	0.60%	410.0	407.9	-2.0	-0.49%	390.9	387.2	-3.7	-0.94%	410.68	390.90	-4.82%	413.14	387.25	-6.27%
		NAAQS	0.86	416.9	417.3	0.4	0.10%	403.8	402.2	-1.6	-0.39%	401.2	395.1	-6.1	-1.51%	416.85	401.17	-3.76%	417.25	395.10	-5.31%
		Utility Based (Coal)	0.86	421.8	418.6	-3.2	-0.75%	399.0	412.8	13.8	3.47%	413.6	401.6	-12.0	-2.91%	421.76	413.60	-1.93%	418.60	401.55	-4.07%
		Utility Based High	0.86	421.8	418.6	-3.2	-0.75%	392.4	397.7	5.3	1.35%	394.3	397.8	3.4	0.87%	421.76	394.35	-6.50%	418.60	397.77	-4.98%
	S(l)	Clear Sky w/Hg	0.50	825.9	814.4	-11.5	-1.39%	782.5	782.0	-0.5	-0.07%	781.0	787.2	6.2	0.79%	825.92	781.02	-5.44%	814.41	787.22	-3.34%
	8	Clear Sky wo/Hg	0.50	777.5	772.1	-5.4	-0.69%	747.3	753.8	6.5	0.87%	717.6	725.2	7.7	1.07%	777.49	717.56	-7.71%	772.11	725.23	-6.07%
		NAAQS	0.50	804.4	809.7	5.3	0.67%	738.3	733.8	-4.6	-0.62%	708.2	693.1	-15.1	-2.13%	804.36	708.20	-11.96%	809.71	693.13	-14.40%
		Utility Based (Coal)	0.50	794.1	795.9	1.7	0.22%	773.1	761.2	-12.0	-1.55%	738.2	732.5	-5.7	-0.77%	794.13	738.18	-7.04%	795.87	732.48	-7.96%
		Utility Based High	0.50	794.1	795.9	1.7	0.22%	750.6	756.3	5.7	0.76%	744.2	718.9	-25.3	-3.40%	794.13	744.20	-6.29%	795.87	718.93	-9.67%
	SB(s)	Clear Sky w/Hg	1.97	16.3	16.6	0.3	2.03%	12.8	12.8	0.0	-0.12%	11.8	11.7	0.0	-0.35%	16.26	11.76	-27.67%	16.59	11.72	-29.36%
	14	Clear Sky wo/Hg	1.97	11.8	12.6	0.8	6.65%	12.2	12.4	0.2	1.49%	9.1	10.0	0.8	9.07%	11.80	9.12	-22.69%	12.58	9.95	-20.93%
		NAAQS	1.97	14.5	16.2	1.6	11.24%	10.3	10.3	-0.1	-0.65%	7.9	8.2	0.4	4.84%	14.53	7.85	-45.94%	16.16	8.23	-49.06%
		Utility Based (Coal)	1.97	13.2	14.9	1.7	13.28%	12.0	11.9	-0.1	-0.92%	10.0	10.5	0.5	5.05%	13.15	10.02	-23.80%	14.90	10.53	-29.34%
		Utility Based High	1.97	13.2	14.9	1.7	13.28%	12.1	12.7	0.6	4.59%	8.2	8.9	0.6	7.89%	13.15	8.22	-37.50%	14.90	8.87	-40.48%

[1]ES(s)=Emerald Shiner(spawning); ES(f)=Emerald Shiner (fry); P(s)=Paddlefish(spawning); P(l)=Paddlefish(larval); FD(l)=Freshwater Drum(larval); S(s)=Sauger(spawning); S(l)=Sauger(larval); SB(s)=Spotted Bass(spawning)

TABLE 8
Dashields Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Dashields	ES(s)	Clear Sky w/Hg	1.20	322.2	316.0	-6.2	-1.92%	309.8	309.0	-0.8	-0.26%	314.4	312.0	-2.4	-0.75%	322.22	314.40	-2.43%	316.03	312.03	-1.26%
	1	Clear Sky wo/Hg	1.20	313.4	319.2	5.8	1.85%	308.3	306.8	-1.5	-0.49%	308.8	306.8	-2.0	-0.65%	313.37	308.83	-1.45%	319.15	306.83	-3.86%
		NAAQS	1.20	318.2	315.4	-2.8	-0.87%	299.8	299.3	-0.6	-0.19%	302.3	289.2	-13.0	-4.31%	318.20	302.27	-5.01%	315.42	289.23	-8.30%
		Utility Based (Coal)	1.20	312.0	302.2	-9.8	-3.14%	296.9	299.3	2.4	0.81%	293.5	292.4	-1.1	-0.38%	312.00	293.55	-5.91%	302.21	292.43	-3.23%
		Utility Based High	1.20	312.0	302.2	-9.8	-3.14%	291.2	293.6	2.4	0.82%	288.8	282.6	-6.2	-2.15%	312.00	288.79	-7.44%	302.21	282.59	-6.49%
	ES(f)	Clear Sky w/Hg	1.47	273.0	264.6	-8.4	-3.07%	245.5	247.1	1.7	0.68%	253.4	249.3	-4.1	-1.62%	273.02	253.40	-7.18%	264.65	249.29	-5.80%
	2	Clear Sky wo/Hg	1.47	249.4	256.0	6.6	2.64%	248.2	247.7	-0.5	-0.20%	240.7	240.9	0.2	0.09%	249.41	240.68	-3.50%	255.98	240.89	-5.90%
		NAAQS	1.47	258.5	254.7	-3.8	-1.49%	241.9	237.5	-4.4	-1.80%	231.1	221.3	-9.8	-4.26%	258.54	231.11	-10.61%	254.69	221.26	-13.12%
		Utility Based (Coal)	1.47	260.5	245.1	-15.3	-5.89%	251.0	248.2	-2.7	-1.09%	235.8	237.1	1.3	0.57%	260.48	235.76	-9.49%	245.14	237.09	-3.28%
		Utility Based High	1.47	260.5	245.1	-15.3	-5.89%	237.9	241.1	3.2	1.37%	233.2	231.1	-2.2	-0.93%	260.48	233.24	-10.46%	245.14	231.06	-5.74%
	P(s)	Clear Sky w/Hg	0.48	437.6	422.8	-14.8	-3.39%	429.4	427.1	-2.2	-0.52%	425.1	425.9	0.8	0.18%	437.59	425.11	-2.85%	422.76	425.88	0.74%
	3	Clear Sky wo/Hg	0.48	414.3	417.2	2.9	0.70%	424.2	420.2	-4.0	-0.95%	409.9	415.9	6.1	1.48%	414.31	409.85	-1.08%	417.22	415.91	-0.31%
		NAAQS	0.48	418.7	422.0	3.3	0.80%	424.8	429.2	4.4	1.03%	418.8	415.4	-3.3	-0.80%	418.66	418.77	0.03%	422.00	415.43	-1.56%
		Utility Based (Coal)	0.48	421.4	421.8	0.4	0.09%	413.8	416.0	2.2	0.53%	413.2	407.3	-5.9	-1.42%	421.39	413.16	-1.95%	421.78	407.27	-3.44%
		Utility Based High	0.48	421.4	421.8	0.4	0.09%	408.3	409.6	1.2	0.30%	411.6	404.3	-7.3	-1.77%	421.39	411.64	-2.31%	421.78	404.34	-4.14%
	P(l)	Clear Sky w/Hg	0.49	723.2	703.8	-19.4	-2.68%	652.5	653.5	1.0	0.15%	655.9	645.1	-10.8	-1.65%	723.18	655.91	-9.30%	703.83	645.10	-8.34%
	4	Clear Sky wo/Hg	0.49	638.8	658.8	20.0	3.13%	614.7	631.8	17.2	2.79%	610.0	618.3	8.3	1.36%	638.83	609.97	-4.52%	658.82	618.27	-6.15%
		NAAQS	0.49	686.3	690.5	4.2	0.62%	608.3	607.1	-1.2	-0.19%	580.2	563.3	-16.9	-2.91%	686.26	580.20	-15.45%	690.50	563.33	-18.42%
		Utility Based (Coal)	0.49	667.5	646.8	-20.7	-3.10%	656.1	646.2	-9.9	-1.50%	609.8	604.0	-5.9	-0.96%	667.47	609.82	-8.64%	646.75	603.95	-6.62%
		Utility Based High	0.49	667.5	646.8	-20.7	-3.10%	637.0	637.3	0.4	0.06%	608.9	598.8	-10.1	-1.66%	667.47	608.90	-8.77%	646.75	598.81	-7.41%
	FD(l)	Clear Sky w/Hg	0.49	713.0	688.7	-24.3	-3.41%	635.9	641.9	6.0	0.95%	647.8	639.4	-8.4	-1.30%	713.00	647.80	-9.14%	688.66	639.40	-7.15%
	6	Clear Sky wo/Hg	0.49	633.5	653.2	19.7	3.11%	634.6	643.5	8.9	1.40%	603.1	609.0	5.9	0.98%	633.47	603.10	-4.80%	653.17	608.98	-6.77%
		NAAQS	0.49	666.5	650.5	-16.0	-2.40%	611.6	597.6	-14.0	-2.29%	564.3	541.7	-22.7	-4.02%	666.50	564.35	-15.33%	650.48	541.66	-16.73%
		Utility Based (Coal)	0.49	679.6	623.9	-55.6	-8.19%	631.8	623.1	-8.7	-1.37%	581.0	574.5	-6.6	-1.13%	679.56	581.03	-14.50%	623.93	574.46	-7.93%
		Utility Based High	0.49	679.6	623.9	-55.6	-8.19%	595.4	604.8	9.4	1.58%	579.4	568.4	-11.0	-1.89%	679.56	579.37	-14.74%	623.93	568.39	-8.90%
	S(s)	Clear Sky w/Hg	0.77	402.5	410.6	8.2	2.03%	385.3	387.0	1.7	0.44%	380.0	381.9	2.0	0.52%	402.48	379.96	-5.60%	410.65	381.95	-6.99%
	7	Clear Sky wo/Hg	0.77	373.0	382.1	9.1	2.44%	380.0	383.5	3.5	0.93%	364.3	369.6	5.3	1.47%	372.99	364.29	-2.33%	382.08	369.63	-3.26%
		NAAQS	0.77	380.5	385.5	5.0	1.32%	379.2	382.9	3.7	0.97%	381.8	373.4	-8.4	-2.21%	380.49	381.83	0.35%	385.52	373.38	-3.15%
		Utility Based (Coal)	0.77	383.8	381.1	-2.7	-0.71%	371.5	378.6	7.1	1.91%	375.5	365.1	-10.4	-2.76%	383.84	375.46	-2.18%	381.12	365.10	-4.20%
		Utility Based High	0.77	383.8	381.1	-2.7	-0.71%	366.9	373.2	6.3	1.72%	365.8	368.0	2.2	0.61%	383.84	365.79	-4.70%	381.12	368.01	-3.44%
	S(l)	Clear Sky w/Hg	0.49	731.9	714.3	-17.7	-2.42%	689.0	688.7	-0.3	-0.05%	680.2	688.1	7.9	1.15%	731.95	680.25	-7.06%	714.26	688.10	-3.66%
	8	Clear Sky wo/Hg	0.49	679.0	669.9	-9.2	-1.35%	643.7	656.6	12.9	2.00%	620.4	628.8	8.4	1.35%	679.04	620.42	-8.63%	669.85	628.79	-6.13%
		NAAQS	0.49	710.6	713.5	2.8	0.40%	637.2	633.7	-3.4	-0.54%	606.4	593.4	-13.0	-2.15%	710.65	606.42	-14.67%	713.46	593.37	-16.83%
		Utility Based (Coal)	0.49	703.6	701.8	-1.8	-0.26%	677.0	661.8	-15.2	-2.24%	638.8	629.0	-9.8	-1.53%	703.60	638.79	-9.21%	701.78	629.01	-10.37%
		Utility Based High	0.49	703.6	701.8	-1.8	-0.26%	648.6	656.1	7.5	1.16%	643.5	620.7	-22.8	-3.54%	703.60	643.52	-8.54%	701.78	620.73	-11.55%
	SB(s)	Clear Sky w/Hg	2.07	15.1	14.7	-0.4	-2.70%	11.7	11.7	0.0	0.35%	11.2	11.2	0.0	-0.02%	15.09	11.18	-25.87%	14.68	11.18	-23.83%
	14	Clear Sky wo/Hg	2.07	10.8	11.5	0.7	6.89%	11.8	11.6	-0.2	-1.41%	9.0	9.4	0.4	4.19%	10.75	8.97	-16.55%	11.50	9.35	-18.66%
		NAAQS	2.07	14.4	14.5	0.2	1.05%	9.5	9.6	0.1	1.45%	8.3	8.2	-0.1	-1.72%	14.36	8.34	-41.92%	14.52	8.20	-43.51%
		Utility Based (Coal)	2.07	12.4	12.4	0.1	0.66%	11.1	10.8	-0.3	-2.99%	10.0	9.3	-0.7	-6.61%	12.35	9.96	-19.34%	12.44	9.31	-25.17%
		Utility Based High	2.07	12.4	12.4	0.1	0.66%	11.0	11.4	0.4	3.26%	8.6	8.8	0.1	1.74%	12.35	8.60	-30.37%	12.44	8.75	-29.62%

TABLE 9
Montgomery Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Montgomery	ES(s)	Clear Sky w/Hg	3.65	1242.5	1233.3	-9.2	-0.74%	1220.3	1222.5	2.2	0.18%	1233.1	1225.0	-8.2	-0.66%	1242.47	1233.15	-0.75%	1233.30	1224.95	-0.68%
	1	Clear Sky wo/Hg	3.65	1230.5	1235.3	4.8	0.39%	1199.3	1195.6	-3.8	-0.31%	1211.4	1207.8	-3.6	-0.30%	1230.55	1211.38	-1.56%	1235.30	1207.78	-2.23%
		NAAQS	3.65	1233.7	1231.0	-2.8	-0.22%	1196.9	1196.9	0.0	0.00%	1200.6	1184.8	-15.8	-1.31%	1233.75	1200.62	-2.69%	1231.00	1184.83	-3.75%
		Utility Based (Coal)	3.65	1235.5	1205.8	-29.7	-2.40%	1193.5	1205.4	11.9	0.99%	1180.4	1173.0	-7.5	-0.63%	1235.49	1180.43	-4.46%	1205.77	1172.97	-2.72%
		Utility Based High	3.65	1235.5	1205.8	-29.7	-2.40%	1184.7	1183.6	-1.1	-0.09%	1179.1	1165.9	-13.2	-1.12%	1235.49	1179.12	-4.56%	1205.77	1165.92	-3.30%
	ES(f)	Clear Sky w/Hg	4.36	856.7	844.6	-12.0	-1.40%	807.3	808.1	0.8	0.10%	828.3	820.7	-7.6	-0.92%	856.65	828.27	-3.31%	844.62	820.68	-2.83%
	2	Clear Sky wo/Hg	4.36	808.0	819.5	11.5	1.43%	809.1	804.7	-4.4	-0.54%	782.1	788.7	6.6	0.85%	808.00	782.11	-3.21%	819.52	788.73	-3.76%
		NAAQS	4.36	838.8	823.3	-15.5	-1.84%	794.3	790.7	-3.6	-0.46%	771.5	758.1	-13.5	-1.75%	838.77	771.53	-8.02%	823.30	758.05	-7.93%
		Utility Based (Coal)	4.36	851.3	810.8	-40.5	-4.76%	823.2	821.7	-1.5	-0.19%	790.9	786.7	-4.2	-0.53%	851.31	790.93	-7.09%	810.80	786.74	-2.97%
		Utility Based High	4.36	851.3	810.8	-40.5	-4.76%	793.6	800.7	7.1	0.90%	783.8	774.3	-9.4	-1.20%	851.31	783.75	-7.94%	810.80	774.34	-4.50%
	P(s)	Clear Sky w/Hg	1.55	1556.7	1516.2	-40.6	-2.61%	1521.7	1516.9	-4.8	-0.31%	1522.9	1526.9	4.0	0.26%	1556.71	1522.87	-2.17%	1516.15	1526.85	0.71%
	3	Clear Sky wo/Hg	1.55	1498.2	1504.7	6.5	0.43%	1510.4	1498.0	-12.4	-0.82%	1480.4	1489.5	9.2	0.62%	1498.20	1480.37	-1.19%	1504.68	1489.55	-1.01%
		NAAQS	1.55	1508.2	1510.1	1.9	0.13%	1513.1	1519.9	6.7	0.44%	1506.8	1485.4	-21.4	-1.42%	1508.17	1506.85	-0.09%	1510.07	1485.42	-1.63%
		Utility Based (Coal)	1.55	1515.1	1505.6	-9.4	-0.62%	1499.8	1502.3	2.5	0.17%	1489.1	1473.4	-15.7	-1.06%	1515.06	1489.12	-1.71%	1505.63	1473.39	-2.14%
		Utility Based High	1.55	1515.1	1505.6	-9.4	-0.62%	1493.7	1487.1	-6.6	-0.44%	1476.2	1467.4	-8.8	-0.60%	1515.06	1476.19	-2.57%	1505.63	1467.37	-2.54%
	P(l)	Clear Sky w/Hg	1.53	2395.2	2383.8	-11.4	-0.48%	2217.3	2213.8	-3.5	-0.16%	2255.2	2237.3	-17.9	-0.80%	2395.20	2255.23	-5.84%	2383.80	2237.29	-6.15%
	4	Clear Sky wo/Hg	1.53	2204.0	2254.5	50.5	2.29%	2149.9	2170.5	20.6	0.96%	2095.8	2126.3	30.5	1.46%	2204.01	2095.80	-4.91%	2254.54	2126.30	-5.69%
		NAAQS	1.53	2327.5	2335.4	7.8	0.34%	2098.9	2119.0	20.1	0.96%	2058.0	2018.0	-40.0	-1.94%	2327.55	2057.98	-11.58%	2335.38	2018.00	-13.59%
		Utility Based (Coal)	1.53	2309.0	2207.8	-101.1	-4.38%	2282.2	2259.5	-22.6	-0.99%	2161.5	2127.2	-34.3	-1.59%	2308.99	2161.52	-6.39%	2207.84	2127.24	-3.65%
		Utility Based High	1.53	2309.0	2207.8	-101.1	-4.38%	2226.3	2227.2	0.9	0.04%	2138.8	2111.8	-27.0	-1.26%	2308.99	2138.80	-7.37%	2207.84	2111.77	-4.35%
	FD(l)	Clear Sky w/Hg	1.53	2395.6	2343.3	-52.3	-2.18%	2208.4	2214.7	6.2	0.28%	2251.3	2228.3	-23.0	-1.02%	2395.58	2251.26	-6.02%	2343.30	2228.29	-4.91%
	6	Clear Sky wo/Hg	1.53	2186.1	2229.0	42.9	1.96%	2198.8	2202.9	4.1	0.19%	2058.3	2106.6	48.4	2.35%	2186.11	2058.28	-5.85%	2229.00	2106.63	-5.49%
		NAAQS	1.53	2304.5	2236.0	-68.5	-2.97%	2130.4	2116.2	-14.2	-0.67%	2023.3	2000.8	-22.5	-1.11%	2304.51	2023.33	-12.20%	2235.99	2000.84	-10.52%
		Utility Based (Coal)	1.53	2374.4	2204.1	-170.3	-7.17%	2228.4	2225.1	-3.3	-0.15%	2102.6	2063.9	-38.7	-1.84%	2374.35	2102.61	-11.44%	2204.07	2063.88	-6.36%
		Utility Based High	1.53	2374.4	2204.1	-170.3	-7.17%	2117.6	2154.7	37.1	1.75%	2093.1	2041.9	-51.2	-2.45%	2374.35	2093.12	-11.84%	2204.07	2041.90	-7.36%
	S(s)	Clear Sky w/Hg	2.36	1418.7	1405.3	-13.5	-0.95%	1339.2	1340.6	1.3	0.10%	1340.7	1344.2	3.5	0.26%	1418.71	1340.66	-5.50%	1405.26	1344.18	-4.35%
	7	Clear Sky wo/Hg	2.36	1315.1	1347.6	32.5	2.47%	1320.0	1332.7	12.7	0.97%	1276.6	1286.0	9.4	0.73%	1315.13	1276.64	-2.93%	1347.59	1285.99	-4.57%
		NAAQS	2.36	1345.5	1349.3	3.7	0.28%	1316.5	1325.2	8.6	0.65%	1337.1	1318.4	-18.7	-1.40%	1345.53	1337.09	-0.63%	1349.28	1318.37	-2.29%
		Utility Based (Coal)	2.36	1364.4	1340.9	-23.5	-1.72%	1320.0	1334.8	14.8	1.12%	1332.3	1303.8	-28.5	-2.14%	1364.36	1332.28	-2.35%	1340.88	1303.82	-2.76%
		Utility Based High	2.36	1364.4	1340.9	-23.5	-1.72%	1317.8	1331.0	13.2	1.00%	1300.9	1308.3	7.4	0.57%	1364.36	1300.91	-4.65%	1340.88	1308.32	-2.43%
	S(l)	Clear Sky w/Hg	1.52	2453.2	2391.4	-61.8	-2.52%	2297.7	2293.9	-3.8	-0.17%	2299.3	2328.0	28.8	1.25%	2453.16	2299.25	-6.27%	2391.36	2328.05	-2.65%
	8	Clear Sky wo/Hg	1.52	2297.9	2290.4	-7.4	-0.32%	2220.7	2224.9	4.3	0.19%	2125.1	2139.0	13.9	0.65%	2297.88	2125.08	-7.52%	2290.43	2138.99	-6.61%
		NAAQS	1.52	2368.8	2390.1	21.3	0.90%	2180.0	2166.7	-13.4	-0.61%	2117.9	2081.5	-36.4	-1.72%	2368.78	2117.88	-10.59%	2390.10	2081.50	-12.91%
		Utility Based (Coal)	1.52	2358.1	2359.9	1.8	0.08%	2319.2	2301.3	-17.9	-0.77%	2219.0	2184.0	-35.0	-1.58%	2358.11	2219.01	-5.90%	2359.89	2183.96	-7.45%
		Utility Based High	1.52	2358.1	2359.9	1.8	0.08%	2234.2	2279.3	45.1	2.02%	2230.3	2165.5	-64.8	-2.91%	2358.11	2230.30	-5.42%	2359.89	2165.45	-8.24%
	SB(s)	Clear Sky w/Hg	5.25	74.1	78.5	4.4	5.91%	68.6	68.9	0.3	0.37%	67.8	69.0	1.2	1.81%	74.11	67.82	-8.49%	78.49	69.05	-12.03%
	14	Clear Sky wo/Hg	5.25	65.2	65.6	0.4	0.59%	64.7	62.0	-2.7	-4.21%	58.8	59.2	0.4	0.69%	65.22	58.83	-9.79%	65.60	59.24	-9.70%
		NAAQS	5.25	75.8	74.1	-1.6	-2.15%	59.9	60.6	0.7	1.24%	57.7	55.3	-2.4	-4.12%	75.78	57.71	-23.84%	74.15	55.33	-25.38%
		Utility Based (Coal)	5.25	68.7	68.1	-0.6	-0.85%	68.0	67.3	-0.6	-0.95%	63.0	59.9	-3.0	-4.83%	68.70	62.96	-8.36%	68.11	59.92	-12.03%
		Utility Based High	5.25	68.7	68.1	-0.6	-0.85%	66.0	66.5	0.4	0.67%	58.4	57.9	-0.4	-0.76%	68.70	58.36	-15.05%	68.11	57.92	-14.97%

TABLE 10
New Cumberland Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
New Cumberland	ES(s)	Clear Sky w/Hg	3.84	1222.8	1213.1	-9.7	-0.79%	1180.2	1183.7	3.5	0.30%	1179.4	1178.2	-1.2	-0.10%	1222.78	1179.37	-3.55%	1213.12	1178.19	-2.88%
	1	Clear Sky wo/Hg	3.84	1168.9	1173.6	4.7	0.40%	1166.0	1165.2	-0.8	-0.07%	1150.1	1153.5	3.4	0.29%	1168.87	1150.11	-1.61%	1173.59	1153.48	-1.71%
		NAAQS	3.84	1197.5	1186.8	-10.7	-0.89%	1157.9	1159.0	1.1	0.09%	1142.2	1142.8	0.6	0.05%	1197.50	1142.21	-4.62%	1186.82	1142.78	-3.71%
		Utility Based (Coal)	3.84	1220.4	1175.7	-44.8	-3.67%	1177.4	1179.7	2.3	0.19%	1157.7	1156.2	-1.5	-0.13%	1220.45	1157.71	-5.14%	1175.65	1156.17	-1.66%
		Utility Based High	3.84	1220.4	1175.7	-44.8	-3.67%	1158.1	1157.1	-0.9	-0.08%	1149.1	1138.2	-10.9	-0.95%	1220.45	1149.11	-5.84%	1175.65	1138.24	-3.18%
	ES(f)	Clear Sky w/Hg	6.16	1315.1	1306.9	-8.2	-0.62%	1250.9	1256.0	5.0	0.40%	1245.3	1240.4	-4.9	-0.39%	1315.07	1245.27	-5.31%	1306.91	1240.37	-5.09%
	2	Clear Sky wo/Hg	6.16	1237.5	1259.4	22.0	1.77%	1245.2	1221.3	-23.9	-1.92%	1193.9	1201.2	7.2	0.61%	1237.47	1193.93	-3.52%	1259.43	1201.17	-4.63%
		NAAQS	6.16	1291.7	1267.7	-24.1	-1.86%	1208.4	1208.9	0.5	0.04%	1191.8	1174.3	-17.5	-1.47%	1291.72	1191.76	-7.74%	1267.67	1174.27	-7.37%
		Utility Based (Coal)	6.16	1304.3	1245.4	-58.9	-4.51%	1226.2	1236.3	10.1	0.83%	1189.7	1198.4	8.7	0.73%	1304.32	1189.67	-8.79%	1245.44	1198.37	-3.78%
		Utility Based High	6.16	1304.3	1245.4	-58.9	-4.51%	1211.7	1216.6	4.9	0.41%	1170.3	1177.3	7.1	0.60%	1304.32	1170.27	-10.28%	1245.44	1177.34	-5.47%
	P(s)	Clear Sky w/Hg	1.82	1368.5	1340.8	-27.7	-2.02%	1304.0	1302.0	-2.0	-0.15%	1305.1	1304.0	-1.1	-0.09%	1368.51	1305.11	-4.63%	1340.81	1303.96	-2.75%
	3	Clear Sky wo/Hg	1.82	1300.5	1299.5	-1.0	-0.08%	1298.2	1285.2	-13.0	-1.00%	1276.7	1284.6	7.8	0.61%	1300.52	1276.71	-1.83%	1299.50	1284.55	-1.15%
		NAAQS	1.82	1304.0	1307.2	3.2	0.25%	1293.6	1296.2	2.6	0.20%	1284.7	1284.2	-0.4	-0.03%	1304.00	1284.66	-1.48%	1307.24	1284.24	-1.76%
		Utility Based (Coal)	1.82	1309.0	1307.8	-1.2	-0.09%	1292.4	1295.8	3.3	0.26%	1279.8	1277.3	-2.6	-0.20%	1309.02	1279.83	-2.23%	1307.82	1277.26	-2.34%
		Utility Based High	1.82	1309.0	1307.8	-1.2	-0.09%	1286.8	1293.1	6.3	0.49%	1278.5	1275.8	-2.7	-0.21%	1309.02	1278.54	-2.33%	1307.82	1275.83	-2.45%
	P(l)	Clear Sky w/Hg	2.38	3174.8	3176.9	2.1	0.06%	2978.1	2983.1	5.1	0.17%	2935.7	2943.0	7.2	0.25%	3174.84	2935.73	-7.53%	3176.89	2942.96	-7.36%
	4	Clear Sky wo/Hg	2.38	2929.1	2970.1	41.0	1.40%	2822.1	2841.0	18.9	0.67%	2802.8	2829.5	26.7	0.95%	2929.14	2802.79	-4.31%	2970.10	2829.52	-4.73%
		NAAQS	2.38	3061.3	3051.1	-10.2	-0.33%	2824.5	2839.5	15.0	0.53%	2751.5	2736.6	-14.9	-0.54%	3061.29	2751.49	-10.12%	3051.12	2736.64	-10.31%
		Utility Based (Coal)	2.38	3045.3	2962.3	-83.0	-2.73%	2916.2	2914.5	-1.7	-0.06%	2820.1	2816.5	-3.6	-0.13%	3045.32	2820.11	-7.40%	2962.29	2816.54	-4.92%
		Utility Based High	2.38	3045.3	2962.3	-83.0	-2.73%	2902.9	2896.1	-6.8	-0.23%	2776.2	2739.1	-37.1	-1.34%	3045.32	2776.16	-8.84%	2962.29	2739.06	-7.54%
	FD(l)	Clear Sky w/Hg	2.37	3170.2	3133.5	-36.7	-1.16%	2947.7	2960.4	12.7	0.43%	2873.3	2875.4	2.2	0.08%	3170.24	2873.27	-9.37%	3133.53	2875.45	-8.24%
	6	Clear Sky wo/Hg	2.37	2872.6	2953.6	81.1	2.82%	2899.2	2863.0	-36.2	-1.25%	2727.9	2732.6	4.7	0.17%	2872.57	2727.90	-5.04%	2953.64	2732.62	-7.48%
		NAAQS	2.37	3060.3	2982.8	-77.5	-2.53%	2791.9	2794.3	2.4	0.09%	2732.4	2696.2	-36.2	-1.32%	3060.31	2732.39	-10.72%	2982.76	2696.20	-9.61%
		Utility Based (Coal)	2.37	3119.1	2921.3	-197.8	-6.34%	2829.0	2888.2	59.2	2.09%	2732.9	2710.0	-22.9	-0.84%	3119.07	2732.87	-12.38%	2921.28	2709.96	-7.23%
		Utility Based High	2.37	3119.1	2921.3	-197.8	-6.34%	2809.3	2836.2	26.9	0.96%	2678.8	2636.1	-42.7	-1.59%	3119.07	2678.77	-14.12%	2921.28	2636.06	-9.76%
	S(s)	Clear Sky w/Hg	2.38	1206.2	1206.9	0.6	0.05%	1128.9	1127.9	-1.0	-0.09%	1143.7	1140.6	-3.1	-0.27%	1206.23	1143.74	-5.18%	1206.86	1140.61	-5.49%
	7	Clear Sky wo/Hg	2.38	1132.2	1136.3	4.1	0.36%	1121.9	1129.9	8.0	0.71%	1092.1	1097.3	5.2	0.47%	1132.21	1092.11	-3.54%	1136.30	1097.28	-3.43%
		NAAQS	2.38	1139.1	1154.6	15.5	1.36%	1115.4	1120.7	5.2	0.47%	1124.2	1113.6	-10.7	-0.95%	1139.07	1124.25	-1.30%	1154.60	1113.58	-3.55%
		Utility Based (Coal)	2.38	1155.3	1145.7	-9.5	-0.82%	1127.6	1140.0	12.4	1.10%	1116.6	1114.1	-2.5	-0.22%	1155.28	1116.64	-3.34%	1145.75	1114.15	-2.76%
		Utility Based High	2.38	1155.3	1145.7	-9.5	-0.82%	1111.6	1127.3	15.8	1.42%	1114.8	1114.2	-0.7	-0.06%	1155.28	1114.83	-3.50%	1145.75	1114.17	-2.76%
	S(l)	Clear Sky w/Hg	2.36	3239.2	3197.1	-42.1	-1.30%	3027.3	3014.9	-12.4	-0.41%	2954.2	3010.6	56.4	1.91%	3239.18	2954.22	-8.80%	3197.08	3010.59	-5.83%
	8	Clear Sky wo/Hg	2.36	3018.5	2990.2	-28.3	-0.94%	2910.7	2902.3	-8.4	-0.29%	2831.4	2835.1	3.7	0.13%	3018.47	2831.43	-6.20%	2990.21	2835.14	-5.19%
		NAAQS	2.36	3043.4	3095.9	52.5	1.73%	2866.9	2845.5	-21.4	-0.75%	2833.2	2816.9	-16.3	-0.57%	3043.36	2833.17	-6.91%	3095.86	2816.91	-9.01%
		Utility Based (Coal)	2.36	3025.2	3010.6	-14.6	-0.48%	2983.0	3015.9	32.9	1.10%	2884.9	2860.6	-24.4	-0.84%	3025.25	2884.93	-4.64%	3010.63	2860.56	-4.98%
		Utility Based High	2.36	3025.2	3010.6	-14.6	-0.48%	2909.8	2943.1	33.3	1.14%	2923.2	2815.1	-108.1	-3.70%	3025.25	2923.21	-3.37%	3010.63	2815.10	-6.49%
	SB(s)	Clear Sky w/Hg	7.51	112.5	111.1	-1.4	-1.26%	93.1	92.8	-0.3	-0.37%	97.5	99.0	1.5	1.56%	112.52	97.48	-13.37%	111.11	98.99	-10.90%
	14	Clear Sky wo/Hg	7.51	89.4	90.5	1.1	1.20%	80.9	82.3	1.4	1.73%	74.3	75.2	0.9	1.17%	89.44	74.34	-16.88%	90.51	75.21	-16.90%
		NAAQS	7.51	102.4	100.5	-2.0	-1.91%	78.8	80.5	1.7	2.11%	78.0	74.4	-3.7	-4.68%	102.44	78.04	-23.82%	100.48	74.38	-25.97%
		Utility Based (Coal)	7.51	99.7	96.8	-2.9	-2.86%	91.8	91.2	-0.6	-0.65%	87.9	82.7	-5.2	-5.92%	99.67	87.94	-11.78%	96.82	82.73	-14.55%
		Utility Based High	7.51	99.7	96.8	-2.9	-2.86%	88.4	88.7	0.4	0.41%	76.1	79.4	3.3	4.35%	99.67	76.10	-23.65%	96.82	79.41	-17.99%

[1]ES(s)=Emerald Shiner (spawning); ES(f)=Emerald Shiner (fry); P(s)=Paddlefish (spawning); P(l)=Paddlefish (larval); FD(l)=Freshwater Drum (larval); S(s)=Sauger (spawning); S(l)=Sauger (larval); SB(s)=Spotted Bass (spawning)

TABLE 11
Pike Island
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Pike Island	ES(s)	Clear Sky w/Hg	3.84	1253.5	1238.0	-15.5	-1.24%	1204.0	1205.0	1.0	0.09%	1199.1	1195.3	-3.8	-0.31%	1253.50	1199.06	-4.34%	1237.98	1195.31	-3.45%
	1	Clear Sky wo/Hg	3.84	1165.9	1175.3	9.4	0.81%	1178.5	1180.3	1.8	0.15%	1170.2	1170.0	-0.2	-0.02%	1165.87	1170.25	0.38%	1175.27	1170.01	-0.45%
		NAAQS	3.84	1206.5	1196.4	-10.1	-0.84%	1167.4	1168.0	0.6	0.06%	1155.8	1156.1	0.3	0.03%	1206.55	1155.78	-4.21%	1196.44	1156.10	-3.37%
		Utility Based (Coal)	3.84	1221.9	1182.9	-39.0	-3.19%	1182.0	1181.5	-0.5	-0.04%	1160.3	1159.6	-0.7	-0.06%	1221.87	1160.33	-5.04%	1182.85	1159.59	-1.97%
		Utility Based High	3.84	1221.9	1182.9	-39.0	-3.19%	1171.0	1177.4	6.5	0.55%	1154.4	1148.1	-6.3	-0.55%	1221.87	1154.44	-5.52%	1182.85	1148.14	-2.93%
	ES(f)	Clear Sky w/Hg	6.16	1165.6	1159.1	-6.5	-0.56%	1115.5	1117.5	2.0	0.18%	1087.4	1091.3	3.9	0.36%	1165.62	1087.36	-6.71%	1159.15	1091.27	-5.86%
	2	Clear Sky wo/Hg	6.16	1081.1	1109.2	28.0	2.59%	1100.0	1087.8	-12.2	-1.11%	1060.8	1056.6	-4.2	-0.39%	1081.13	1060.77	-1.88%	1109.16	1056.60	-4.74%
		NAAQS	6.16	1132.5	1121.8	-10.7	-0.95%	1078.7	1075.0	-3.7	-0.35%	1065.5	1047.1	-18.3	-1.72%	1132.50	1065.48	-5.92%	1121.75	1047.14	-6.65%
		Utility Based (Coal)	6.16	1165.7	1110.6	-55.0	-4.72%	1098.3	1095.7	-2.6	-0.24%	1058.1	1062.0	3.9	0.37%	1165.65	1058.11	-9.23%	1110.61	1062.00	-4.38%
		Utility Based High	6.16	1165.7	1110.6	-55.0	-4.72%	1079.0	1080.6	1.6	0.15%	1039.6	1050.5	10.9	1.05%	1165.65	1039.60	-10.81%	1110.61	1050.54	-5.41%
	P(s)	Clear Sky w/Hg	1.82	1656.6	1619.3	-37.3	-2.25%	1571.2	1561.5	-9.7	-0.61%	1580.2	1574.6	-5.6	-0.35%	1656.64	1580.21	-4.61%	1619.31	1574.62	-2.76%
	3	Clear Sky wo/Hg	1.82	1545.2	1547.6	2.3	0.15%	1556.3	1535.1	-21.3	-1.37%	1529.8	1542.6	12.8	0.84%	1545.21	1529.78	-1.00%	1547.55	1542.58	-0.32%
		NAAQS	1.82	1566.9	1561.3	-5.6	-0.36%	1558.7	1556.9	-1.7	-0.11%	1545.8	1550.9	5.1	0.33%	1566.92	1545.82	-1.35%	1561.29	1550.88	-0.67%
		Utility Based (Coal)	1.82	1563.8	1565.9	2.1	0.14%	1537.9	1548.1	10.1	0.66%	1530.2	1527.4	-2.8	-0.18%	1563.76	1530.22	-2.15%	1565.88	1527.41	-2.46%
		Utility Based High	1.82	1563.8	1565.9	2.1	0.14%	1529.7	1540.4	10.7	0.70%	1500.9	1500.9	0.0	0.00%	1563.76	1500.87	-4.02%	1565.88	1500.90	-4.15%
	P(l)	Clear Sky w/Hg	2.38	3583.9	3548.0	-35.9	-1.00%	3344.5	3357.3	12.7	0.38%	3186.4	3222.3	35.9	1.13%	3583.88	3186.37	-11.09%	3547.99	3222.31	-9.18%
	4	Clear Sky wo/Hg	2.38	3242.3	3287.2	44.8	1.38%	3132.0	3170.5	38.5	1.23%	3131.4	3148.7	17.3	0.55%	3242.34	3131.37	-3.42%	3287.16	3148.67	-4.21%
		NAAQS	2.38	3421.7	3384.7	-37.0	-1.08%	3150.1	3163.0	13.0	0.41%	3058.1	3043.1	-15.0	-0.49%	3421.66	3058.14	-10.62%	3384.67	3043.14	-10.09%
		Utility Based (Coal)	2.38	3466.3	3333.1	-133.2	-3.84%	3257.3	3297.6	40.3	1.24%	3129.7	3123.7	-6.0	-0.19%	3466.29	3129.73	-9.71%	3333.10	3123.69	-6.28%
		Utility Based High	2.38	3466.3	3333.1	-133.2	-3.84%	3235.1	3221.1	-14.0	-0.43%	3067.0	3032.4	-34.7	-1.13%	3466.29	3067.05	-11.52%	3333.10	3032.38	-9.02%
	FD(l)	Clear Sky w/Hg	2.37	3533.2	3486.0	-47.2	-1.34%	3275.3	3282.7	7.4	0.23%	3119.7	3144.7	25.0	0.80%	3533.17	3119.67	-11.70%	3485.97	3144.71	-9.79%
	6	Clear Sky wo/Hg	2.37	3104.7	3217.8	113.2	3.64%	3186.0	3171.4	-14.6	-0.46%	3000.7	2964.8	-35.9	-1.20%	3104.67	3000.69	-3.35%	3217.82	2964.81	-7.86%
		NAAQS	2.37	3331.3	3282.7	-48.7	-1.46%	3106.0	3088.2	-17.8	-0.57%	3040.3	2962.7	-77.6	-2.55%	3331.35	3040.31	-8.74%	3282.68	2962.68	-9.75%
		Utility Based (Coal)	2.37	3503.2	3245.3	-257.9	-7.36%	3163.2	3175.1	11.9	0.38%	3006.1	2968.9	-37.2	-1.24%	3503.22	3006.10	-14.19%	3245.29	2968.87	-8.52%
		Utility Based High	2.37	3503.2	3245.3	-257.9	-7.36%	3122.6	3144.5	22.0	0.70%	2920.7	2913.1	-7.6	-0.26%	3503.22	2920.73	-16.63%	3245.29	2913.09	-10.24%
	S(s)	Clear Sky w/Hg	2.38	1291.5	1288.7	-2.9	-0.22%	1207.0	1202.1	-4.9	-0.41%	1235.2	1230.3	-4.9	-0.39%	1291.55	1235.16	-4.37%	1288.66	1230.30	-4.53%
	7	Clear Sky wo/Hg	2.38	1191.9	1206.1	14.1	1.19%	1181.4	1172.8	-8.5	-0.72%	1157.0	1175.8	18.8	1.62%	1191.94	1157.05	-2.93%	1206.06	1175.83	-2.51%
		NAAQS	2.38	1200.6	1199.2	-1.4	-0.11%	1185.8	1190.2	4.3	0.37%	1201.8	1176.3	-25.5	-2.13%	1200.59	1201.84	0.10%	1199.23	1176.30	-1.91%
		Utility Based (Coal)	2.38	1213.5	1223.5	10.0	0.82%	1198.7	1208.1	9.4	0.79%	1188.4	1180.6	-7.8	-0.65%	1213.55	1188.38	-2.07%	1223.50	1180.60	-3.51%
		Utility Based High	2.38	1213.5	1223.5	10.0	0.82%	1166.9	1199.4	32.5	2.79%	1162.2	1156.1	-6.0	-0.52%	1213.55	1162.15	-4.23%	1223.50	1156.14	-5.51%
	S(l)	Clear Sky w/Hg	2.36	3656.6	3618.9	-37.7	-1.03%	3409.0	3396.8	-12.2	-0.36%	3317.2	3365.7	48.5	1.46%	3656.64	3317.16	-9.28%	3618.90	3365.69	-7.00%
	8	Clear Sky wo/Hg	2.36	3393.5	3344.8	-48.7	-1.43%	3275.0	3263.4	-11.5	-0.35%	3158.4	3179.4	21.0	0.67%	3393.49	3158.39	-6.93%	3344.83	3179.42	-4.95%
		NAAQS	2.36	3447.2	3448.8	1.6	0.05%	3260.2	3257.2	-3.1	-0.09%	3175.8	3167.4	-8.5	-0.27%	3447.22	3175.83	-7.87%	3448.82	3167.35	-8.16%
		Utility Based (Coal)	2.36	3454.0	3454.6	0.6	0.02%	3395.6	3438.9	43.3	1.27%	3226.1	3211.5	-14.6	-0.45%	3453.98	3226.11	-6.60%	3454.57	3211.48	-7.04%
		Utility Based High	2.36	3454.0	3454.6	0.6	0.02%	3305.4	3366.5	61.1	1.85%	3259.0	3121.8	-137.1	-4.21%	3453.98	3258.96	-5.65%	3454.57	3121.82	-9.63%
	SB(s)	Clear Sky w/Hg	7.51	84.2	81.0	-3.2	-3.77%	74.3	73.3	-1.0	-1.35%	71.2	72.3	1.1	1.57%	84.19	71.15	-15.48%	81.01	72.27	-10.79%
	14	Clear Sky wo/Hg	7.51	69.3	65.6	-3.7	-5.31%	64.3	63.3	-1.0	-1.61%	58.3	57.7	-0.6	-0.98%	69.28	58.29	-15.86%	65.60	57.72	-12.01%
		NAAQS	7.51	71.8	73.2	1.4	1.88%	60.1	61.6	1.5	2.49%	56.4	57.2	0.8	1.39%	71.83	56.40	-21.47%	73.18	57.19	-21.85%
		Utility Based (Coal)	7.51	83.1	78.5	-4.7	-5.61%	69.4	68.9	-0.5	-0.78%	65.7	65.6	-0.1	-0.11%	83.12	65.66	-21.00%	78.46	65.58	-16.41%
		Utility Based High	7.51	83.1	78.5	-4.7	-5.61%	68.7	66.8	-1.9	-2.76%	58.6	62.7	4.1	6.97%	83.12	58.61	-29.48%	78.46	62.70	-20.08%

TABLE 12
Hannibal Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Hannibal	ES(s)	Clear Sky w/Hg	5.11	1694.7	1696.1	1.3	0.08%	1661.7	1665.8	4.2	0.25%	1648.1	1645.2	-2.9	-0.18%	1694.73	1648.14	-2.75%	1696.06	1645.21	-3.00%
	1	Clear Sky wo/Hg	5.11	1634.3	1663.3	29.0	1.78%	1635.6	1634.6	-1.0	-0.06%	1610.4	1619.9	9.5	0.59%	1634.28	1610.39	-1.46%	1663.31	1619.88	-2.61%
		NAAQS	5.11	1670.1	1665.6	-4.5	-0.27%	1619.7	1619.8	0.1	0.01%	1615.7	1625.3	9.6	0.59%	1670.11	1615.66	-3.26%	1665.63	1625.27	-2.42%
		Utility Based (Coal)	5.11	1690.7	1644.6	-46.1	-2.73%	1636.8	1636.7	-0.1	0.00%	1615.6	1621.8	6.1	0.38%	1690.71	1615.65	-4.44%	1644.58	1621.78	-1.39%
		Utility Based High	5.11	1690.7	1644.6	-46.1	-2.73%	1624.3	1624.8	0.5	0.03%	1612.4	1598.7	-13.7	-0.85%	1690.71	1612.39	-4.63%	1644.58	1598.69	-2.79%
	ES(f)	Clear Sky w/Hg	7.74	1449.9	1458.1	8.2	0.56%	1397.1	1399.6	2.5	0.18%	1380.2	1379.1	-1.1	-0.08%	1449.86	1380.22	-4.80%	1458.05	1379.14	-5.41%
	2	Clear Sky wo/Hg	7.74	1379.7	1409.7	30.0	2.17%	1359.2	1356.1	-3.1	-0.23%	1314.8	1307.4	-7.3	-0.56%	1379.74	1314.76	-4.71%	1409.71	1307.41	-7.26%
		NAAQS	7.74	1400.9	1395.6	-5.2	-0.37%	1336.4	1335.0	-1.4	-0.11%	1314.4	1308.3	-6.1	-0.46%	1400.86	1314.36	-6.17%	1395.63	1308.28	-6.26%
		Utility Based (Coal)	7.74	1440.8	1389.0	-51.8	-3.60%	1379.3	1377.6	-1.7	-0.12%	1330.1	1326.3	-3.8	-0.28%	1440.81	1330.07	-7.69%	1388.99	1326.31	-4.51%
		Utility Based High	7.74	1440.8	1389.0	-51.8	-3.60%	1341.8	1335.9	-5.9	-0.44%	1311.8	1307.4	-4.3	-0.33%	1440.81	1311.78	-8.96%	1388.99	1307.44	-5.87%
	P(s)	Clear Sky w/Hg	2.49	2255.7	2217.2	-38.5	-1.71%	2177.3	2175.9	-1.4	-0.06%	2190.3	2188.0	-2.3	-0.11%	2255.72	2190.34	-2.90%	2217.18	2188.01	-1.32%
	3	Clear Sky wo/Hg	2.49	2166.9	2185.6	18.7	0.86%	2163.7	2157.9	-5.8	-0.27%	2139.7	2151.5	11.8	0.55%	2166.91	2139.72	-1.25%	2185.60	2151.48	-1.56%
		NAAQS	2.49	2183.6	2176.6	-7.1	-0.32%	2180.6	2170.2	-10.4	-0.48%	2142.6	2149.8	7.2	0.34%	2183.64	2142.63	-1.88%	2176.59	2149.83	-1.23%
		Utility Based (Coal)	2.49	2176.5	2200.0	23.5	1.08%	2159.5	2155.1	-4.4	-0.20%	2150.1	2147.7	-2.4	-0.11%	2176.47	2150.15	-1.21%	2199.98	2147.72	-2.38%
		Utility Based High	2.49	2176.5	2200.0	23.5	1.08%	2149.1	2151.7	2.6	0.12%	2133.2	2143.7	10.5	0.49%	2176.47	2133.20	-1.99%	2199.98	2143.72	-2.56%
	P(l)	Clear Sky w/Hg	3.15	4522.0	4434.0	-88.0	-1.95%	4219.8	4227.3	7.5	0.18%	4066.4	4095.5	29.0	0.71%	4521.98	4066.45	-10.07%	4433.96	4095.49	-7.63%
	4	Clear Sky wo/Hg	3.15	4073.0	4166.5	93.4	2.29%	3963.7	3981.0	17.3	0.44%	3881.8	3866.0	-15.8	-0.41%	4073.03	3881.76	-4.70%	4166.46	3865.97	-7.21%
		NAAQS	3.15	4219.4	4185.7	-33.7	-0.80%	4012.4	4009.8	-2.6	-0.06%	3845.2	3845.1	-0.2	0.00%	4219.40	3845.22	-8.87%	4185.73	3845.05	-8.14%
		Utility Based (Coal)	3.15	4383.9	4219.1	-164.8	-3.76%	4132.8	4167.7	34.9	0.84%	3957.3	3911.3	-46.0	-1.16%	4383.92	3957.31	-9.73%	4219.15	3911.33	-7.30%
		Utility Based High	3.15	4383.9	4219.1	-164.8	-3.76%	4009.3	3997.5	-11.8	-0.30%	3820.5	3770.4	-50.1	-1.31%	4383.92	3820.50	-12.85%	4219.15	3770.38	-10.64%
	FD(l)	Clear Sky w/Hg	3.15	4431.1	4403.0	-28.1	-0.63%	4115.8	4127.1	11.4	0.28%	3952.2	3957.7	5.5	0.14%	4431.07	3952.19	-10.81%	4402.98	3957.70	-10.11%
	6	Clear Sky wo/Hg	3.15	3978.6	4122.2	143.6	3.61%	3941.1	3962.9	21.8	0.55%	3713.4	3660.9	-52.5	-1.41%	3978.62	3713.42	-6.67%	4122.21	3660.90	-11.19%
		NAAQS	3.15	4114.5	4102.5	-12.1	-0.29%	3856.6	3839.7	-16.9	-0.44%	3746.5	3720.1	-26.4	-0.71%	4114.53	3746.51	-8.94%	4102.47	3720.07	-9.32%
		Utility Based (Coal)	3.15	4342.5	4106.6	-235.9	-5.43%	3987.2	4009.1	21.9	0.55%	3777.8	3726.2	-51.6	-1.36%	4342.52	3777.79	-13.00%	4106.63	3726.24	-9.26%
		Utility Based High	3.15	4342.5	4106.6	-235.9	-5.43%	3867.5	3841.4	-26.1	-0.67%	3656.7	3649.4	-7.2	-0.20%	4342.52	3656.65	-15.79%	4106.63	3649.41	-11.13%
	S(s)	Clear Sky w/Hg	3.03	1566.7	1564.4	-2.3	-0.15%	1510.3	1507.0	-3.3	-0.22%	1511.9	1510.7	-1.3	-0.08%	1566.74	1511.93	-3.50%	1564.41	1510.68	-3.43%
	7	Clear Sky wo/Hg	3.03	1484.7	1504.2	19.5	1.31%	1480.2	1482.0	1.9	0.13%	1456.9	1448.4	-8.5	-0.59%	1484.75	1456.95	-1.87%	1504.23	1448.42	-3.71%
		NAAQS	3.03	1497.4	1500.7	3.2	0.22%	1491.7	1488.5	-3.2	-0.21%	1486.3	1464.0	-22.4	-1.50%	1497.44	1486.34	-0.74%	1500.69	1463.97	-2.45%
		Utility Based (Coal)	3.03	1531.9	1540.5	8.6	0.56%	1504.3	1498.6	-5.7	-0.38%	1472.7	1466.3	-6.3	-0.43%	1531.87	1472.65	-3.87%	1540.50	1466.33	-4.81%
		Utility Based High	3.03	1531.9	1540.5	8.6	0.56%	1453.5	1476.2	22.7	1.56%	1469.5	1477.5	8.0	0.55%	1531.87	1469.51	-4.07%	1540.50	1477.54	-4.09%
	S(l)	Clear Sky w/Hg	3.14	4609.2	4472.4	-136.7	-2.97%	4343.2	4335.5	-7.8	-0.18%	4236.5	4285.6	49.1	1.16%	4609.18	4236.50	-8.09%	4472.44	4285.57	-4.18%
	8	Clear Sky wo/Hg	3.14	4273.0	4244.7	-28.4	-0.66%	4132.2	4102.3	-29.9	-0.72%	3932.7	3961.4	28.7	0.73%	4273.04	3932.67	-7.97%	4244.68	3961.37	-6.67%
		NAAQS	3.14	4265.8	4265.9	0.1	0.00%	4125.5	4101.7	-23.7	-0.58%	3931.2	3924.0	-7.2	-0.18%	4265.80	3931.20	-7.84%	4265.94	3924.04	-8.01%
		Utility Based (Coal)	3.14	4363.8	4395.9	32.1	0.73%	4245.9	4305.3	59.3	1.40%	4058.2	4036.3	-21.8	-0.54%	4363.80	4058.15	-7.00%	4395.87	4036.32	-8.18%
		Utility Based High	3.14	4363.8	4395.9	32.1	0.73%	4144.3	4187.0	42.6	1.03%	3981.4	3926.1	-55.3	-1.39%	4363.80	3981.41	-8.76%	4395.87	3926.14	-10.69%
	SB(s)	Clear Sky w/Hg	8.62	114.9	113.5	-1.5	-1.28%	108.9	110.1	1.2	1.11%	109.2	109.9	0.7	0.64%	114.92	109.20	-4.97%	113.45	109.90	-3.13%
	14	Clear Sky wo/Hg	8.62	108.9	105.0	-3.9	-3.57%	101.7	100.0	-1.7	-1.67%	98.2	97.8	-0.4	-0.38%	108.87	98.22	-9.78%	104.98	97.85	-6.79%
		NAAQS	8.62	105.0	105.2	0.2	0.22%	98.7	100.7	2.0	1.99%	96.4	96.5	0.1	0.13%	105.00	96.38	-8.21%	105.23	96.51	-8.29%
		Utility Based (Coal)	8.62	115.8	112.5	-3.3	-2.84%	105.9	107.4	1.5	1.40%	101.3	100.7	-0.6	-0.58%	115.81	101.27	-12.56%	112.52	100.68	-10.52%
		Utility Based High	8.62	115.8	112.5	-3.3	-2.84%	103.0	103.0	0.0	0.00%	94.9	98.3	3.4	3.58%	115.81	94.87	-18.08%	112.52	98.27	-12.67%

TABLE 13
Willow Island Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010 Without Project HSI Units	2010 With Project HSI Units	2010 Delta	2010 % Delta	2040 Without Project HSI Units	2040 With Project HSI Units	2040 Delta	2040 % Delta	2070 Without Project HSI Units	2070 With Project HSI Units	2070 Delta	2070 % Delta	2010-2070 Without Project 2010	2010-2070 Without Project 2070	2010-2070 % Delta	2010-2070 With Project 2010	2010-2070 With Project 2070	2010-2070 % Delta
Willow Island	ES(s)	Clear Sky w/Hg	5.072029	1377.41273	1377.41273	0.0	0.00%	1363.43827	1371.88983	8.5	0.62%	1326.31173	1329.9217	3.6	0.27%	1377.41	1326.31	-3.71%	1377.41	1329.92	-3.45%
	1	Clear Sky wo/Hg	5.072029	1353.8357	1353.8357	0.0	0.00%	1307.80247	1319.18483	11.4	0.87%	1295.7115	1280.40723	-15.3	-1.18%	1353.84	1295.71	-4.29%	1353.84	1280.41	-5.42%
		NAAQS	5.072029	1340.6041	1340.6041	0.0	0.00%	1298.58427	1302.4077	3.8	0.29%	1279.3067	1300.05057	20.7	1.62%	1340.60	1279.31	-4.57%	1340.60	1300.05	-3.03%
		Utility Based (Coal)	5.072029	1329.2633	1329.2633	0.0	0.00%	1328.84947	1335.43123	6.6	0.50%	1305.33903	1292.59883	-12.7	-0.98%	1329.26	1305.34	-1.80%	1329.26	1292.60	-2.76%
		Utility Based High	5.072029	1329.2633	1329.2633	0.0	0.00%	1297.0056	1303.27813	6.3	0.48%	1282.22953	1273.55447	-8.7	-0.68%	1329.26	1282.23	-3.54%	1329.26	1273.55	-4.19%
	ES(f)	Clear Sky w/Hg	7.046262	1232.33353	1248.21357	15.9	1.29%	1199.0941	1203.66173	4.6	0.38%	1170.41833	1172.93843	2.5	0.22%	1232.33	1170.42	-5.02%	1248.21	1172.94	-6.03%
	2	Clear Sky wo/Hg	7.046262	1190.78193	1218.94407	28.2	2.37%	1154.07897	1154.5206	0.4	0.04%	1110.9291	1102.2541	-8.7	-0.78%	1190.78	1110.93	-6.71%	1218.94	1102.25	-9.57%
		NAAQS	7.046262	1183.97077	1182.50123	-1.5	-0.12%	1129.7271	1127.77477	-2.0	-0.17%	1102.27207	1098.6512	-3.6	-0.33%	1183.97	1102.27	-6.90%	1182.50	1098.65	-7.09%
		Utility Based (Coal)	7.046262	1240.49127	1183.80923	-56.7	-4.57%	1191.11053	1197.34027	6.2	0.52%	1139.65463	1126.61913	-13.0	-1.14%	1240.49	1139.65	-8.13%	1183.81	1126.62	-4.83%
		Utility Based High	7.046262	1240.49127	1183.80923	-56.7	-4.57%	1146.8465	1147.73453	0.9	0.08%	1110.86907	1107.9996	-2.9	-0.26%	1240.49	1110.87	-10.45%	1183.81	1108.00	-6.40%
	P(s)	Clear Sky w/Hg	2.291467	2037.9545	1996.2875	-41.7	-2.04%	1987.96425	1981.8255	-6.1	-0.31%	1987.506	1986.728	-0.8	-0.04%	2037.95	1987.51	-2.48%	1996.29	1986.73	-0.48%
	3	Clear Sky wo/Hg	2.291467	1947.61775	1966.9345	19.3	0.99%	1951.535	1954.3625	2.8	0.14%	1928.47775	1957.74725	29.3	1.52%	1947.62	1928.48	-0.98%	1966.93	1957.75	-0.47%
		NAAQS	2.291467	1969.404	1980.4995	11.1	0.56%	1975.23975	1965.1785	-10.1	-0.51%	1943.168	1943.3795	0.2	0.01%	1969.40	1943.17	-1.33%	1980.50	1943.38	-1.87%
		Utility Based (Coal)	2.291467	1954.55075	1980.65975	26.1	1.34%	1933.7845	1944.54175	10.8	0.56%	1930.433	1923.7395	-6.7	-0.35%	1954.55	1930.43	-1.23%	1980.66	1923.74	-2.87%
		Utility Based High	2.291467	1954.55075	1980.65975	26.1	1.34%	1932.87525	1925.81125	-7.1	-0.37%	1919.93025	1920.57675	0.6	0.03%	1954.55	1919.93	-1.77%	1980.66	1920.58	-3.03%
	P(l)	Clear Sky w/Hg	2.728571	3740.7072	3684.0658	-56.6	-1.51%	3550.7846	3560.3462	9.6	0.27%	3443.7322	3472.2996	28.6	0.83%	3740.71	3443.73	-7.94%	3684.07	3472.30	-5.75%
	4	Clear Sky wo/Hg	2.728571	3432.462	3475.2578	42.8	1.25%	3314.2594	3342.829	28.6	0.86%	3210.7452	3196.1912	-14.6	-0.45%	3432.46	3210.75	-6.46%	3475.26	3196.19	-8.03%
		NAAQS	2.728571	3481.214	3445.6014	-35.6	-1.02%	3336.6776	3332.0314	-4.6	-0.14%	3186.1858	3228.26	42.1	1.32%	3481.21	3186.19	-8.47%	3445.60	3228.26	-6.31%
		Utility Based (Coal)	2.728571	3683.9778	3544.0632	-139.9	-3.80%	3498.6728	3532.4884	33.8	0.97%	3314.759	3281.7012	-33.1	-1.00%	3683.98	3314.76	-10.02%	3544.06	3281.70	-7.40%
		Utility Based High	2.728571	3683.9778	3544.0632	-139.9	-3.80%	3344.804	3341.4048	-3.4	-0.10%	3210.277	3182.6354	-27.6	-0.86%	3683.98	3210.28	-12.86%	3544.06	3182.64	-10.20%
	FD(a)	Clear Sky w/Hg		2967.564	2967.968	0.4	0.01%	2964.4715	2965.91625	1.4	0.05%	2961.78575	2962.16925	0.4	0.01%	2967.56	2961.79	-0.19%	2967.97	2962.17	-0.20%
	5	Clear Sky wo/Hg		2962.123	2960.07325	-2.0	-0.07%	2958.56425	2959.88725	1.3	0.04%	2955.01175	2954.1915	-0.8	-0.03%	2962.12	2955.01	-0.24%	2960.07	2954.19	-0.20%
		NAAQS		2962.3805	2963.001	0.6	0.02%	2961.13275	2960.55025	-0.6	-0.02%	2954.923	2957.20625	2.3	0.08%	2962.38	2954.92	-0.25%	2963.00	2957.21	-0.20%
		Utility Based (Coal)		2959.71075	2963.51175	3.8	0.13%	2961.7	2961.10475	-0.6	-0.02%	2956.43625	2956.81925	0.4	0.01%	2959.71	2956.44	-0.11%	2963.51	2956.82	-0.23%
		Utility Based High		2959.71075	2963.51175	3.8	0.13%	2958.94675	2960.46525	1.5	0.05%	2950.4755	2952.849	2.4	0.08%	2959.71	2950.48	-0.31%	2963.51	2952.85	-0.36%
	FD(l)	Clear Sky w/Hg	2.733197	3675.2	3695.00167	19.8	0.54%	3509.70267	3535.55933	25.9	0.74%	3348.78567	3375.91633	27.1	0.81%	3675.20	3348.79	-8.88%	3695.00	3375.92	-8.64%
	6	Clear Sky wo/Hg	2.733197	3467.77433	3580.72433	113.0	3.26%	3316.909	3344.66867	27.8	0.84%	3146.14633	3098.51633	-47.6	-1.51%	3467.77	3146.15	-9.27%	3580.72	3098.52	-13.47%
		NAAQS	2.733197	3425.49733	3430.84367	5.3	0.16%	3218.962	3205.471	-13.5	-0.42%	3084.31533	3106.52467	22.2	0.72%	3425.50	3084.32	-9.96%	3430.84	3106.52	-9.45%
		Utility Based (Coal)	2.733197	3680.15367	3477.50133	-202.7	-5.51%	3460.22967	3520.96567	60.7	1.76%	3242.7	3173.381	-69.3	-2.14%	3680.15	3242.70	-11.89%	3477.50	3173.38	-8.75%
		Utility Based High	2.733197	3680.15367	3477.50133	-202.7	-5.51%	3293.11867	3295.157	2.0	0.06%	3104.06067	3104.48033	0.4	0.01%	3680.15	3104.06	-15.65%	3477.50	3104.48	-10.73%
	S(s)	Clear Sky w/Hg	2.868303	1292.25933	1289.26733	-3.0	-0.23%	1273.38667	1263.24133	-10.1	-0.80%	1243.24	1242.997	-0.2	-0.02%	1292.26	1243.24	-3.79%	1289.27	1243.00	-3.59%
	7	Clear Sky wo/Hg	2.868303	1198.127	1209.42367	11.3	0.94%	1216.04133	1202.37567	-13.7	-1.12%	1189.46567	1201.63867	12.2	1.02%	1198.13	1189.47	-0.72%	1209.42	1201.64	-0.64%
		NAAQS	2.868303	1263.62867	1244.219	-19.4	-1.54%	1205.63833	1209.71633	4.1	0.34%	1210.53367	1192.72267	-17.8	-1.47%	1263.63	1210.53	-4.20%	1244.22	1192.72	-4.14%
		Utility Based (Coal)	2.868303	1259.17833	1274.95233	15.8	1.25%	1219.62267	1244.15467	24.5	2.01%	1212.42467	1182.18747	-30.2	-2.49%	1259.18	1212.42	-3.71%	1274.95	1182.19	-7.28%
		Utility Based High	2.868303	1259.17833	1274.95233	15.8	1.25%	1208.818	1221.13833	12.3	1.02%	1187.47833	1190.478	3.0	0.25%	1259.18	1187.48	-5.69%	1274.95	1190.48	-6.63%
	S(l)	Clear Sky w/Hg	2.705963	3757.67583	3642.53517	-115.1	-3.06%	3669.6125	3662.30017	-7.3	-0.20%	3588.76917	3631.7595	43.0	1.20%	3757.68	3588.77	-4.49%	3642.54	3631.76	-0.30%
	8	Clear Sky wo/Hg	2.705963	3520.1465	3499.18483	-21.0	-0.60%	3407.52283	3396.085	-11.4	-0.34%	3208.44233	3235.9365	27.5	0.86%	3520.15	3208.44	-8.85%	3499.18	3235.94	-7.52%
		NAAQS	2.705963	3508.031	3503.05783	-5.0	-0.14%	3399.97283	3373.84117	-26.1	-0.77%	3196.6875	3207.096	10.4	0.33%	3508.03	3196.69	-8.88%	3503.06	3207.10	-8.45%
		Utility Based (Coal)	2.705963	3609.3725	3647.8155	38.4	1.07%	3546.93133	3578.503	31.6	0.89%	3369.55283	3342.04083	-27.5	-0.82%	3609.37	3369.55	-6.64%	3647.82	3342.04	-8.38%
		Utility Based High	2.705963	3609.3725	3647.8155	38.4	1.07%	3442.05467	3451.637	9.6	0.28%	3308.276	3239.671	-68.6	-2.07%	3609.37	3308.28	-8.34%	3647.82	3239.67	-11.19%
	CC(y)	Clear Sky w/Hg		318.3972	318.6243	0.2	0.07%	318.382033	318.3957	0.0	0.00%	318.532133	318.368733	-0.2	-0.05%	318.40	318.53	0.04%	318.62	318.37	-0.08%
	9	Clear Sky wo/Hg		318.2629	318.4496	0.2	0.06%	318.2963	318.411933	0.1	0.04%	318.210133	318.3391	0.1	0.04%	318.26	318.21	-0.02%	318.45	318.34	-0.03%
		NAAQS		318.5031	318.462933	0.0	-0.01%	318.436133	318.461333	0.0	0.01%	318.266033	318.299467	0.0	0.01%	318.50	318.27	-0.07%	318.46	318.30	-0.05%
		Utility Based (Coal)		318.278733	318.353267	0.1	0.02%	318.123567	318.431367	0.3	0.10%	318.419067	318.4187	0.0	0.00%	318.28	318.42	0.04%	318.35	318.42	0.02%
		Utility Based High		318.278733	318.353267	0.1	0.02%	318.432267	318.525367	0.1	0.03%	318.459667	318.4118	0.0	-0.02%	318.28	318.46	0.06%	318.35	318.41	0.02%
	BC(s)	Clear Sky w/Hg		109.017083	110.037323	1.0	0.94%	112.239787	112.791807	0.6	0.49%	110.78592	110.64747	-0.1	-0.12%	109.02	110.79	1.62%	110.04	110.65	0.55%
	10	Clear Sky wo/Hg		109.9796	109.784663	-0.2	-0.18%	111.298823	109.993793	-1.3	-1.17%	110.806483	109.511647	-1.3	-1.17%	109.98	110.81	0.75%	109.78	109.51	-0.25%
		NAAQS		108.69907	109.25396	0.6	0.51%	109.44109	109.869907	0.4	0.39%	110.919983	109.379573	-1.5	-1.39%	108.70	110.92	2.04%	109.25	109.38	0.11%
		Utility Based (Coal)		110.42978	110.24152	-0.2	-0.17%	108.811203	110.13534	1.3	1.22%	109.989473	109.98512	0.0	0.00%	110.43	109.99	-0.40%	110.24	109.99	-0.23%
		Utility Based High		110.42978	110.24152	-0.2	-0.17%	109.305517	109.623423	0.3	0.29%	108.461393	109.43257	1.0	0.90%	110.43	108.46	-1.78%	110.24	109.43	-0.73%
	BC(f)	Clear Sky w/Hg		304.437267	304.5269	0.1	0.03%	305.0082	305.0595	0.1	0.02%	304.6754	304.6832	0.0	0.00%	304.44	304.68	0.08%	304.53	304.68	0.05%
	11	Clear Sky wo/Hg		304.597267	304.515967	-0.1	-0.03%	304.745333	304.388267	-0.4	-0.12%	304.5842	304.338233	-0.2	-0.08%	304.60	304.58	0.00%	304.52	304.34	-0.06%
		NAAQS		304.327233	304.349133	0.0	0.01%	304.403333	304.459067	0.1	0.02%	304.617167	304.3468	-0.3	-0.09%	304.33	304.62	0.10%	304.35	304.35	0.00%
		Utility Based (Coal)		304.652533	304.6427	0.0	0.00%	304.3471	304.627633	0.3	0.09%	304.4053	304.520133	0.1	0.04%	304.65	304.41	-0.08%	304.64	304.52	-0.04%
		Utility Based High		304.652533	304.6427	0.0	0.00%	304.381067	304.476367	0.1	0.03%	304.128033	304.406967	0.3	0.09%	304.65	304.13	-0.17%	304.64	304.41	-0.08%
	BC(j)	Clear Sky w/Hg		1978.37834	1979.34706	1.0	0.05%	1978.56072	1978.46668	-0.1	0.00%	1978.19154	1977.52174	-0.7	-0.03%	1978.38	1978.19	-0.01%	1979.35	1977.52	-0.09%
	12	Clear Sky wo/Hg		1977.94958	1977.25974	-0.7	-0.03%	1975.68958	1976.26674	0.6	0.03%	1974.96836	1975.66974	0.7	0.04%	1977.95	1974.97	-0.15%	1977.26	1975.67	-0.08%
		NAAQS		1977.88822	1979.02126	1.1	0.06%	1977.5385	1977.42802	-0.1	-0.01%	1975.8883	1976.003	0.1	0.01%	1977.89	1975.89	-0.10%	1979.02	1976.00	-0.15%
		Utility Based (Coal)		1977.74856	1977.17882	-0.6	-0.03%	1976.98006	1976.78136	-0.2	-0.01%	1975.69786	1976.55366	0.9	0.04%	1977.75	1975.70	-0.10%	1977.18	1976.55	-0.03%
		Utility Based High		1977.74856	1977.17882	-0.6	-0.03%	1978.10018	1977.34702	-0.8	-0.04%	1974.9645	1974.9672	0.0	0.00%	1977.75	1974.96	-0.14%	1977.18	1974.97	-0.11%
	BC(a)	Clear Sky w/Hg		1829.61307	1829.84445	0.2	0.01%	1829.00255	1829.25337	0.3	0.01%	1828.29252	1828.47565	0.2	0.01%	1829.61	1828.29	-0.07%	1829.84	1828.48	-0.07%
	13	Clear Sky wo/Hg		1828.23602	1828.35923	0.1	0.01%	1827.5811	1827.41197	-0.2	-0.01%	1826.74565	1826.45892	-0.3	-0.02%	1828.24	1826.75	-0.08%	1828.36	1826.46	-0.10%
		NAAQS		1828.3729	1828.17485	-0.2	-0.01%	1827.59188	1827.42725	-0.2	-0.01%	1826.10945	1826.35238	0.2	0.01%	1828.37	1826.11	-0.12%	1828.17	1826.35	-0.10%
		Utility Based (Coal)		1828.00037	1828.338	0.3	0.02%	1827.84922	1828.07638	0.2	0.01%	1826.85365	1826.48707	-0.4	-0.02%	1828.00	1826.85	-0.06%	1828.34	1826.49	-0.10%
		Utility Based High		1828.00037	1828.338	0.3	0.02%	1827.27767	1827.6251	0.3	0.02%	1826.85303	1826.37262	-0.5	-0.03%	1828.00	1826.85	-0.06%	1828.34	1826.37	-0.11%
	SB(s)	Clear Sky w/Hg	6.077946	34.2223333	36.01089	1.8	5.23%	32.0324533	33.35716	1.3	4.14%	34.8408467	35.4975633	0.7	1.88%	34.22	34.84	1.81%	36.01	35.50	-1.43%
	14	Clear Sky wo/Hg	6.077946	31.8434233	32.3885267	0.5	1.71%	25.7767433	26.2941967	0.5	2.01%	25.2027533	24.905705	-0.3	-1.18%	31.84	25.20	-20.85%	32.39	24.91	-23.10%
		NAAQS	6.077946	29.6040467	29.72807	0.1	0.42%	26.1766103	26.034742	-0.1	-0.54%	24.189594	25.0473643	0.9	3.55%	29.60	24.19	-18.29%	29.73	25.05	-15.75%
		Utility Based (Coal)	6.077946	39.8532033	38.54513	-1.3	-3.28%	32.5347533	33.4475767	0.9	2.81%	28.37287	27.1688767	-1.2	-4.24%	39.85	28.37	-28.81%	38.55	27.17	-29.51%
		Utility Based High	6.077946	39.8532033	38.54513	-1.3	-3.28%	31.5494167	31.07214	-0.5	-1.51%	24.4188583	25.944797	1.5	6.25%	39.85	24.42	-38.73%	38.55	25.94	-32.69%
	SB(j)	Clear Sky w/Hg		578.163917	578.175517	0.0	0.00%	578.183617	578.155967	0.0	0.00%	578.080383	578.09345	0.0	0.00%	578.16	578.08	-0.01%	578.18	578.09	-0.01%
	15	Clear Sky wo/Hg		578.046867	577.923433	-0.1	-0.02%	577.996717	577.8625	-0.1	-0.02%	577.71015	577.6673	0.0	-0.01%	578.05	577.71	-0.06%	577.92	577.67	-0.04%
		NAAQS		577.880283	578.039767	0.2	0.03%	578.00675	578.094667	0.1	0.02%	577.782733	577.79485	0.0	0.00%	577.88	577.78	-0.02%	578.04	577.79	-0.04%
		Utility Based (Coal)		578.02335	578.064933	0.0	0.01%	577.843417	577.938117	0.1	0.02%	577.9916	578.063933	0.1	0.01%	578.02	577.99	-0.01%	578.06	578.06	0.00%
		Utility Based High		578.02335	578.064933	0.0	0.01%	577.880667	577.938167	0.1	0.01%	577.7473	577.899217	0.2	0.03%	578.02	577.75	-0.05%	578.06	577.90	-0.03%

TABLE 14
Belleville Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Belleville	ES(s)	Clear Sky w/Hg	4.46	1407.7	1406.3	-1.4	-0.10%	1404.0	1409.1	5.1	0.36%	1375.2	1376.7	1.5	0.11%	1407.73	1375.23	-2.31%	1406.30	1376.74	-2.10%
	1	Clear Sky wo/Hg	4.46	1379.2	1396.0	16.8	1.22%	1354.8	1364.2	9.4	0.69%	1341.3	1345.5	4.2	0.31%	1379.18	1341.31	-2.75%	1396.01	1345.46	-3.62%
		NAAQS	4.46	1389.6	1386.3	-3.3	-0.24%	1367.0	1365.6	-1.4	-0.10%	1342.4	1355.4	13.0	0.97%	1389.61	1342.40	-3.40%	1386.32	1355.41	-2.23%
		Utility Based (Coal)	4.46	1419.6	1382.4	-37.2	-2.62%	1375.4	1382.2	6.8	0.49%	1362.0	1356.3	-5.7	-0.42%	1419.58	1361.98	-4.06%	1382.35	1356.32	-1.88%
		Utility Based High	4.46	1419.6	1382.4	-37.2	-2.62%	1362.0	1364.7	2.7	0.20%	1351.8	1348.5	-3.4	-0.25%	1419.58	1351.85	-4.77%	1382.35	1348.49	-2.45%
	ES(f)	Clear Sky w/Hg	5.39	1030.9	1036.0	5.2	0.50%	1012.8	1019.4	6.5	0.65%	999.0	997.0	-2.0	-0.20%	1030.87	998.99	-3.09%	1036.05	997.00	-3.77%
	2	Clear Sky wo/Hg	5.39	998.1	1019.4	21.2	2.13%	983.6	988.2	4.6	0.47%	953.1	954.0	0.9	0.10%	998.13	953.06	-4.52%	1019.35	953.97	-6.41%
		NAAQS	5.39	1010.8	1003.5	-7.3	-0.72%	977.2	977.9	0.7	0.07%	953.4	953.0	-0.4	-0.04%	1010.78	953.43	-5.67%	1003.46	953.01	-5.03%
		Utility Based (Coal)	5.39	1038.2	1000.2	-37.9	-3.66%	998.1	1009.0	10.8	1.09%	975.1	971.0	-4.1	-0.42%	1038.19	975.07	-6.08%	1000.24	970.96	-2.93%
		Utility Based High	5.39	1038.2	1000.2	-37.9	-3.66%	977.2	977.2	0.1	0.01%	964.2	965.1	0.9	0.10%	1038.19	964.20	-7.13%	1000.24	965.13	-3.51%
	P(s)	Clear Sky w/Hg	2.95	2651.2	2600.7	-50.6	-1.91%	2599.4	2592.5	-7.0	-0.27%	2594.7	2592.4	-2.4	-0.09%	2651.24	2594.73	-2.13%	2600.68	2592.36	-0.32%
	3	Clear Sky wo/Hg	2.95	2555.2	2566.6	11.4	0.45%	2561.8	2554.5	-7.3	-0.29%	2529.8	2554.7	24.9	0.99%	2555.24	2529.77	-1.00%	2566.62	2554.69	-0.46%
		NAAQS	2.95	2574.5	2587.6	13.1	0.51%	2580.1	2566.1	-14.0	-0.54%	2546.4	2557.5	11.1	0.43%	2574.47	2546.43	-1.09%	2587.56	2557.48	-1.16%
		Utility Based (Coal)	2.95	2584.8	2596.7	11.9	0.46%	2547.8	2558.1	10.2	0.40%	2541.2	2542.6	1.4	0.05%	2584.79	2541.22	-1.69%	2596.71	2542.60	-2.08%
		Utility Based High	2.95	2584.8	2596.7	11.9	0.46%	2547.1	2550.3	3.2	0.13%	2536.2	2527.5	-8.7	-0.34%	2584.79	2536.22	-1.88%	2596.71	2527.50	-2.67%
	P(l)	Clear Sky w/Hg	3.42	4945.8	4876.7	-69.2	-1.40%	4691.4	4701.6	10.2	0.22%	4622.4	4651.8	29.4	0.64%	4945.85	4622.38	-6.54%	4876.66	4651.81	-4.61%
	4	Clear Sky wo/Hg	3.42	4557.1	4601.3	44.2	0.97%	4465.1	4501.0	36.0	0.81%	4303.1	4282.0	-21.2	-0.49%	4557.15	4303.14	-5.57%	4601.34	4281.98	-6.94%
		NAAQS	3.42	4631.9	4567.3	-64.6	-1.39%	4458.2	4449.1	-9.0	-0.20%	4277.1	4337.4	60.3	1.41%	4631.88	4277.07	-7.66%	4567.29	4337.37	-5.03%
		Utility Based (Coal)	3.42	4896.8	4665.0	-231.8	-4.73%	4578.0	4662.9	84.9	1.86%	4461.3	4417.1	-44.2	-0.99%	4896.80	4461.31	-8.89%	4664.96	4417.09	-5.31%
		Utility Based High	3.42	4896.8	4665.0	-231.8	-4.73%	4492.4	4481.2	-11.3	-0.25%	4322.3	4332.0	9.7	0.22%	4896.80	4322.29	-11.73%	4664.96	4331.98	-7.14%
	FD(l)	Clear Sky w/Hg	3.42	4807.4	4815.4	8.1	0.17%	4630.8	4689.0	58.2	1.26%	4489.3	4484.0	-5.3	-0.12%	4807.36	4489.29	-6.62%	4815.43	4483.96	-6.88%
	6	Clear Sky wo/Hg	3.42	4522.1	4680.5	158.5	3.50%	4403.8	4470.7	66.9	1.52%	4185.2	4153.9	-31.2	-0.75%	4522.09	4185.17	-7.45%	4680.54	4153.93	-11.25%
		NAAQS	3.42	4581.8	4536.1	-45.7	-1.00%	4343.4	4345.6	2.2	0.05%	4156.3	4202.2	45.9	1.11%	4581.78	4156.30	-9.29%	4536.10	4202.23	-7.36%
		Utility Based (Coal)	3.42	4900.1	4579.3	-320.7	-6.55%	4493.0	4611.7	118.7	2.64%	4335.4	4269.2	-66.2	-1.53%	4900.08	4335.45	-11.52%	4579.35	4269.20	-6.77%
		Utility Based High	3.42	4900.1	4579.3	-320.7	-6.55%	4376.9	4380.1	3.1	0.07%	4202.0	4208.1	6.1	0.15%	4900.08	4201.96	-14.25%	4579.35	4208.11	-8.11%
	S(s)	Clear Sky w/Hg	3.67	1941.9	1924.8	-17.2	-0.88%	1924.8	1913.0	-11.8	-0.61%	1902.5	1895.7	-6.9	-0.36%	1941.94	1902.54	-2.03%	1924.78	1895.69	-1.51%
	7	Clear Sky wo/Hg	3.67	1852.6	1865.2	12.6	0.68%	1872.9	1871.6	-1.3	-0.07%	1852.0	1860.2	8.2	0.44%	1852.61	1851.99	-0.03%	1865.22	1860.18	-0.27%
		NAAQS	3.67	1911.0	1886.3	-24.7	-1.29%	1868.0	1863.6	-4.4	-0.23%	1853.3	1840.9	-12.4	-0.67%	1911.01	1853.30	-3.02%	1886.32	1840.86	-2.41%
		Utility Based (Coal)	3.67	1929.8	1935.4	5.6	0.29%	1870.6	1914.4	43.8	2.34%	1856.0	1834.6	-21.4	-1.15%	1929.82	1856.05	-3.82%	1935.38	1834.64	-5.21%
		Utility Based High	3.67	1929.8	1935.4	5.6	0.29%	1854.3	1876.1	21.8	1.18%	1854.0	1845.2	-8.8	-0.47%	1929.82	1853.98	-3.93%	1935.38	1845.21	-4.66%
	S(l)	Clear Sky w/Hg	3.39	4985.0	4844.0	-141.0	-2.83%	4867.0	4860.1	-6.9	-0.14%	4774.1	4786.6	12.5	0.26%	4984.99	4774.14	-4.23%	4844.02	4786.61	-1.19%
	8	Clear Sky wo/Hg	3.39	4675.6	4655.4	-20.2	-0.43%	4577.0	4541.2	-35.9	-0.78%	4332.7	4350.7	17.9	0.41%	4675.62	4332.73	-7.33%	4655.38	4350.67	-6.55%
		NAAQS	3.39	4679.8	4705.9	26.1	0.56%	4588.7	4551.7	-37.0	-0.81%	4341.6	4329.0	-12.7	-0.29%	4679.77	4341.62	-7.23%	4705.85	4328.95	-8.01%
		Utility Based (Coal)	3.39	4841.8	4829.0	-12.8	-0.26%	4705.7	4774.0	68.2	1.45%	4512.3	4480.0	-32.3	-0.72%	4841.77	4512.27	-6.81%	4828.97	4480.00	-7.23%
		Utility Based High	3.39	4841.8	4829.0	-12.8	-0.26%	4642.4	4661.0	18.6	0.40%	4485.5	4429.4	-56.1	-1.25%	4841.77	4485.53	-7.36%	4828.97	4429.44	-8.27%
	SB(s)	Clear Sky w/Hg	5.09	40.4	41.6	1.2	3.00%	37.5	37.7	0.1	0.34%	42.1	42.5	0.4	0.97%	40.37	42.12	4.32%	41.58	42.52	2.26%
	14	Clear Sky wo/Hg	5.09	39.2	38.8	-0.4	-1.08%	32.4	32.0	-0.4	-1.28%	31.5	30.9	-0.6	-1.96%	39.23	31.51	-19.69%	38.80	30.89	-20.40%
		NAAQS	5.09	36.5	37.0	0.5	1.32%	34.2	34.4	0.2	0.56%	31.4	32.1	0.7	2.33%	36.48	31.35	-14.07%	36.96	32.08	-13.21%
		Utility Based (Coal)	5.09	45.8	45.6	-0.3	-0.57%	37.9	38.7	0.7	1.97%	33.6	33.4	-0.2	-0.56%	45.83	33.61	-26.66%	45.57	33.42	-26.66%
		Utility Based High	5.09	45.8	45.6	-0.3	-0.57%	38.4	37.1	-1.4	-3.61%	32.3	34.5	2.2	6.95%	45.83	32.25	-29.63%	45.57	34.49	-24.31%

TABLE 15
Racine Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Racine	ES(s)	Clear Sky w/Hg	2.84	977.5	980.9	3.4	0.35%	968.1	973.1	5.0	0.52%	956.0	956.3	0.3	0.03%	977.54	955.98	-2.21%	980.94	956.27	-2.51%
	1	Clear Sky wo/Hg	2.84	958.2	968.7	10.5	1.10%	950.9	958.7	7.8	0.82%	930.8	930.1	-0.7	-0.07%	958.17	930.76	-2.86%	968.68	930.08	-3.98%
		NAAQS	2.84	963.0	959.5	-3.6	-0.37%	944.1	949.5	5.4	0.58%	934.4	939.0	4.6	0.49%	963.03	934.39	-2.97%	959.45	939.00	-2.13%
		Utility Based (Coal)	2.84	984.8	959.3	-25.5	-2.59%	954.0	961.8	7.8	0.82%	938.3	937.4	-0.9	-0.10%	984.85	938.33	-4.72%	959.32	937.43	-2.28%
		Utility Based High	2.84	984.8	959.3	-25.5	-2.59%	947.8	948.1	0.4	0.04%	933.1	937.5	4.5	0.48%	984.85	933.07	-5.26%	959.32	937.54	-2.27%
	ES(f)	Clear Sky w/Hg	3.12	607.6	612.5	4.9	0.81%	595.9	599.2	3.3	0.55%	593.5	589.7	-3.7	-0.63%	607.57	593.45	-2.32%	612.47	589.72	-3.71%
	2	Clear Sky wo/Hg	3.12	589.9	600.5	10.5	1.78%	582.4	585.3	2.9	0.49%	561.5	560.7	-0.8	-0.14%	589.94	561.51	-4.82%	600.46	560.74	-6.61%
		NAAQS	3.12	594.9	591.8	-3.1	-0.52%	572.7	575.8	3.0	0.52%	561.1	561.1	0.0	0.00%	594.91	561.10	-5.68%	591.82	561.07	-5.20%
		Utility Based (Coal)	3.12	610.3	593.2	-17.1	-2.80%	589.1	596.7	7.7	1.30%	574.3	573.1	-1.3	-0.22%	610.33	574.34	-5.90%	593.23	573.07	-3.40%
		Utility Based High	3.12	610.3	593.2	-17.1	-2.80%	578.1	577.9	-0.2	-0.03%	567.1	569.9	2.8	0.49%	610.33	567.08	-7.09%	593.23	569.86	-3.94%
	P(s)	Clear Sky w/Hg	2.80	2662.5	2625.4	-37.1	-1.39%	2626.7	2622.3	-4.4	-0.17%	2628.0	2630.3	2.4	0.09%	2662.52	2627.96	-1.30%	2625.39	2630.31	0.19%
	3	Clear Sky wo/Hg	2.80	2602.8	2599.2	-3.5	-0.14%	2612.9	2596.8	-16.1	-0.62%	2578.6	2593.8	15.2	0.59%	2602.75	2578.61	-0.93%	2599.22	2593.81	-0.21%
		NAAQS	2.80	2616.2	2630.6	14.4	0.55%	2611.1	2610.4	-0.7	-0.03%	2593.1	2596.2	3.1	0.12%	2616.23	2593.08	-0.88%	2630.62	2596.23	-1.31%
		Utility Based (Coal)	2.80	2607.3	2613.6	6.3	0.24%	2584.1	2596.4	12.2	0.47%	2582.8	2577.5	-5.3	-0.20%	2607.34	2582.79	-0.94%	2613.60	2577.54	-1.38%
		Utility Based High	2.80	2607.3	2613.6	6.3	0.24%	2583.5	2590.2	6.7	0.26%	2584.1	2576.5	-7.6	-0.29%	2607.34	2584.12	-0.89%	2613.60	2576.50	-1.42%
	P(l)	Clear Sky w/Hg	2.76	3924.4	3870.4	-54.0	-1.38%	3675.1	3681.8	6.6	0.18%	3658.8	3672.6	13.8	0.38%	3924.38	3658.75	-6.77%	3870.36	3672.57	-5.11%
	4	Clear Sky wo/Hg	2.76	3562.1	3644.9	82.9	2.33%	3491.6	3509.3	17.7	0.51%	3334.0	3304.0	-29.9	-0.90%	3562.07	3333.95	-6.40%	3644.93	3304.04	-9.35%
		NAAQS	2.76	3616.5	3578.7	-37.7	-1.04%	3444.4	3460.5	16.0	0.47%	3306.2	3378.0	71.8	2.17%	3616.47	3306.18	-8.58%	3578.74	3378.01	-5.61%
		Utility Based (Coal)	2.76	3879.2	3668.9	-210.3	-5.42%	3574.2	3627.5	53.3	1.49%	3470.2	3412.2	-58.0	-1.67%	3879.22	3470.25	-10.54%	3668.94	3412.21	-7.00%
		Utility Based High	2.76	3879.2	3668.9	-210.3	-5.42%	3488.4	3495.9	7.5	0.21%	3330.8	3312.8	-18.0	-0.54%	3879.22	3330.79	-14.14%	3668.94	3312.81	-9.71%
	FD(l)	Clear Sky w/Hg	2.76	3815.4	3835.1	19.8	0.52%	3623.1	3661.9	38.7	1.07%	3546.8	3539.7	-7.2	-0.20%	3815.36	3546.83	-7.04%	3835.13	3539.67	-7.70%
	6	Clear Sky wo/Hg	2.76	3549.2	3699.7	150.5	4.24%	3470.5	3543.3	72.8	2.10%	3243.1	3181.4	-61.7	-1.90%	3549.24	3243.12	-8.62%	3699.70	3181.42	-14.01%
		NAAQS	2.76	3593.6	3567.1	-26.5	-0.74%	3326.0	3353.6	27.6	0.83%	3186.0	3229.5	43.6	1.37%	3593.62	3185.95	-11.34%	3567.12	3229.51	-9.46%
		Utility Based (Coal)	2.76	3867.9	3641.9	-226.0	-5.84%	3497.5	3631.5	134.1	3.83%	3349.4	3298.3	-51.1	-1.53%	3867.94	3349.42	-13.41%	3641.92	3298.31	-9.43%
		Utility Based High	2.76	3867.9	3641.9	-226.0	-5.84%	3427.1	3453.8	26.7	0.78%	3229.0	3256.2	27.2	0.84%	3867.94	3228.98	-16.52%	3641.92	3256.15	-10.59%
	S(s)	Clear Sky w/Hg	3.37	1654.0	1642.8	-11.3	-0.68%	1631.9	1629.8	-2.2	-0.13%	1625.9	1615.2	-10.6	-0.65%	1654.05	1625.86	-1.70%	1642.78	1615.24	-1.68%
	7	Clear Sky wo/Hg	3.37	1572.7	1585.1	12.4	0.79%	1598.1	1578.0	-20.2	-1.26%	1574.5	1570.0	-4.5	-0.29%	1572.68	1574.52	0.12%	1585.13	1570.00	-0.95%
		NAAQS	3.37	1632.8	1620.5	-12.3	-0.75%	1578.1	1583.9	5.8	0.37%	1569.4	1566.4	-3.0	-0.19%	1632.81	1569.42	-3.88%	1620.55	1566.43	-3.34%
		Utility Based (Coal)	3.37	1643.1	1647.6	4.5	0.27%	1595.0	1605.1	10.1	0.63%	1573.9	1543.9	-30.0	-1.90%	1643.13	1573.85	-4.22%	1647.62	1543.90	-6.30%
		Utility Based High	3.37	1643.1	1647.6	4.5	0.27%	1564.0	1585.7	21.7	1.38%	1568.7	1588.6	19.9	1.27%	1643.13	1568.68	-4.53%	1647.62	1588.61	-3.58%
	S(l)	Clear Sky w/Hg	2.74	3943.2	3822.6	-120.6	-3.06%	3848.4	3850.4	2.1	0.05%	3769.7	3777.7	8.0	0.21%	3943.21	3769.69	-4.40%	3822.64	3777.69	-1.18%
	8	Clear Sky wo/Hg	2.74	3677.2	3673.9	-3.3	-0.09%	3580.8	3541.3	-39.5	-1.10%	3382.1	3393.4	11.3	0.33%	3677.21	3382.10	-8.03%	3673.91	3393.42	-7.63%
		NAAQS	2.74	3671.4	3734.8	63.4	1.73%	3575.3	3564.3	-11.1	-0.31%	3362.8	3368.7	5.9	0.18%	3671.41	3362.76	-8.41%	3734.77	3368.65	-9.80%
		Utility Based (Coal)	2.74	3839.5	3823.1	-16.4	-0.43%	3723.5	3743.8	20.4	0.55%	3525.0	3534.0	9.1	0.26%	3839.53	3524.98	-8.19%	3823.09	3534.03	-7.56%
		Utility Based High	2.74	3839.5	3823.1	-16.4	-0.43%	3652.4	3656.2	3.8	0.11%	3527.4	3476.7	-50.7	-1.44%	3839.53	3527.36	-8.13%	3823.09	3476.69	-9.06%
	SB(s)	Clear Sky w/Hg	2.33	20.4	21.0	0.6	3.13%	18.9	19.1	0.2	1.10%	19.3	19.7	0.4	1.98%	20.40	19.34	-5.20%	21.04	19.72	-6.25%
	14	Clear Sky wo/Hg	2.33	19.9	19.0	-1.0	-4.84%	16.4	16.3	-0.2	-0.98%	15.6	15.3	-0.3	-1.69%	19.93	15.60	-21.75%	18.97	15.33	-19.16%
		NAAQS	2.33	17.7	17.8	0.2	0.96%	16.4	16.5	0.1	0.33%	17.3	16.0	-1.3	-7.73%	17.67	17.29	-2.12%	17.84	15.96	-10.54%
		Utility Based (Coal)	2.33	21.2	20.5	-0.7	-3.23%	18.9	19.0	0.1	0.32%	17.6	18.1	0.5	2.99%	21.23	17.56	-17.30%	20.54	18.08	-11.98%
		Utility Based High	2.33	21.2	20.5	-0.7	-3.23%	18.1	17.9	-0.1	-0.77%	17.1	16.7	-0.4	-2.28%	21.23	17.10	-19.46%	20.54	16.71	-18.67%

TABLE 16
R C Byrd Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
RC Byrd	ES(s)	Clear Sky w/Hg	2.18	810.4	815.8	5.5	0.67%	817.9	819.5	1.6	0.19%	810.3	807.7	-2.6	-0.32%	810.36	810.28	-0.01%	815.83	807.65	-1.00%
	1	Clear Sky wo/Hg	2.18	814.0	817.7	3.7	0.46%	803.6	806.3	2.7	0.33%	798.2	798.8	0.6	0.08%	814.01	798.19	-1.94%	817.71	798.80	-2.31%
		NAAQS	2.18	810.2	812.6	2.4	0.29%	803.2	805.8	2.6	0.32%	796.3	796.7	0.4	0.05%	810.17	796.27	-1.72%	812.56	796.68	-1.95%
		Utility Based (Coal)	2.18	819.2	806.1	-13.1	-1.60%	803.4	808.1	4.7	0.59%	801.0	797.8	-3.2	-0.41%	819.18	801.02	-2.22%	806.10	797.77	-1.03%
		Utility Based High	2.18	819.2	806.1	-13.1	-1.60%	801.7	800.1	-1.6	-0.20%	793.1	794.9	1.8	0.22%	819.18	793.09	-3.18%	806.10	794.87	-1.39%
	ES(f)	Clear Sky w/Hg	3.38	679.7	683.9	4.2	0.62%	682.5	685.5	3.0	0.44%	676.5	673.7	-2.8	-0.41%	679.71	676.52	-0.47%	683.95	673.74	-1.49%
	2	Clear Sky wo/Hg	3.38	681.1	689.2	8.1	1.19%	665.1	669.3	4.2	0.63%	653.0	655.2	2.1	0.33%	681.05	653.04	-4.11%	689.19	655.18	-4.93%
		NAAQS	3.38	676.4	678.7	2.3	0.34%	665.7	667.0	1.2	0.19%	652.0	652.7	0.6	0.10%	676.37	652.03	-3.60%	678.67	652.67	-3.83%
		Utility Based (Coal)	3.38	682.6	668.1	-14.5	-2.13%	655.7	662.5	6.8	1.04%	648.4	646.6	-1.8	-0.27%	682.57	648.37	-5.01%	668.05	646.60	-3.21%
		Utility Based High	3.38	682.6	668.1	-14.5	-2.13%	654.9	650.9	-4.0	-0.61%	634.9	639.1	4.2	0.67%	682.57	634.87	-6.99%	668.05	639.12	-4.33%
	P(s)	Clear Sky w/Hg	1.90	1879.8	1870.3	-9.5	-0.51%	1874.0	1869.5	-4.4	-0.24%	1868.9	1876.1	7.3	0.39%	1879.78	1868.88	-0.58%	1870.27	1876.13	0.31%
	3	Clear Sky wo/Hg	1.90	1857.8	1856.9	-0.9	-0.05%	1861.4	1855.5	-5.9	-0.31%	1848.0	1859.3	11.3	0.61%	1857.79	1847.96	-0.53%	1856.93	1859.30	0.13%
		NAAQS	1.90	1860.3	1872.9	12.6	0.68%	1871.8	1867.4	-4.4	-0.23%	1857.2	1852.0	-5.2	-0.28%	1860.29	1857.21	-0.17%	1872.87	1851.99	-1.12%
		Utility Based (Coal)	1.90	1856.4	1863.0	6.6	0.35%	1843.7	1850.1	6.4	0.35%	1842.1	1838.7	-3.4	-0.18%	1856.42	1842.05	-0.77%	1862.98	1838.68	-1.30%
		Utility Based High	1.90	1856.4	1863.0	6.6	0.35%	1843.8	1841.5	-2.4	-0.13%	1844.6	1837.9	-6.7	-0.36%	1856.42	1844.59	-0.64%	1862.98	1837.89	-1.35%
	P(l)	Clear Sky w/Hg	3.22	4608.4	4573.6	-34.8	-0.76%	4497.9	4500.3	2.3	0.05%	4474.7	4505.5	30.8	0.69%	4608.44	4474.66	-2.90%	4573.60	4505.51	-1.49%
	4	Clear Sky wo/Hg	3.22	4405.8	4513.8	108.0	2.45%	4283.6	4307.5	24.0	0.56%	4116.6	4110.0	-6.6	-0.16%	4405.78	4116.63	-6.56%	4513.78	4110.02	-8.95%
		NAAQS	3.22	4381.0	4372.8	-8.1	-0.19%	4264.2	4287.9	23.7	0.56%	4131.4	4181.9	50.5	1.22%	4380.97	4131.37	-5.70%	4372.82	4181.88	-4.37%
		Utility Based (Coal)	3.22	4555.5	4352.8	-202.7	-4.45%	4201.0	4240.7	39.7	0.94%	4075.1	4026.8	-48.3	-1.19%	4555.46	4075.14	-10.54%	4352.78	4026.80	-7.49%
		Utility Based High	3.22	4555.5	4352.8	-202.7	-4.45%	4092.7	4130.3	37.6	0.92%	3901.5	3930.5	29.0	0.74%	4555.46	3901.47	-14.36%	4352.78	3930.47	-9.70%
	FD(l)	Clear Sky w/Hg	3.22	4479.5	4476.7	-2.8	-0.06%	4474.1	4513.1	38.9	0.87%	4374.5	4360.2	-14.3	-0.33%	4479.50	4374.49	-2.34%	4476.71	4360.19	-2.60%
	6	Clear Sky wo/Hg	3.22	4396.8	4549.8	152.9	3.48%	4228.7	4311.0	82.3	1.95%	4059.7	4007.0	-52.7	-1.30%	4396.84	4059.70	-7.67%	4549.75	4006.96	-11.93%
		NAAQS	3.22	4332.5	4332.9	0.4	0.01%	4173.9	4202.6	28.7	0.69%	3973.3	4019.8	46.5	1.17%	4332.46	3973.27	-8.29%	4332.86	4019.79	-7.23%
		Utility Based (Coal)	3.22	4542.1	4292.6	-249.5	-5.49%	4098.8	4216.8	118.0	2.88%	3988.5	3919.2	-69.3	-1.74%	4542.09	3988.49	-12.19%	4292.56	3919.16	-8.70%
		Utility Based High	3.22	4542.1	4292.6	-249.5	-5.49%	4078.4	4077.8	-0.7	-0.02%	3804.5	3847.2	42.7	1.12%	4542.09	3804.50	-16.24%	4292.56	3847.17	-10.38%
	S(s)	Clear Sky w/Hg	1.51	930.4	927.9	-2.6	-0.28%	927.9	924.1	-3.8	-0.41%	921.3	922.9	1.7	0.18%	930.44	921.28	-0.98%	927.86	922.94	-0.53%
	7	Clear Sky wo/Hg	1.51	910.6	918.3	7.7	0.85%	920.8	915.0	-5.8	-0.63%	912.9	914.2	1.2	0.14%	910.57	912.94	0.26%	918.27	914.19	-0.44%
		NAAQS	1.51	928.2	921.2	-7.0	-0.75%	917.4	916.1	-1.3	-0.15%	912.7	903.4	-9.4	-1.03%	928.19	912.73	-1.67%	921.19	903.35	-1.94%
		Utility Based (Coal)	1.51	925.1	922.6	-2.5	-0.27%	906.6	911.0	4.4	0.48%	898.4	891.1	-7.3	-0.82%	925.12	898.43	-2.88%	922.62	891.10	-3.42%
		Utility Based High	1.51	925.1	922.6	-2.5	-0.27%	897.9	904.0	6.0	0.67%	897.2	897.4	0.2	0.02%	925.12	897.23	-3.01%	922.62	897.43	-2.73%
	S(l)	Clear Sky w/Hg	3.19	4654.3	4544.9	-109.4	-2.35%	4690.2	4694.0	3.8	0.08%	4593.7	4621.2	27.5	0.60%	4654.29	4593.73	-1.30%	4544.93	4621.19	1.68%
	8	Clear Sky wo/Hg	3.19	4504.1	4505.2	1.1	0.02%	4417.2	4400.6	-16.6	-0.38%	4233.3	4246.5	13.2	0.31%	4504.13	4233.33	-6.01%	4505.23	4246.53	-5.74%
		NAAQS	3.19	4473.2	4492.8	19.7	0.44%	4436.4	4394.8	-41.7	-0.94%	4204.6	4198.0	-6.5	-0.16%	4473.16	4204.56	-6.00%	4492.85	4198.03	-6.56%
		Utility Based (Coal)	3.19	4543.0	4523.6	-19.4	-0.43%	4406.5	4399.9	-6.5	-0.15%	4220.9	4178.7	-42.2	-1.00%	4543.03	4220.95	-7.09%	4523.59	4178.70	-7.62%
		Utility Based High	3.19	4543.0	4523.6	-19.4	-0.43%	4297.5	4325.6	28.1	0.65%	4145.7	4105.7	-40.0	-0.97%	4543.03	4145.68	-8.75%	4523.59	4105.67	-9.24%
	SB(s)	Clear Sky w/Hg	2.40	23.0	22.0	-1.0	-4.27%	21.8	22.1	0.2	1.09%	22.8	23.2	0.4	1.57%	22.99	22.82	-0.74%	22.01	23.18	5.32%
	14	Clear Sky wo/Hg	2.40	22.8	22.5	-0.2	-1.01%	19.4	18.8	-0.6	-2.92%	18.4	18.1	-0.3	-1.54%	22.75	18.36	-19.31%	22.52	18.08	-19.74%
		NAAQS	2.40	21.8	21.5	-0.3	-1.35%	20.1	20.1	-0.1	-0.26%	18.7	18.8	0.1	0.49%	21.83	18.72	-14.26%	21.54	18.81	-12.66%
		Utility Based (Coal)	2.40	22.5	20.8	-1.7	-7.69%	20.6	20.9	0.3	1.33%	18.5	19.0	0.5	2.65%	22.48	18.51	-17.67%	20.75	19.00	-8.45%
		Utility Based High	2.40	22.5	20.8	-1.7	-7.69%	20.1	20.1	0.0	0.14%	17.2	17.9	0.6	3.63%	22.48	17.24	-23.33%	20.75	17.86	-13.94%

TABLE 17
Greenup Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Greenup	ES(s)	Clear Sky w/Hg	4.11	1570.9	1582.0	11.1	0.71%	1582.3	1585.8	3.5	0.22%	1564.8	1563.1	-1.8	-0.11%	1570.91	1564.83	-0.39%	1582.02	1563.07	-1.20%
	1	Clear Sky wo/Hg	4.11	1588.7	1598.0	9.3	0.59%	1554.7	1561.7	7.0	0.45%	1540.2	1540.5	0.3	0.02%	1588.70	1540.20	-3.05%	1598.03	1540.49	-3.60%
		NAAQS	4.11	1572.6	1582.5	10.0	0.64%	1556.2	1566.6	10.4	0.67%	1537.0	1545.9	8.9	0.58%	1572.55	1536.99	-2.26%	1582.54	1545.92	-2.31%
		Utility Based (Coal)	4.11	1595.0	1559.3	-35.6	-2.23%	1554.1	1552.5	-1.6	-0.10%	1553.3	1542.1	-11.1	-0.72%	1594.98	1553.25	-2.62%	1559.33	1542.12	-1.10%
		Utility Based High	4.11	1595.0	1559.3	-35.6	-2.23%	1557.5	1558.4	1.0	0.06%	1537.1	1543.6	6.4	0.42%	1594.98	1537.13	-3.63%	1559.33	1543.55	-1.01%
	ES(f)	Clear Sky w/Hg	4.15	845.8	847.1	1.3	0.16%	846.6	846.7	0.1	0.01%	838.5	833.5	-5.0	-0.59%	845.80	838.50	-0.86%	847.13	833.52	-1.61%
	2	Clear Sky wo/Hg	4.15	851.4	859.7	8.3	0.98%	828.1	834.6	6.5	0.79%	812.4	815.3	2.9	0.36%	851.35	812.44	-4.57%	859.66	815.34	-5.16%
		NAAQS	4.15	842.2	843.6	1.4	0.17%	829.0	828.3	-0.7	-0.09%	817.0	817.1	0.1	0.02%	842.19	817.00	-2.99%	843.60	817.15	-3.14%
		Utility Based (Coal)	4.15	835.3	825.4	-9.9	-1.18%	808.7	813.9	5.2	0.64%	793.5	790.0	-3.5	-0.44%	835.26	793.49	-5.00%	825.37	789.97	-4.29%
		Utility Based High	4.15	835.3	825.4	-9.9	-1.18%	804.5	802.5	-2.0	-0.25%	782.3	777.5	-4.7	-0.61%	835.26	782.27	-6.34%	825.37	777.53	-5.80%
	P(s)	Clear Sky w/Hg	6.20	5767.1	5770.6	3.5	0.06%	5734.8	5725.3	-9.5	-0.16%	5720.5	5727.3	6.8	0.12%	5767.15	5720.48	-0.81%	5770.64	5727.32	-0.75%
	3	Clear Sky wo/Hg	6.20	5728.4	5710.4	-18.0	-0.31%	5712.7	5700.6	-12.0	-0.21%	5645.6	5699.5	53.9	0.95%	5728.40	5645.61	-1.45%	5710.42	5699.51	-0.19%
		NAAQS	6.20	5761.2	5829.2	68.0	1.18%	5748.3	5715.7	-32.6	-0.57%	5694.3	5691.9	-2.3	-0.04%	5761.18	5694.26	-1.16%	5829.22	5691.93	-2.36%
		Utility Based (Coal)	6.20	5709.2	5706.8	-2.3	-0.04%	5646.6	5652.9	6.4	0.11%	5623.5	5628.6	5.1	0.09%	5709.17	5623.47	-1.50%	5706.84	5628.56	-1.37%
		Utility Based High	6.20	5709.2	5706.8	-2.3	-0.04%	5638.3	5631.9	-6.4	-0.11%	5667.6	5598.2	-69.5	-1.23%	5709.17	5667.65	-0.73%	5706.84	5598.18	-1.90%
	P(l)	Clear Sky w/Hg	5.28	7582.2	7549.5	-32.7	-0.43%	7347.5	7350.7	3.3	0.04%	7256.6	7293.5	37.0	0.51%	7582.25	7256.58	-4.30%	7549.52	7293.54	-3.39%
	4	Clear Sky wo/Hg	5.28	7483.3	7647.7	164.5	2.20%	7103.5	7174.5	70.9	1.00%	6831.3	6892.0	60.7	0.89%	7483.25	6831.31	-8.71%	7647.75	6892.01	-9.88%
		NAAQS	5.28	7424.1	7428.1	4.0	0.05%	7090.3	7127.5	37.2	0.52%	6880.5	6942.9	62.4	0.91%	7424.11	6880.48	-7.32%	7428.12	6942.93	-6.53%
		Utility Based (Coal)	5.28	7265.1	7009.3	-255.8	-3.52%	6734.8	6773.3	38.5	0.57%	6445.8	6392.5	-53.3	-0.83%	7265.09	6445.76	-11.28%	7009.31	6392.50	-8.80%
		Utility Based High	5.28	7265.1	7009.3	-255.8	-3.52%	6524.7	6584.4	59.7	0.91%	6207.8	6168.0	-39.9	-0.64%	7265.09	6207.82	-14.55%	7009.31	6167.95	-12.00%
	FD(l)	Clear Sky w/Hg	5.27	7348.8	7298.9	-49.8	-0.68%	7153.4	7198.9	45.6	0.64%	7003.9	7034.3	30.4	0.43%	7348.79	7003.92	-4.69%	7298.95	7034.33	-3.63%
	6	Clear Sky wo/Hg	5.27	7409.5	7656.3	246.8	3.33%	6889.9	7036.3	146.4	2.12%	6655.8	6597.4	-58.4	-0.88%	7409.46	6655.82	-10.17%	7656.29	6597.43	-13.83%
		NAAQS	5.27	7250.8	7277.6	26.8	0.37%	6989.4	7021.7	32.3	0.46%	6621.7	6674.6	52.9	0.80%	7250.77	6621.70	-8.68%	7277.61	6674.55	-8.29%
		Utility Based (Coal)	5.27	7179.2	6876.9	-302.2	-4.21%	6498.0	6631.5	133.5	2.05%	6192.2	6102.5	-89.7	-1.45%	7179.16	6192.22	-13.75%	6876.94	6102.54	-11.26%
		Utility Based High	5.27	7179.2	6876.9	-302.2	-4.21%	6459.2	6444.5	-14.7	-0.23%	5973.1	5920.7	-52.4	-0.88%	7179.16	5973.06	-16.80%	6876.94	5920.68	-13.91%
	S(s)	Clear Sky w/Hg	6.87	3553.4	3554.7	1.3	0.04%	3520.3	3510.5	-9.8	-0.28%	3511.9	3487.6	-24.3	-0.69%	3553.44	3511.94	-1.17%	3554.69	3487.62	-1.89%
	7	Clear Sky wo/Hg	6.87	3471.6	3505.6	34.0	0.98%	3494.2	3473.8	-20.4	-0.58%	3434.6	3447.2	12.6	0.37%	3471.59	3434.62	-1.06%	3505.57	3447.19	-1.67%
		NAAQS	6.87	3576.7	3565.9	-10.8	-0.30%	3457.5	3460.4	3.0	0.09%	3452.0	3411.7	-40.3	-1.17%	3576.73	3452.04	-3.49%	3565.92	3411.73	-4.32%
		Utility Based (Coal)	6.87	3541.1	3538.2	-2.9	-0.08%	3435.6	3419.7	-15.9	-0.46%	3390.5	3362.9	-27.6	-0.82%	3541.09	3390.50	-4.25%	3538.22	3362.87	-4.96%
		Utility Based High	6.87	3541.1	3538.2	-2.9	-0.08%	3367.7	3397.3	29.6	0.88%	3391.7	3356.1	-35.6	-1.05%	3541.09	3391.70	-4.22%	3538.22	3356.06	-5.15%
	S(l)	Clear Sky w/Hg	5.26	7770.1	7645.5	-124.6	-1.60%	7701.9	7723.3	21.4	0.28%	7478.9	7504.0	25.1	0.34%	7770.12	7478.91	-3.75%	7645.53	7503.98	-1.85%
	8	Clear Sky wo/Hg	5.26	7615.9	7659.4	43.6	0.57%	7384.9	7367.5	-17.4	-0.24%	7106.0	7145.7	39.7	0.56%	7615.87	7106.01	-6.69%	7659.42	7145.74	-6.71%
		NAAQS	5.26	7635.5	7683.8	48.3	0.63%	7493.9	7444.1	-49.8	-0.66%	7093.9	7116.7	22.8	0.32%	7635.49	7093.90	-7.09%	7683.79	7116.72	-7.38%
		Utility Based (Coal)	5.26	7381.9	7379.2	-2.7	-0.04%	7043.0	6996.4	-46.6	-0.66%	6698.0	6681.7	-16.3	-0.24%	7381.87	6698.05	-9.26%	7379.21	6681.72	-9.45%
		Utility Based High	5.26	7381.9	7379.2	-2.7	-0.04%	6885.7	6898.7	13.0	0.19%	6550.1	6499.3	-50.8	-0.78%	7381.87	6550.13	-11.27%	7379.21	6499.29	-11.92%
	SB(s)	Clear Sky w/Hg	5.36	51.4	50.6	-0.8	-1.59%	49.2	49.8	0.6	1.26%	50.6	51.2	0.6	1.09%	51.44	50.64	-1.55%	50.62	51.19	1.14%
	14	Clear Sky wo/Hg	5.36	52.9	51.5	-1.4	-2.74%	45.7	44.3	-1.4	-3.07%	42.8	42.7	0.0	-0.10%	52.92	42.79	-19.15%	51.48	42.74	-16.96%
		NAAQS	5.36	50.3	50.7	0.3	0.66%	46.2	46.8	0.6	1.26%	45.3	44.5	-0.8	-1.69%	50.33	45.31	-9.98%	50.66	44.54	-12.08%
		Utility Based (Coal)	5.36	50.5	46.3	-4.2	-8.38%	46.3	46.7	0.3	0.66%	42.5	43.1	0.6	1.47%	50.55	42.51	-15.91%	46.31	43.13	-6.87%
		Utility Based High	5.36	50.5	46.3	-4.2	-8.38%	46.4	45.9	-0.5	-1.01%	41.2	42.4	1.3	3.07%	50.55	41.15	-18.58%	46.31	42.42	-8.41%

TABLE 18
Meldahl Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Meldahl	ES(s)	Clear Sky w/Hg	7.60	2942.3	2939.6	-2.7	-0.09%	2933.7	2937.8	4.1	0.14%	2909.7	2909.3	-0.4	-0.01%	2942.27	2909.69	-1.11%	2939.56	2909.31	-1.03%
	1	Clear Sky wo/Hg	7.60	2928.7	2933.7	5.1	0.17%	2885.5	2920.0	34.6	1.20%	2850.9	2868.8	17.9	0.63%	2928.66	2850.90	-2.65%	2933.75	2868.76	-2.22%
		NAAQS	7.60	2948.9	2926.7	-22.2	-0.75%	2905.5	2918.3	12.8	0.44%	2849.6	2878.2	28.6	1.00%	2948.88	2849.60	-3.37%	2926.68	2878.17	-1.66%
		Utility Based (Coal)	7.60	2948.9	2888.5	-60.4	-2.05%	2878.6	2889.6	11.0	0.38%	2879.5	2848.3	-31.2	-1.08%	2948.88	2879.50	-2.35%	2888.45	2848.30	-1.39%
		Utility Based High	7.60	2948.9	2888.5	-60.4	-2.05%	2878.8	2873.8	-5.0	-0.17%	2859.3	2878.8	19.5	0.68%	2948.88	2859.30	-3.04%	2888.45	2878.80	-0.33%
	ES(f)	Clear Sky w/Hg	8.70	1727.9	1728.3	0.5	0.03%	1717.4	1718.5	1.1	0.06%	1706.9	1697.6	-9.3	-0.54%	1727.86	1706.89	-1.21%	1728.31	1697.59	-1.78%
	2	Clear Sky wo/Hg	8.70	1745.9	1767.6	21.7	1.24%	1674.5	1702.3	27.7	1.66%	1641.0	1648.5	7.5	0.46%	1745.86	1640.97	-6.01%	1767.55	1648.51	-6.74%
		NAAQS	8.70	1727.3	1714.6	-12.7	-0.74%	1672.5	1668.5	-3.9	-0.24%	1652.5	1670.5	17.9	1.08%	1727.34	1652.52	-4.33%	1714.59	1670.45	-2.57%
		Utility Based (Coal)	8.70	1703.4	1677.7	-25.7	-1.51%	1622.6	1636.7	14.1	0.87%	1591.7	1582.4	-9.2	-0.58%	1703.42	1591.67	-6.56%	1677.70	1582.45	-5.68%
		Utility Based High	8.70	1703.4	1677.7	-25.7	-1.51%	1622.4	1623.7	1.3	0.08%	1554.9	1551.1	-3.8	-0.24%	1703.42	1554.88	-8.72%	1677.70	1551.12	-7.54%
	P(s)	Clear Sky w/Hg	9.16	9039.6	9061.4	21.8	0.24%	9000.5	8994.6	-5.9	-0.07%	8957.4	8963.3	5.9	0.07%	9039.58	8957.40	-0.91%	9061.41	8963.29	-1.08%
	3	Clear Sky wo/Hg	9.16	9040.4	8980.3	-60.1	-0.66%	8984.0	8990.8	6.8	0.08%	8899.9	8947.3	47.5	0.53%	9040.40	8899.86	-1.55%	8980.29	8947.33	-0.37%
		NAAQS	9.16	9038.1	9081.6	43.5	0.48%	8976.0	8938.2	-37.8	-0.42%	8897.8	8863.2	-34.6	-0.39%	9038.07	8897.82	-1.55%	9081.56	8863.17	-2.40%
		Utility Based (Coal)	9.16	9055.3	9046.1	-9.3	-0.10%	8977.5	8968.3	-9.3	-0.10%	8898.5	8883.0	-15.5	-0.17%	9055.35	8898.52	-1.73%	9046.06	8883.02	-1.80%
		Utility Based High	9.16	9055.3	9046.1	-9.3	-0.10%	8915.4	8893.9	-21.5	-0.24%	8900.3	8924.7	24.4	0.27%	9055.35	8900.28	-1.71%	9046.06	8924.67	-1.34%
	P(l)	Clear Sky w/Hg	9.16	13494.4	13721.2	226.7	1.68%	13525.3	13505.7	-19.6	-0.15%	13057.2	12911.2	-146.0	-1.12%	13494.43	13057.20	-3.24%	13721.17	12911.21	-5.90%
	4	Clear Sky wo/Hg	9.16	13604.1	13363.5	-240.6	-1.77%	13070.2	13055.1	-15.1	-0.12%	12538.2	12610.8	72.6	0.58%	13604.14	12538.17	-7.84%	13363.53	12610.81	-5.63%
		NAAQS	9.16	13595.5	13750.1	154.6	1.14%	13253.5	13194.9	-58.7	-0.44%	12529.2	12449.5	-79.7	-0.64%	13595.48	12529.18	-7.84%	13750.10	12449.52	-9.46%
		Utility Based (Coal)	9.16	12734.3	12795.4	61.1	0.48%	12163.0	12066.8	-96.2	-0.79%	11708.3	11626.0	-82.3	-0.70%	12734.32	11708.32	-8.06%	12795.44	11626.03	-9.14%
		Utility Based High	9.16	12734.3	12795.4	61.1	0.48%	12016.4	12006.3	-10.1	-0.08%	11206.1	11015.5	-190.5	-1.70%	12734.32	11206.08	-12.00%	12795.44	11015.54	-13.91%
	FD(l)	Clear Sky w/Hg	9.15	13811.6	13631.6	-179.9	-1.30%	13574.3	13705.2	130.9	0.96%	12930.0	13056.9	126.9	0.98%	13811.57	12930.00	-6.38%	13631.64	13056.90	-4.22%
	6	Clear Sky wo/Hg	9.15	13213.0	13639.4	426.4	3.23%	13055.2	13059.9	4.7	0.04%	12531.2	12597.4	66.2	0.53%	13212.96	12531.19	-5.16%	13639.39	12597.38	-7.64%
		NAAQS	9.15	13526.2	13256.3	-270.0	-2.00%	13216.2	13275.7	59.5	0.45%	12502.4	12708.5	206.2	1.65%	13526.22	12502.38	-7.57%	13256.26	12708.54	-4.13%
		Utility Based (Coal)	9.15	12933.0	12554.8	-378.2	-2.92%	12043.5	12048.0	4.5	0.04%	11421.2	11429.0	7.8	0.07%	12933.01	11421.24	-11.69%	12554.77	11429.04	-8.97%
		Utility Based High	9.15	12933.0	12554.8	-378.2	-2.92%	11991.4	11881.1	-110.3	-0.92%	11269.8	10982.6	-287.3	-2.55%	12933.01	11269.82	-12.86%	12554.77	10982.55	-12.52%
	S(s)	Clear Sky w/Hg	8.81	5144.0	5129.3	-14.8	-0.29%	5103.5	5089.7	-13.9	-0.27%	5067.0	5045.1	-21.9	-0.43%	5144.03	5066.99	-1.50%	5129.27	5045.10	-1.64%
	7	Clear Sky wo/Hg	8.81	5069.2	5078.0	8.8	0.17%	5077.1	5066.8	-10.3	-0.20%	5014.4	4993.5	-20.8	-0.42%	5069.20	5014.36	-1.08%	5077.96	4993.53	-1.66%
		NAAQS	8.81	5108.4	5153.2	44.8	0.88%	5061.9	5056.1	-5.8	-0.11%	5037.3	4983.7	-53.6	-1.06%	5108.42	5037.32	-1.39%	5153.18	4983.74	-3.29%
		Utility Based (Coal)	8.81	5125.8	5140.1	14.4	0.28%	5033.6	5034.0	0.4	0.01%	4955.3	4957.4	2.1	0.04%	5125.78	4955.29	-3.33%	5140.15	4957.35	-3.56%
		Utility Based High	8.81	5125.8	5140.1	14.4	0.28%	4968.6	4950.1	-18.4	-0.37%	4947.9	4931.4	-16.4	-0.33%	5125.78	4947.85	-3.47%	5140.15	4931.42	-4.06%
	S(l)	Clear Sky w/Hg	9.13	14052.0	13890.8	-161.2	-1.15%	14027.3	14050.0	22.7	0.16%	13365.1	13359.2	-5.9	-0.04%	14051.98	13365.09	-4.89%	13890.80	13359.23	-3.83%
	8	Clear Sky wo/Hg	9.13	13870.4	13850.1	-20.3	-0.15%	13471.0	13405.3	-65.7	-0.49%	12995.9	12993.5	-2.5	-0.02%	13870.40	12995.93	-6.30%	13850.09	12993.47	-6.18%
		NAAQS	9.13	13984.6	13986.2	1.6	0.01%	13559.6	13387.3	-172.3	-1.27%	12910.0	12887.8	-22.2	-0.17%	13984.63	12909.96	-7.68%	13986.19	12887.78	-7.85%
		Utility Based (Coal)	9.13	13314.3	13087.2	-227.1	-1.71%	12729.1	12553.4	-175.7	-1.38%	11953.3	11871.8	-81.5	-0.68%	13314.29	11953.31	-10.22%	13087.17	11871.78	-9.29%
		Utility Based High	9.13	13314.3	13087.2	-227.1	-1.71%	12283.8	12281.8	-2.0	-0.02%	11659.6	11642.7	-16.8	-0.14%	13314.29	11659.56	-12.43%	13087.17	11642.71	-11.04%
	SB(s)	Clear Sky w/Hg	4.98	53.9	52.4	-1.4	-2.69%	52.8	53.5	0.7	1.26%	53.2	53.6	0.4	0.76%	53.88	53.20	-1.28%	52.44	53.60	2.23%
	14	Clear Sky wo/Hg	4.98	51.7	52.6	0.8	1.62%	49.1	48.7	-0.4	-0.82%	45.7	47.0	1.3	2.77%	51.74	45.69	-11.70%	52.58	46.95	-10.70%
		NAAQS	4.98	50.8	50.9	0.2	0.35%	49.2	49.4	0.2	0.42%	46.6	48.1	1.4	3.05%	50.77	46.63	-8.15%	50.95	48.06	-5.68%
		Utility Based (Coal)	4.98	49.2	47.6	-1.6	-3.29%	46.4	46.6	0.2	0.48%	43.9	43.8	-0.1	-0.23%	49.22	43.88	-10.86%	47.61	43.78	-8.04%
		Utility Based High	4.98	49.2	47.6	-1.6	-3.29%	45.8	46.5	0.7	1.55%	44.2	43.4	-0.8	-1.85%	49.22	44.20	-10.20%	47.61	43.39	-8.86%

TABLE 19
Markland Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Markland	ES(s)	Clear Sky w/Hg	9.45	3795.9	3791.5	-4.4	-0.12%	3775.7	3782.9	7.2	0.19%	3762.2	3744.8	-17.5	-0.46%	3795.88	3762.23	-0.89%	3791.47	3744.76	-1.23%
	1	Clear Sky wo/Hg	9.45	3788.9	3780.9	-8.0	-0.21%	3744.2	3775.1	30.9	0.83%	3706.9	3713.6	6.7	0.18%	3788.92	3706.91	-2.16%	3780.90	3713.58	-1.78%
		NAAQS	9.45	3786.6	3779.9	-6.7	-0.18%	3754.3	3766.6	12.3	0.33%	3714.4	3722.6	8.2	0.22%	3786.63	3714.39	-1.91%	3779.91	3722.64	-1.52%
		Utility Based (Coal)	9.45	3780.4	3737.7	-42.7	-1.13%	3728.6	3731.0	2.5	0.07%	3728.0	3696.0	-32.0	-0.86%	3780.42	3728.01	-1.39%	3737.68	3695.99	-1.12%
		Utility Based High	9.45	3780.4	3737.7	-42.7	-1.13%	3733.7	3720.6	-13.1	-0.35%	3696.5	3716.1	19.6	0.53%	3780.42	3696.54	-2.22%	3737.68	3716.10	-0.58%
	ES(f)	Clear Sky w/Hg	12.18	2455.5	2455.4	-0.1	0.00%	2418.8	2419.1	0.2	0.01%	2392.9	2388.4	-4.6	-0.19%	2455.51	2392.94	-2.55%	2455.44	2388.39	-2.73%
	2	Clear Sky wo/Hg	12.18	2436.5	2491.3	54.8	2.25%	2357.6	2406.7	49.1	2.08%	2333.4	2349.8	16.4	0.70%	2436.49	2333.43	-4.23%	2491.26	2349.84	-5.68%
		NAAQS	12.18	2455.4	2440.2	-15.2	-0.62%	2366.9	2374.3	7.4	0.31%	2352.8	2381.7	28.9	1.23%	2455.39	2352.83	-4.18%	2440.19	2381.70	-2.40%
		Utility Based (Coal)	12.18	2433.3	2395.2	-38.1	-1.57%	2321.0	2351.4	30.4	1.31%	2297.7	2271.3	-26.4	-1.15%	2433.33	2297.66	-5.58%	2395.23	2271.30	-5.17%
		Utility Based High	12.18	2433.3	2395.2	-38.1	-1.57%	2342.8	2367.4	24.6	1.05%	2255.8	2286.8	31.0	1.38%	2433.33	2255.80	-7.30%	2395.23	2286.84	-4.53%
	P(s)	Clear Sky w/Hg	10.12	10664.9	10644.4	-20.5	-0.19%	10616.7	10613.4	-3.4	-0.03%	10586.4	10598.9	12.4	0.12%	10664.90	10586.44	-0.74%	10644.43	10598.86	-0.43%
	3	Clear Sky wo/Hg	10.12	10662.1	10618.1	-44.0	-0.41%	10617.5	10616.0	-1.5	-0.01%	10528.0	10571.6	43.6	0.41%	10662.12	10527.99	-1.26%	10618.08	10571.58	-0.44%
		NAAQS	10.12	10665.9	10703.9	38.0	0.36%	10615.4	10576.4	-39.0	-0.37%	10569.9	10511.7	-58.3	-0.55%	10665.93	10569.93	-0.90%	10703.90	10511.65	-1.80%
		Utility Based (Coal)	10.12	10675.2	10668.2	-7.0	-0.07%	10599.6	10615.4	15.8	0.15%	10547.6	10525.5	-22.1	-0.21%	10675.19	10547.64	-1.19%	10668.20	10525.51	-1.34%
		Utility Based High	10.12	10675.2	10668.2	-7.0	-0.07%	10573.5	10531.7	-41.8	-0.40%	10529.3	10535.0	5.7	0.05%	10675.19	10529.28	-1.37%	10668.20	10535.02	-1.25%
	P(l)	Clear Sky w/Hg	9.49	14269.3	14485.0	215.7	1.51%	14059.7	14048.2	-11.5	-0.08%	13518.8	13304.5	-214.3	-1.59%	14269.29	13518.84	-5.26%	14484.98	13304.52	-8.15%
	4	Clear Sky wo/Hg	9.49	14187.8	13979.0	-208.8	-1.47%	13609.7	13659.2	49.4	0.36%	13127.2	13220.9	93.7	0.71%	14187.84	13127.23	-7.48%	13979.02	13220.95	-5.42%
		NAAQS	9.49	14266.3	14459.9	193.6	1.36%	13875.6	13756.2	-119.4	-0.86%	13115.4	12955.2	-160.2	-1.22%	14266.27	13115.41	-8.07%	14459.89	12955.20	-10.41%
		Utility Based (Coal)	9.49	13430.3	13631.4	201.1	1.50%	13125.1	13007.5	-117.7	-0.90%	12580.7	12598.9	18.2	0.14%	13430.31	12580.73	-6.33%	13631.45	12598.95	-7.57%
		Utility Based High	9.49	13430.3	13631.4	201.1	1.50%	12948.6	12941.6	-7.0	-0.05%	12201.9	11963.3	-238.6	-1.96%	13430.31	12201.93	-9.15%	13631.45	11963.33	-12.24%
	FD(l)	Clear Sky w/Hg	9.48	14287.5	14433.8	146.3	1.02%	13955.8	14117.1	161.2	1.16%	13434.2	13412.8	-21.4	-0.16%	14287.51	13434.19	-5.97%	14433.78	13412.76	-7.07%
	6	Clear Sky wo/Hg	9.48	13864.8	14258.2	393.4	2.84%	13651.3	13737.4	86.1	0.63%	13128.7	13217.9	89.2	0.68%	13864.82	13128.70	-5.31%	14258.18	13217.93	-7.30%
		NAAQS	9.48	14189.2	14090.0	-99.2	-0.70%	13794.8	13898.5	103.7	0.75%	13074.7	13083.3	8.6	0.07%	14189.23	13074.67	-7.86%	14090.03	13083.30	-7.14%
		Utility Based (Coal)	9.48	13745.7	13329.9	-415.8	-3.02%	13011.6	13060.8	49.3	0.38%	12393.1	12445.4	52.3	0.42%	13745.70	12393.14	-9.84%	13329.92	12445.41	-6.64%
		Utility Based High	9.48	13745.7	13329.9	-415.8	-3.02%	13023.4	12953.7	-69.6	-0.53%	12268.6	11969.0	-299.7	-2.44%	13745.70	12268.65	-10.75%	13329.92	11968.97	-10.21%
	S(s)	Clear Sky w/Hg	12.01	7364.7	7380.4	15.7	0.21%	7293.7	7286.1	-7.6	-0.10%	7240.7	7207.8	-32.9	-0.45%	7364.74	7240.73	-1.68%	7380.44	7207.79	-2.34%
	7	Clear Sky wo/Hg	12.01	7272.8	7304.7	31.9	0.44%	7242.5	7223.5	-18.9	-0.26%	7168.6	7142.4	-26.3	-0.37%	7272.82	7168.64	-1.43%	7304.74	7142.36	-2.22%
		NAAQS	12.01	7335.7	7381.9	46.2	0.63%	7277.9	7249.9	-28.0	-0.38%	7211.0	7157.4	-53.6	-0.74%	7335.67	7211.03	-1.70%	7381.86	7157.44	-3.04%
		Utility Based (Coal)	12.01	7345.1	7369.7	24.6	0.34%	7213.4	7226.6	13.1	0.18%	7147.0	7111.9	-35.2	-0.49%	7345.11	7147.04	-2.70%	7369.73	7111.88	-3.50%
		Utility Based High	12.01	7345.1	7369.7	24.6	0.34%	7114.6	7107.3	-7.3	-0.10%	7084.7	7095.5	10.8	0.15%	7345.11	7084.65	-3.55%	7369.73	7095.48	-3.72%
	S(l)	Clear Sky w/Hg	9.45	14867.6	14861.1	-6.5	-0.04%	14488.9	14502.6	13.7	0.09%	13852.0	13895.2	43.2	0.31%	14867.57	13852.02	-6.83%	14861.08	13895.17	-6.50%
	8	Clear Sky wo/Hg	9.45	14608.5	14647.7	39.2	0.27%	14128.3	14114.2	-14.1	-0.10%	13501.2	13608.3	107.1	0.79%	14608.47	13501.24	-7.58%	14647.70	13608.30	-7.10%
		NAAQS	9.45	14698.6	14819.7	121.1	0.82%	14126.7	13927.0	-199.6	-1.41%	13409.7	13499.0	89.3	0.67%	14698.58	13409.74	-8.77%	14819.66	13499.01	-8.91%
		Utility Based (Coal)	9.45	14177.0	13908.9	-268.1	-1.89%	13541.5	13458.9	-82.5	-0.61%	12912.6	12846.0	-66.6	-0.52%	14177.02	12912.59	-8.92%	13908.95	12846.03	-7.64%
		Utility Based High	9.45	14177.0	13908.9	-268.1	-1.89%	13236.2	13271.1	34.9	0.26%	12720.4	12655.2	-65.2	-0.51%	14177.02	12720.40	-10.27%	13908.95	12655.24	-9.01%
	SB(s)	Clear Sky w/Hg	13.31	195.1	196.5	1.4	0.70%	196.2	198.2	2.0	1.00%	191.3	194.0	2.8	1.45%	195.15	191.27	-1.99%	196.50	194.04	-1.25%
	14	Clear Sky wo/Hg	13.31	194.9	198.2	3.2	1.66%	187.9	187.5	-0.4	-0.20%	177.9	182.6	4.8	2.68%	194.94	177.85	-8.77%	198.17	182.62	-7.85%
		NAAQS	13.31	193.8	198.2	4.4	2.26%	182.7	184.3	1.6	0.88%	179.8	183.2	3.4	1.89%	193.80	179.82	-7.21%	198.18	183.22	-7.55%
		Utility Based (Coal)	13.31	184.5	176.5	-8.0	-4.33%	176.8	182.9	6.2	3.48%	171.7	171.8	0.0	0.02%	184.48	171.72	-6.91%	176.49	171.75	-2.68%
		Utility Based High	13.31	184.5	176.5	-8.0	-4.33%	176.8	177.3	0.5	0.27%	172.8	171.2	-1.6	-0.95%	184.48	172.85	-6.31%	176.49	171.21	-2.99%

TABLE 20
McAlpine Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010 Without Project HSI Units	2010 With Project HSI Units	2010 Delta	2010 % Delta	2040 Without Project HSI Units	2040 With Project HSI Units	2040 Delta	2040 % Delta	2070 Without Project HSI Units	2070 With Project HSI Units	2070 Delta	2070 % Delta	2010-2070 Without Project 2010	2010-2070 Without Project 2070	2010-2070 % Delta	2010-2070 With Project 2010	2010-2070 With Project 2070	2010-2070 % Delta
McAlpine	ES(s)	Clear Sky w/Hg	7.617776	2707.24563	2701.246	-6.0	-0.22%	2670.76228	2683.64528	12.9	0.48%	2649.85438	2638.51998	-11.3	-0.43%	2707.25	2649.85	-2.12%	2701.25	2638.52	-2.32%
	1	Clear Sky wo/Hg	7.617776	2690.45445	2693.24655	2.8	0.10%	2648.94898	2669.83763	20.9	0.79%	2614.1629	2614.31838	0.2	0.01%	2690.45	2614.16	-2.84%	2693.25	2614.32	-2.93%
		NAAQS	7.617776	2683.7275	2690.3329	6.6	0.25%	2643.06045	2657.80303	14.7	0.56%	2600.65883	2606.19373	5.5	0.21%	2683.73	2600.66	-3.10%	2690.33	2606.19	-3.13%
		Utility Based (Coal)	7.617776	2694.50165	2645.54863	-49.0	-1.82%	2644.09968	2633.06358	-11.0	-0.42%	2622.48413	2593.18945	-29.3	-1.12%	2694.50	2622.48	-2.67%	2645.55	2593.19	-1.98%
		Utility Based High	7.617776	2694.50165	2645.54863	-49.0	-1.82%	2647.95713	2629.46405	-18.5	-0.70%	2617.62578	2637.8174	20.2	0.77%	2694.50	2617.63	-2.85%	2645.55	2637.82	-0.29%
	ES(f)	Clear Sky w/Hg	8.528969	1714.32583	1713.9015	-0.4	-0.02%	1676.63203	1674.43483	-2.2	-0.13%	1650.92353	1654.3847	3.5	0.21%	1714.33	1650.92	-3.70%	1713.90	1654.38	-3.47%
	2	Clear Sky wo/Hg	8.528969	1700.6355	1720.5528	19.9	1.17%	1647.30563	1687.4259	40.1	2.44%	1649.8377	1662.74143	12.9	0.78%	1700.64	1649.84	-2.99%	1720.55	1662.74	-3.36%
		NAAQS	8.528969	1724.74817	1703.35277	-21.4	-1.24%	1659.7108	1670.12183	10.4	0.63%	1650.75527	1663.22303	12.5	0.76%	1724.75	1650.76	-4.29%	1703.35	1663.22	-2.36%
		Utility Based (Coal)	8.528969	1710.81653	1692.9425	-17.9	-1.04%	1641.94263	1672.0746	30.1	1.84%	1643.7716	1630.57453	-13.2	-0.80%	1710.82	1643.77	-3.92%	1692.94	1630.57	-3.68%
		Utility Based High	8.528969	1710.81653	1692.9425	-17.9	-1.04%	1646.67423	1661.39677	14.7	0.89%	1618.70543	1650.4152	31.7	1.96%	1710.82	1618.71	-5.38%	1692.94	1650.42	-2.51%
	P(s)	Clear Sky w/Hg	10.63525	10643.6333	10586.9745	-56.7	-0.53%	10458.5333	10453.88	-4.7	-0.04%	10445.8013	10460.1083	14.3	0.14%	10643.63	10445.80	-1.86%	10586.97	10460.11	-1.20%
	3	Clear Sky wo/Hg	10.63525	10557.541	10566.2045	8.7	0.08%	10537.725	10517.654	-20.1	-0.19%	10375.3935	10440.708	65.3	0.63%	10557.54	10375.39	-1.73%	10566.20	10440.71	-1.19%
		NAAQS	10.63525	10596.2443	10635.2483	39.0	0.37%	10528.8975	10474.636	-54.3	-0.52%	10416.5385	10371.574	-45.0	-0.43%	10596.24	10416.54	-1.70%	10635.25	10371.57	-2.48%
		Utility Based (Coal)	10.63525	10619.3755	10597.9685	-21.4	-0.20%	10513.1033	10550.9483	37.8	0.36%	10450.384	10461.5385	11.2	0.11%	10619.38	10450.38	-1.59%	10597.97	10461.54	-1.29%
		Utility Based High	10.63525	10619.3755	10597.9685	-21.4	-0.20%	10514.2125	10462.1288	-52.1	-0.50%	10431.6613	10434.498	2.8	0.03%	10619.38	10431.66	-1.77%	10597.97	10434.50	-1.54%
	P(l)	Clear Sky w/Hg	8.891487	13826.9808	13912.5002	85.5	0.62%	13396.3644	13395.5816	-0.8	-0.01%	13110.389	13013.8128	-96.6	-0.74%	13826.98	13110.39	-5.18%	13912.50	13013.81	-6.46%
	4	Clear Sky wo/Hg	8.891487	13790.1616	13750.5586	-39.6	-0.29%	13387.7248	13466.9268	79.2	0.59%	13098.9884	13128.0888	29.1	0.22%	13790.16	13098.99	-5.01%	13750.56	13128.09	-4.53%
		NAAQS	8.891487	13749.859	13900.2196	150.4	1.09%	13602.734	13429.8244	-172.9	-1.27%	12979.4636	12807.449	-172.0	-1.33%	13749.86	12979.46	-5.60%	13900.22	12807.45	-7.86%
		Utility Based (Coal)	8.891487	13600.4038	13717.083	116.7	0.86%	13225.2234	13200.4296	-24.8	-0.19%	12955.5172	13008.433	52.9	0.41%	13600.40	12955.52	-4.74%	13717.08	13008.43	-5.17%
		Utility Based High	8.891487	13600.4038	13717.083	116.7	0.86%	13089.8724	13190.2526	100.4	0.77%	12571.473	12628.9086	57.4	0.46%	13600.40	12571.47	-7.57%	13717.08	12628.91	-7.93%
		Clear Sky w/Hg		11212.2366	11211.1434	-1.1	-0.01%	11192.4358	11191.9114	-0.5	0.00%	11189.3056	11189.4934	0.2	0.00%	11212.24	11189.31	-0.20%	11211.14	11189.49	-0.19%
	5	Clear Sky wo/Hg		11209.4982	11212.0262	2.5	0.02%	11200.5222	11199.8464	-0.7	-0.01%	11191.6242	11188.3588	-3.3	-0.03%	11209.50	11191.62	-0.16%	11212.03	11188.36	-0.21%
		NAAQS		11208.0904	11206.3942	-1.7	-0.02%	11198.8916	11197.029	-1.9	-0.02%	11193.9252	11190.7112	-3.2	-0.03%	11208.09	11193.93	-0.13%	11206.39	11190.71	-0.14%
		Utility Based (Coal)		11206.889	11203.3108	-3.6	-0.03%	11198.3846	11203.8348	5.5	0.05%	11202.8932	11196.4854	-6.4	-0.06%	11206.89	11202.89	-0.04%	11203.31	11196.49	-0.06%
		Utility Based High		11206.889	11203.3108	-3.6	-0.03%	11200.3766	11200.1238	-0.3	0.00%	11193.4934	11194.2966	0.8	0.01%	11206.89	11193.49	-0.12%	11203.31	11194.30	-0.08%
	FD(l)	Clear Sky w/Hg	8.88	13843.6423	13944.572	100.9	0.73%	13330.7457	13426.203	95.5	0.72%	12909.8597	12819.1797	-90.7	-0.70%	13843.64	12909.86	-6.75%	13944.57	12819.18	-8.07%
	6	Clear Sky wo/Hg	8.88	13477.9677	13869.1417	391.2	2.90%	13420.3827	13490.678	70.3	0.52%	13008.2227	13116.6753	108.5	0.83%	13477.97	13008.22	-3.49%	13869.14	13116.68	-5.43%
		NAAQS	8.88	13584.8737	13665.5443	80.7	0.59%	13385.2423	13498.624	113.4	0.85%	12801.1927	12763.6037	-37.6	-0.29%	13584.87	12801.19	-5.77%	13665.54	12763.60	-6.60%
		Utility Based (Coal)	8.88	13652.2837	13389.6453	-262.6	-1.92%	13128.5707	13096.9863	-31.6	-0.24%	12866.296	12845.7907	-20.5	-0.16%	13652.28	12866.30	-5.76%	13389.65	12845.79	-4.06%
		Utility Based High	8.88	13652.2837	13389.6453	-262.6	-1.92%	13174.4953	13260.9113	86.4	0.66%	12767.1797	12690.1917	-77.0	-0.60%	13652.28	12767.18	-6.48%	13389.65	12690.19	-5.22%
	S(s)	Clear Sky w/Hg	11.96	6784.18167	6752.82933	-31.4	-0.46%	6643.69	6615.63967	-28.1	-0.42%	6566.826	6533.54967	-33.3	-0.51%	6784.18	6566.83	-3.20%	6752.83	6533.55	-3.25%
	7	Clear Sky wo/Hg	11.96	6635.028	6642.843	7.8	0.12%	6600.11433	6510.57033	-89.5	-1.36%	6521.13667	6530.475	9.3	0.14%	6635.03	6521.14	-1.72%	6642.84	6530.48	-1.69%
		NAAQS	11.96	6709.81267	6810.42633	100.6	1.50%	6607.67533	6587.413	-20.3	-0.31%	6541.93233	6502.32433	-39.6	-0.61%	6709.81	6541.93	-2.50%	6810.43	6502.32	-4.52%
		Utility Based (Coal)	11.96	6727.67533	6744.83933	17.2	0.26%	6565.14933	6581.89667	16.7	0.26%	6505.28833	6524.378	19.1	0.29%	6727.68	6505.29	-3.31%	6744.84	6524.38	-3.27%
		Utility Based High	11.96	6727.67533	6744.83933	17.2	0.26%	6539.35067	6512.76533	-26.6	-0.41%	6471.24633	6483.32733	12.1	0.19%	6727.68	6471.25	-3.81%	6744.84	6483.33	-3.88%
	S(l)	Clear Sky w/Hg	8.85	14329.1203	14262.9947	-66.1	-0.46%	13691.0273	13685.2033	-5.8	-0.04%	13324.139	13377.3597	53.2	0.40%	14329.12	13324.14	-7.01%	14262.99	13377.36	-6.21%
	8	Clear Sky wo/Hg	8.85	14163.0382	14295.1867	132.1	0.93%	13749.0992	13926.4532	177.4	1.29%	13316.5593	13494.5308	178.0	1.34%	14163.04	13316.56	-5.98%	14295.19	13494.53	-5.60%
		NAAQS	8.85	14191.2122	14317.1777	126.0	0.89%	13712.1202	13640.4728	-71.6	-0.52%	13092.4565	13223.4753	131.0	1.00%	14191.21	13092.46	-7.74%	14317.18	13223.48	-7.64%
		Utility Based (Coal)	8.85	14122.8287	13849.8337	-273.0	-1.93%	13529.152	13461.681	-67.5	-0.50%	13234.1303	13232.6533	-1.5	-0.01%	14122.83	13234.13	-6.29%	13849.83	13232.65	-4.46%
		Utility Based High	8.85	14122.8287	13849.8337	-273.0	-1.93%	13436.411	13437.7582	1.3	0.01%	13092.134	13221.0725	128.9	0.98%	14122.83	13092.13	-7.30%	13849.83	13221.07	-4.54%
		Clear Sky w/Hg		817.94795	817.9437	0.0	0.00%	817.952225	817.9806	0.0	0.00%	817.901575	817.927525	0.0	0.00%	817.95	817.90	-0.01%	817.94	817.93	0.00%
	9	Clear Sky wo/Hg		817.8881	817.93855	0.1	0.01%	817.925425	817.94195	0.0	0.00%	817.92615	817.943875	0.0	0.00%	817.89	817.93	0.00%	817.94	817.94	0.00%
		NAAQS		817.95515	817.925	0.0	0.00%	817.93895	817.959975	0.0	0.00%	817.914	817.9156	0.0	0.00%	817.96	817.91	-0.01%	817.93	817.92	0.00%
		Utility Based (Coal)		817.9861	817.875925	-0.1	-0.01%	817.8892	817.9398	0.1	0.01%	817.907975	817.9258	0.0	0.00%	817.99	817.91	-0.01%	817.88	817.93	0.01%
		Utility Based High		817.9861	817.875925	-0.1	-0.01%	817.93215	817.97565	0.0	0.01%	817.95465	817.94985	0.0	0.00%	817.99	817.95	0.00%	817.88	817.95	0.01%
		Clear Sky w/Hg		172.501187	172.627437	0.1	0.07%	172.404507	172.458683	0.1	0.03%	173.49884	173.24791	-0.3	-0.14%	172.50	173.50	0.58%	172.63	173.25	0.36%
	10	Clear Sky wo/Hg		172.237533	172.4252	0.2	0.11%	173.32356	172.820453	-0.5	-0.29%	172.980553	172.542127	-0.4	-0.25%	172.24	172.98	0.43%	172.43	172.54	0.07%
		NAAQS		172.77442	172.43339	-0.3	-0.20%	171.77402	172.028603	0.3	0.15%	173.022313	172.664677	-0.4	-0.21%	172.77	173.02	0.14%	172.43	172.66	0.13%
		Utility Based (Coal)		172.677873	172.635967	0.0	-0.02%	171.852887	172.359997	0.5	0.30%	172.52752	172.19249	-0.3	-0.19%	172.68	172.53	-0.09%	172.64	172.19	-0.26%
		Utility Based High		172.677873	172.635967	0.0	-0.02%	172.411787	172.726137	0.3	0.18%	172.555717	173.11449	0.6	0.32%	172.68	172.56	-0.07%	172.64	173.11	0.28%
		Clear Sky w/Hg		189.877343	189.84688	0.0	-0.02%	189.841403	189.849677	0.0	0.00%	190.024137	189.987863	0.0	-0.02%	189.88	190.02	0.08%	189.85	189.99	0.07%
	11	Clear Sky wo/Hg		189.858327	189.85757	0.0	0.00%	189.99253	189.906993	-0.1	-0.05%	189.926993	189.870007	-0.1	-0.03%	189.86	189.93	0.04%	189.86	189.87	0.01%
		NAAQS		189.90584	189.842717	-0.1	-0.03%	189.740313	189.741617	0.0	0.00%	189.925313	189.896433	0.0	-0.02%	189.91	189.93	0.01%	189.84	189.90	0.03%
		Utility Based (Coal)		189.89018	189.874363	0.0	-0.01%	189.788727	189.827823	0.0	0.02%	189.87817	189.874377	0.0	0.00%	189.89	189.88	-0.01%	189.87	189.87	0.00%
		Utility Based High		189.89018	189.874363	0.0	-0.01%	189.814153	189.88346	0.1	0.04%	189.918137	189.972657	0.1	0.03%	189.89	189.92	0.01%	189.87	189.97	0.05%
		Clear Sky w/Hg		3225.45408	3225.30474	-0.1	0.00%	3224.57008	3224.64568	0.1	0.00%	3224.20092	3224.07964	-0.1	0.00%	3225.45	3224.20	-0.04%	3225.30	3224.08	-0.04%
	12	Clear Sky wo/Hg		3224.91998	3225.24942	0.3	0.01%	3224.90308	3224.73096	-0.2	-0.01%	3224.39348	3224.24018	-0.2	0.00%	3224.92	3224.39	-0.02%	3225.25	3224.24	-0.03%
		NAAQS		3224.90922	3225.18456	0.3	0.01%	3224.79746	3224.6368	-0.2	0.00%	3224.76502	3224.33178	-0.4	-0.01%	3224.91	3224.77	0.00%	3225.18	3224.33	-0.03%
		Utility Based (Coal)		3225.20708	3224.91992	-0.3	-0.01%	3225.14524	3225.20146	0.1	0.00%	3224.69026	3224.60486	-0.1	0.00%	3225.21	3224.69	-0.02%	3224.92	3224.60	-0.01%
		Utility Based High		3225.20708	3224.91992	-0.3	-0.01%	3224.86676	3224.74406	-0.1	0.00%	3224.66892	3224.71756	0.0	0.00%	3225.21	3224.67	-0.02%	3224.92	3224.72	-0.01%
		Clear Sky w/Hg		4279.14234	4278.99633	-0.1	0.00%	4277.81284	4277.8153	0.0	0.00%	4277.40187	4277.34901	-0.1	0.00%	4279.14	4277.40	-0.04%	4279.00	4277.35	-0.04%
	13	Clear Sky wo/Hg		4278.70449	4278.68374	0.0	0.00%	4278.35594	4277.85261	-0.5	-0.01%	4277.70063	4277.73241	0.0	0.00%	4278.70	4277.70	-0.02%	4278.68	4277.73	-0.02%
		NAAQS		4278.43331	4278.80687	0.4	0.01%	4278.01547	4277.87469	-0.1	0.00%	4277.39156	4277.40614	0.0	0.00%	4278.43	4277.39	-0.02%	4278.81	4277.41	-0.03%
		Utility Based (Coal)		4278.43821	4278.54133	0.1	0.00%	4278.3274	4278.10123	-0.2	-0.01%	4277.61447	4277.67679	0.1	0.00%	4278.44	4277.61	-0.02%	4278.54	4277.68	-0.02%
		Utility Based High		4278.43821	4278.54133	0.1	0.00%	4277.96956	4278.20281	0.2	0.01%	4277.44897	4277.42706	0.0	0.00%	4278.44	4277.45	-0.02%	4278.54	4277.43	-0.03%
	SB(s)	Clear Sky w/Hg	4.13	45.8087987	47.0993003	1.3	2.82%	45.9176507	46.7373153	0.8	1.79%	45.2572723	46.130524	0.9	1.93%	45.81	45.26	-1.20%	47.10	46.13	-2.06%
	14	Clear Sky wo/Hg	4.13	47.5919827	48.502252	0.9	1.91%	46.4727143	45.3728187	-1.1	-2.37%	42.7344127	43.843885	1.1	2.60%	47.59	42.73	-10.21%	48.50	43.84	-9.60%
		NAAQS	4.13	49.45978	49.1167657	-0.3	-0.69%	43.0315103	43.8486017	0.8	1.90%	41.6179947	43.745283	2.1	5.11%	49.46	41.62	-15.85%	49.12	43.75	-10.94%
		Utility Based (Coal)	4.13	45.9836143	41.9755037	-4.0	-8.72%	43.0903137	43.265942	0.2	0.41%	40.8045453	41.18795	0.4	0.94%	45.98	40.80	-11.26%	41.98	41.19	-1.88%
		Utility Based High	4.13	45.9836143	41.9755037	-4.0	-8.72%	42.5779113	42.7042103	0.1	0.30%	41.6738553	42.303795	0.6	1.51%	45.98	41.67	-9.37%	41.98	42.30	0.78%
		Clear Sky w/Hg		1636.40539	1636.3992	0.0	0.00%	1636.27777	1636.30887	0.0	0.00%	1636.28151	1636.26714	0.0	0.00%	1636.41	1636.28	-0.01%	1636.40	1636.27	-0.01%
	15	Clear Sky wo/Hg		1636.40686	1636.34651	-0.1	0.00%	1636.31284	1636.26847	0.0	0.00%	1636.2025	1636.27391	0.1	0.00%	1636.41	1636.20	-0.01%	1636.35	1636.27	0.00%
		NAAQS		1636.33883	1636.34893	0.0	0.00%	1636.25724	1636.27871	0.0	0.00%	1636.20946	1636.18581	0.0	0.00%	1636.34	1636.21	-0.01%	1636.35	1636.19	-0.01%
		Utility Based (Coal)		1636.39531	1636.35654	0.0	0.00%	1636.35597	1636.33177	0.0	0.00%	1636.26119	1636.28997	0.0	0.00%	1636.40	1636.26	-0.01%	1636.36	1636.29	0.00%
		Utility Based High		1636.39531	1636.35654	0.0	0.00%	1636.31739	1636.31116	0.0	0.00%	1636.29507	1636.27029	0.0	0.00%	1636.40	1636.30	-0.01%	1636.36	1636.27	-0.01%

TABLE 21
Cannelton Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Cannelton	ES(s)	Clear Sky w/Hg	11.30	4336.0	4340.7	4.7	0.11%	4306.4	4301.9	-4.5	-0.10%	4295.5	4298.5	3.0	0.07%	4335.99	4295.45	-0.93%	4340.70	4298.48	-0.97%
	1	Clear Sky wo/Hg	11.30	4333.2	4328.9	-4.3	-0.10%	4299.4	4311.0	11.6	0.27%	4234.6	4272.3	37.7	0.89%	4333.20	4234.60	-2.28%	4328.92	4272.33	-1.31%
		NAAQS	11.30	4324.5	4346.2	21.8	0.50%	4318.8	4313.8	-5.0	-0.12%	4243.7	4243.3	-0.5	-0.01%	4324.45	4243.73	-1.87%	4346.21	4243.26	-2.37%
		Utility Based (Coal)	11.30	4327.2	4289.6	-37.6	-0.87%	4265.2	4274.1	8.8	0.21%	4253.9	4250.8	-3.1	-0.07%	4327.19	4253.92	-1.69%	4289.55	4250.82	-0.90%
		Utility Based High	11.30	4327.2	4289.6	-37.6	-0.87%	4299.7	4290.1	-9.5	-0.22%	4235.9	4260.7	24.8	0.59%	4327.19	4235.94	-2.11%	4289.55	4260.75	-0.67%
	ES(f)	Clear Sky w/Hg	5.71	1221.2	1213.6	-7.5	-0.62%	1204.4	1206.6	2.2	0.18%	1194.7	1193.4	-1.3	-0.11%	1221.16	1194.65	-2.17%	1213.61	1193.36	-1.67%
	2	Clear Sky wo/Hg	5.71	1209.6	1217.1	7.5	0.62%	1200.5	1211.9	11.4	0.95%	1188.7	1186.6	-2.2	-0.18%	1209.63	1188.74	-1.73%	1217.11	1186.58	-2.51%
		NAAQS	5.71	1219.5	1213.3	-6.2	-0.51%	1205.4	1213.0	7.6	0.63%	1186.0	1180.3	-5.6	-0.47%	1219.47	1185.96	-2.75%	1213.29	1180.33	-2.72%
		Utility Based (Coal)	5.71	1206.0	1211.2	5.2	0.43%	1199.8	1192.2	-7.5	-0.63%	1187.6	1185.7	-1.9	-0.16%	1205.99	1187.57	-1.53%	1211.22	1185.69	-2.11%
		Utility Based High	5.71	1206.0	1211.2	5.2	0.43%	1202.6	1199.7	-2.9	-0.25%	1186.7	1172.9	-13.9	-1.17%	1205.99	1186.74	-1.60%	1211.22	1172.87	-3.17%
	P(s)	Clear Sky w/Hg	12.19	12665.7	12641.7	-24.0	-0.19%	12529.8	12526.7	-3.1	-0.02%	12509.3	12514.7	5.4	0.04%	12665.74	12509.34	-1.23%	12641.75	12514.73	-1.00%
	3	Clear Sky wo/Hg	12.19	12593.1	12596.0	2.9	0.02%	12512.9	12559.0	46.2	0.37%	12437.1	12514.6	77.6	0.62%	12593.15	12437.06	-1.24%	12596.01	12514.62	-0.65%
		NAAQS	12.19	12611.5	12688.7	77.2	0.61%	12534.0	12538.7	4.7	0.04%	12470.7	12415.4	-55.3	-0.44%	12611.48	12470.72	-1.12%	12688.73	12415.39	-2.15%
		Utility Based (Coal)	12.19	12646.4	12624.2	-22.2	-0.18%	12568.1	12572.5	4.4	0.04%	12496.8	12487.9	-8.9	-0.07%	12646.36	12496.77	-1.18%	12624.15	12487.91	-1.08%
		Utility Based High	12.19	12646.4	12624.2	-22.2	-0.18%	12549.1	12494.9	-54.2	-0.43%	12454.3	12459.6	5.3	0.04%	12646.36	12454.30	-1.52%	12624.15	12459.57	-1.30%
	P(l)	Clear Sky w/Hg	11.80	17992.4	18022.4	29.9	0.17%	17149.2	17098.8	-50.4	-0.29%	16729.4	16716.0	-13.4	-0.08%	17992.44	16729.37	-7.02%	18022.36	16715.96	-7.25%
	4	Clear Sky wo/Hg	11.80	17805.9	17889.9	84.1	0.47%	17094.0	17073.6	-20.4	-0.12%	16452.2	16769.8	317.6	1.93%	17805.85	16452.22	-7.60%	17889.93	16769.84	-6.26%
		NAAQS	11.80	17835.0	17767.5	-67.6	-0.38%	17042.6	17231.0	188.4	1.11%	16265.4	16389.4	124.0	0.76%	17835.03	16265.42	-8.80%	17767.47	16389.45	-7.76%
		Utility Based (Coal)	11.80	17743.5	17795.4	51.9	0.29%	16917.7	17022.2	104.5	0.62%	16566.2	16163.5	-402.7	-2.43%	17743.53	16566.18	-6.64%	17795.42	16163.48	-9.17%
		Utility Based High	11.80	17743.5	17795.4	51.9	0.29%	17030.7	17022.6	-8.1	-0.05%	16002.3	16271.4	269.0	1.68%	17743.53	16002.33	-9.81%	17795.42	16271.37	-8.56%
	FD(l)	Clear Sky w/Hg	11.81	17735.4	17982.3	246.9	1.39%	17348.3	17384.2	35.9	0.21%	16787.3	16417.3	-370.1	-2.20%	17735.42	16787.34	-5.35%	17982.30	16417.25	-8.70%
	6	Clear Sky wo/Hg	11.81	17869.3	17709.5	-159.8	-0.89%	17259.4	17549.9	290.6	1.68%	16340.8	16867.5	526.7	3.22%	17869.26	16340.77	-8.55%	17709.48	16867.52	-4.75%
		NAAQS	11.81	17640.3	18216.7	576.4	3.27%	17322.2	17258.5	-63.7	-0.37%	16216.1	16663.7	447.7	2.76%	17640.31	16216.06	-8.07%	18216.71	16663.72	-8.53%
		Utility Based (Coal)	11.81	17870.0	17866.8	-3.2	-0.02%	17358.9	17136.6	-222.3	-1.28%	16953.8	16600.7	-353.1	-2.08%	17870.04	16953.84	-5.13%	17866.84	16600.71	-7.09%
		Utility Based High	11.81	17870.0	17866.8	-3.2	-0.02%	16718.7	17032.9	314.2	1.88%	16465.0	16192.0	-273.0	-1.66%	17870.04	16465.00	-7.86%	17866.84	16192.04	-9.37%
	S(s)	Clear Sky w/Hg	10.01	5455.5	5451.9	-3.6	-0.07%	5421.7	5419.8	-1.9	-0.04%	5265.8	5257.2	-8.7	-0.16%	5455.47	5265.82	-3.48%	5451.86	5257.16	-3.57%
	7	Clear Sky wo/Hg	10.01	5385.9	5420.9	35.0	0.65%	5391.5	5339.3	-52.2	-0.97%	5271.3	5263.2	-8.1	-0.15%	5385.86	5271.30	-2.13%	5420.89	5263.22	-2.91%
		NAAQS	10.01	5389.1	5469.2	80.1	1.49%	5319.0	5300.4	-18.6	-0.35%	5297.9	5255.4	-42.5	-0.80%	5389.10	5297.92	-1.69%	5469.18	5255.45	-3.91%
		Utility Based (Coal)	10.01	5411.1	5484.6	73.5	1.36%	5308.2	5424.1	115.9	2.18%	5269.7	5242.2	-27.5	-0.52%	5411.08	5269.72	-2.61%	5484.58	5242.18	-4.42%
		Utility Based High	10.01	5411.1	5484.6	73.5	1.36%	5345.8	5360.0	14.2	0.27%	5230.7	5286.1	55.5	1.06%	5411.08	5230.66	-3.33%	5484.58	5286.13	-3.62%
	S(l)	Clear Sky w/Hg	11.86	18852.2	18902.3	50.1	0.27%	18214.7	18151.7	-63.0	-0.35%	17682.6	17706.8	24.2	0.14%	18852.20	17682.63	-6.20%	18902.31	17706.84	-6.32%
	8	Clear Sky wo/Hg	11.86	18594.6	18822.9	228.3	1.23%	18160.9	18253.4	92.5	0.51%	17508.7	17966.3	457.6	2.61%	18594.63	17508.69	-5.84%	18822.89	17966.33	-4.55%
		NAAQS	11.86	18720.7	19260.1	539.4	2.88%	18188.2	18136.1	-52.1	-0.29%	17188.8	17377.4	188.5	1.10%	18720.71	17188.83	-8.18%	19260.11	17377.37	-9.78%
		Utility Based (Coal)	11.86	18875.2	18604.0	-271.2	-1.44%	17911.6	18074.2	162.6	0.91%	17465.1	17307.8	-157.3	-0.90%	18875.19	17465.06	-7.47%	18603.95	17307.78	-6.97%
		Utility Based High	11.86	18875.2	18604.0	-271.2	-1.44%	17921.4	17954.3	32.9	0.18%	17226.6	17351.2	124.6	0.72%	18875.19	17226.56	-8.73%	18603.95	17351.17	-6.73%
	SB(s)	Clear Sky w/Hg	8.34	117.7	118.7	1.0	0.81%	117.7	117.2	-0.5	-0.41%	112.2	110.4	-1.8	-1.65%	117.74	112.21	-4.70%	118.70	110.37	-7.02%
	14	Clear Sky wo/Hg	8.34	116.9	112.1	-4.8	-4.12%	113.2	114.4	1.2	1.07%	106.9	110.1	3.2	3.03%	116.86	106.86	-8.56%	112.05	110.09	-1.75%
		NAAQS	8.34	114.0	117.2	3.2	2.84%	111.9	110.5	-1.4	-1.24%	106.2	112.8	6.6	6.25%	114.01	106.16	-6.89%	117.25	112.80	-3.80%
		Utility Based (Coal)	8.34	120.4	114.8	-5.6	-4.69%	112.9	109.0	-3.9	-3.43%	109.6	109.3	-0.3	-0.28%	120.44	109.61	-8.99%	114.79	109.30	-4.78%
		Utility Based High	8.34	120.4	114.8	-5.6	-4.69%	107.6	108.5	0.9	0.82%	105.2	107.2	2.0	1.89%	120.44	105.23	-12.63%	114.79	107.22	-6.60%

TABLE 22
Newburgh Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Newburgh	ES(s)	Clear Sky w/Hg	8.38	2854.2	2869.6	15.3	0.54%	2844.5	2843.1	-1.4	-0.05%	2840.4	2831.8	-8.6	-0.30%	2854.21	2840.41	-0.48%	2869.55	2831.78	-1.32%
	1	Clear Sky wo/Hg	8.38	2831.4	2842.9	11.5	0.41%	2821.9	2849.8	27.9	0.99%	2774.4	2810.7	36.3	1.31%	2831.36	2774.41	-2.01%	2842.90	2810.68	-1.13%
		NAAQS	8.38	2839.4	2858.3	18.9	0.66%	2829.6	2834.5	4.9	0.17%	2767.0	2771.1	4.1	0.15%	2839.38	2767.02	-2.55%	2858.25	2771.13	-3.05%
		Utility Based (Coal)	8.38	2835.2	2827.3	-7.9	-0.28%	2824.5	2829.8	5.2	0.19%	2805.5	2797.3	-8.2	-0.29%	2835.24	2805.46	-1.05%	2827.29	2797.28	-1.06%
		Utility Based High	8.38	2835.2	2827.3	-7.9	-0.28%	2845.0	2840.9	-4.1	-0.14%	2794.8	2804.8	10.0	0.36%	2835.24	2794.80	-1.43%	2827.29	2804.82	-0.79%
	ES(f)	Clear Sky w/Hg	3.39	742.1	739.1	-3.0	-0.41%	737.2	737.8	0.6	0.08%	734.4	732.7	-1.8	-0.24%	742.08	734.42	-1.03%	739.07	732.66	-0.87%
	2	Clear Sky wo/Hg	3.39	737.8	739.4	1.6	0.21%	732.3	736.5	4.2	0.58%	731.0	728.2	-2.8	-0.38%	737.83	730.96	-0.93%	739.39	728.21	-1.51%
		NAAQS	3.39	739.8	739.9	0.1	0.01%	735.9	738.1	2.2	0.30%	730.5	729.8	-0.7	-0.10%	739.79	730.55	-1.25%	739.88	729.81	-1.36%
		Utility Based (Coal)	3.39	737.0	739.3	2.3	0.31%	733.5	732.3	-1.2	-0.17%	732.6	731.5	-1.0	-0.14%	736.98	732.55	-0.60%	739.25	731.52	-1.05%
		Utility Based High	3.39	737.0	739.3	2.3	0.31%	736.4	737.1	0.7	0.10%	733.0	727.9	-5.1	-0.69%	736.98	733.02	-0.54%	739.25	727.94	-1.53%
	P(s)	Clear Sky w/Hg	8.10	8164.4	8193.4	29.0	0.36%	8109.0	8115.1	6.0	0.07%	8085.8	8060.0	-25.8	-0.32%	8164.38	8085.84	-0.96%	8193.39	8060.03	-1.63%
	3	Clear Sky wo/Hg	8.10	8144.9	8139.1	-5.9	-0.07%	8066.7	8103.5	36.9	0.46%	8010.1	8040.4	30.3	0.38%	8144.91	8010.13	-1.65%	8139.06	8040.42	-1.21%
		NAAQS	8.10	8122.4	8203.2	80.8	0.99%	8077.2	8073.0	-4.2	-0.05%	8020.9	7995.7	-25.3	-0.31%	8122.44	8020.95	-1.25%	8203.25	7995.69	-2.53%
		Utility Based (Coal)	8.10	8165.0	8149.8	-15.2	-0.19%	8086.3	8111.7	25.3	0.31%	8068.0	8052.5	-15.5	-0.19%	8165.00	8068.04	-1.19%	8149.77	8052.51	-1.19%
		Utility Based High	8.10	8165.0	8149.8	-15.2	-0.19%	8090.5	8060.7	-29.8	-0.37%	8052.3	8040.1	-12.2	-0.15%	8165.00	8052.28	-1.38%	8149.77	8040.09	-1.35%
	P(l)	Clear Sky w/Hg	7.93	12669.1	12645.8	-23.3	-0.18%	12342.9	12303.1	-39.9	-0.32%	12078.5	12019.9	-58.6	-0.48%	12669.11	12078.47	-4.66%	12645.77	12019.91	-4.95%
	4	Clear Sky wo/Hg	7.93	12592.7	12596.1	3.4	0.03%	12162.6	12214.6	52.0	0.43%	11812.2	11948.3	136.1	1.15%	12592.66	11812.19	-6.20%	12596.07	11948.28	-5.14%
		NAAQS	7.93	12680.8	12651.1	-29.7	-0.23%	12111.3	12259.7	148.4	1.23%	11764.1	11919.4	155.3	1.32%	12680.82	11764.14	-7.23%	12651.12	11919.43	-5.78%
		Utility Based (Coal)	7.93	12635.6	12617.7	-17.9	-0.14%	12146.8	12298.9	152.1	1.25%	12046.9	11772.4	-274.5	-2.28%	12635.62	12046.91	-4.66%	12617.70	11772.42	-6.70%
		Utility Based High	7.93	12635.6	12617.7	-17.9	-0.14%	12285.5	12287.2	1.7	0.01%	11860.0	11991.6	131.6	1.11%	12635.62	11860.01	-6.14%	12617.70	11991.57	-4.96%
	FD(l)	Clear Sky w/Hg	7.95	12572.0	12768.8	196.7	1.56%	12246.9	12304.4	57.5	0.47%	12004.6	11947.8	-56.8	-0.47%	12572.03	12004.62	-4.51%	12768.78	11947.79	-6.43%
	6	Clear Sky wo/Hg	7.95	12585.0	12576.4	-8.7	-0.07%	12243.6	12291.6	48.0	0.39%	11821.0	12042.2	221.2	1.87%	12585.02	11821.04	-6.07%	12576.36	12042.20	-4.25%
		NAAQS	7.95	12536.4	12733.3	196.8	1.57%	12388.6	12245.1	-143.5	-1.16%	11793.7	11929.0	135.3	1.15%	12536.43	11793.67	-5.92%	12733.25	11928.97	-6.32%
		Utility Based (Coal)	7.95	12755.5	12739.9	-15.5	-0.12%	12282.2	12205.6	-76.6	-0.62%	12279.9	12049.0	-230.9	-1.88%	12755.48	12279.92	-3.73%	12739.93	12049.05	-5.42%
		Utility Based High	7.95	12755.5	12739.9	-15.5	-0.12%	12201.1	12324.1	123.0	1.01%	12188.5	11925.7	-262.9	-2.16%	12755.48	12188.53	-4.44%	12739.93	11925.65	-6.39%
	S(s)	Clear Sky w/Hg	7.93	4367.7	4365.8	-1.9	-0.04%	4369.7	4375.4	5.6	0.13%	4247.2	4240.5	-6.7	-0.16%	4367.72	4247.21	-2.76%	4365.83	4240.50	-2.87%
	7	Clear Sky wo/Hg	7.93	4289.7	4327.0	37.4	0.87%	4281.3	4256.5	-24.8	-0.58%	4230.2	4235.9	5.7	0.13%	4289.65	4230.19	-1.39%	4327.02	4235.90	-2.11%
		NAAQS	7.93	4330.2	4382.3	52.1	1.20%	4288.5	4276.5	-12.0	-0.28%	4252.1	4247.5	-4.7	-0.11%	4330.21	4252.15	-1.80%	4382.28	4247.48	-3.08%
		Utility Based (Coal)	7.93	4344.0	4379.1	35.1	0.81%	4301.3	4339.1	37.8	0.88%	4249.8	4246.4	-3.5	-0.08%	4343.98	4249.83	-2.17%	4379.11	4246.37	-3.03%
		Utility Based High	7.93	4344.0	4379.1	35.1	0.81%	4309.1	4293.1	-16.0	-0.37%	4245.8	4274.5	28.8	0.68%	4343.98	4245.76	-2.26%	4379.11	4274.55	-2.39%
	S(l)	Clear Sky w/Hg	7.91	12997.1	12993.9	-3.2	-0.02%	12736.6	12698.6	-38.0	-0.30%	12412.1	12490.6	78.5	0.63%	12997.10	12412.14	-4.50%	12993.87	12490.63	-3.87%
	8	Clear Sky wo/Hg	7.91	12863.6	12952.1	88.5	0.69%	12676.2	12597.8	-78.4	-0.62%	12271.4	12404.7	133.3	1.09%	12863.56	12271.41	-4.60%	12952.07	12404.72	-4.23%
		NAAQS	7.91	13034.0	13242.1	208.1	1.60%	12695.7	12609.4	-86.2	-0.68%	12141.1	12310.2	169.1	1.39%	13034.03	12141.13	-6.85%	13242.12	12310.19	-7.04%
		Utility Based (Coal)	7.91	13050.7	13089.5	38.8	0.30%	12542.1	12603.2	61.1	0.49%	12296.4	12287.1	-9.3	-0.08%	13050.68	12296.42	-5.78%	13089.47	12287.07	-6.13%
		Utility Based High	7.91	13050.7	13089.5	38.8	0.30%	12669.5	12565.8	-103.7	-0.82%	12422.6	12424.3	1.8	0.01%	13050.68	12422.55	-4.81%	13089.47	12424.32	-5.08%
	SB(s)	Clear Sky w/Hg	3.68	36.0	36.7	0.6	1.78%	36.6	36.5	-0.1	-0.23%	34.4	33.6	-0.9	-2.54%	36.03	34.44	-4.40%	36.67	33.56	-8.46%
	14	Clear Sky wo/Hg	3.68	37.0	35.1	-1.9	-5.23%	34.6	35.7	1.1	3.11%	33.4	33.8	0.3	0.97%	37.01	33.44	-9.65%	35.08	33.77	-3.73%
		NAAQS	3.68	36.0	36.0	-0.1	-0.17%	35.3	33.9	-1.4	-3.98%	31.7	32.9	1.2	3.87%	36.01	31.70	-11.99%	35.95	32.92	-8.43%
		Utility Based (Coal)	3.68	37.9	36.6	-1.3	-3.47%	34.6	33.1	-1.5	-4.22%	34.0	33.7	-0.3	-0.98%	37.95	34.00	-10.40%	36.63	33.67	-8.09%
		Utility Based High	3.68	37.9	36.6	-1.3	-3.47%	33.7	33.6	-0.1	-0.28%	33.3	33.3	0.1	0.16%	37.95	33.28	-12.29%	36.63	33.33	-9.00%

TABLE 23
J T Myers Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
JTMyers	ES(s)	Clear Sky w/Hg	11.28	3963.3	3970.8	7.5	0.19%	3907.4	3919.2	11.8	0.30%	3892.1	3884.3	-7.8	-0.20%	3963.30	3892.13	-1.80%	3970.81	3884.30	-2.18%
	1	Clear Sky wo/Hg	11.28	3924.1	3911.8	-12.3	-0.31%	3894.2	3905.1	10.9	0.28%	3828.4	3853.6	25.1	0.66%	3924.14	3828.41	-2.44%	3911.85	3853.55	-1.49%
		NAAQS	11.28	3940.9	3973.4	32.4	0.82%	3916.2	3909.7	-6.5	-0.17%	3801.8	3795.5	-6.3	-0.17%	3940.94	3801.79	-3.53%	3973.37	3795.45	-4.48%
		Utility Based (Coal)	11.28	3920.0	3910.0	-10.0	-0.25%	3901.0	3917.2	16.2	0.42%	3835.7	3819.2	-16.5	-0.43%	3919.96	3835.73	-2.15%	3910.00	3819.19	-2.32%
		Utility Based High	11.28	3920.0	3910.0	-10.0	-0.25%	3914.4	3936.3	21.9	0.56%	3846.1	3838.7	-7.3	-0.19%	3919.96	3846.07	-1.89%	3910.00	3838.74	-1.82%
	ES(f)	Clear Sky w/Hg	6.26	1370.7	1367.7	-3.0	-0.22%	1360.4	1360.8	0.3	0.02%	1351.1	1350.3	-0.7	-0.05%	1370.67	1351.06	-1.43%	1367.68	1350.33	-1.27%
	2	Clear Sky wo/Hg	6.26	1361.9	1368.1	6.2	0.46%	1350.9	1356.8	5.9	0.44%	1352.1	1342.5	-9.6	-0.71%	1361.91	1352.08	-0.72%	1368.11	1342.46	-1.87%
		NAAQS	6.26	1367.0	1365.9	-1.0	-0.08%	1357.2	1361.8	4.6	0.34%	1348.7	1347.6	-1.1	-0.08%	1366.99	1348.67	-1.34%	1365.95	1347.55	-1.35%
		Utility Based (Coal)	6.26	1359.9	1363.6	3.7	0.27%	1354.8	1352.7	-2.1	-0.16%	1349.3	1346.2	-3.1	-0.23%	1359.90	1349.29	-0.78%	1363.56	1346.21	-1.27%
		Utility Based High	6.26	1359.9	1363.6	3.7	0.27%	1357.6	1363.0	5.3	0.39%	1352.5	1341.3	-11.2	-0.83%	1359.90	1352.49	-0.54%	1363.56	1341.27	-1.63%
	P(s)	Clear Sky w/Hg	9.31	9531.5	9537.6	6.2	0.06%	9460.6	9464.5	3.9	0.04%	9405.3	9399.2	-6.1	-0.06%	9531.46	9405.28	-1.32%	9537.63	9399.18	-1.45%
	3	Clear Sky wo/Hg	9.31	9487.7	9510.1	22.4	0.24%	9452.9	9446.0	-6.9	-0.07%	9313.0	9365.8	52.9	0.57%	9487.70	9312.96	-1.84%	9510.12	9365.82	-1.52%
		NAAQS	9.31	9490.2	9544.0	53.7	0.57%	9420.8	9422.0	1.2	0.01%	9338.9	9319.4	-19.5	-0.21%	9490.23	9338.89	-1.59%	9543.96	9319.38	-2.35%
		Utility Based (Coal)	9.31	9506.9	9515.5	8.5	0.09%	9448.5	9432.3	-16.2	-0.17%	9386.0	9348.2	-37.9	-0.40%	9506.94	9386.04	-1.27%	9515.49	9348.19	-1.76%
		Utility Based High	9.31	9506.9	9515.5	8.5	0.09%	9433.1	9399.5	-33.6	-0.36%	9383.6	9366.7	-16.9	-0.18%	9506.94	9383.58	-1.30%	9515.49	9366.71	-1.56%
	P(l)	Clear Sky w/Hg	9.69	15898.1	15814.4	-83.7	-0.53%	15554.2	15539.3	-14.9	-0.10%	15134.6	15176.8	42.2	0.28%	15898.12	15134.63	-4.80%	15814.39	15176.80	-4.03%
	4	Clear Sky wo/Hg	9.69	15779.3	15797.5	18.2	0.12%	15206.7	15347.1	140.4	0.92%	14932.1	15027.9	95.8	0.64%	15779.33	14932.05	-5.37%	15797.55	15027.90	-4.87%
		NAAQS	9.69	15803.3	15732.7	-70.6	-0.45%	15225.6	15401.6	176.0	1.16%	14840.7	14879.4	38.7	0.26%	15803.30	14840.68	-6.09%	15732.69	14879.39	-5.42%
		Utility Based (Coal)	9.69	15753.6	15759.4	5.8	0.04%	15169.6	15378.1	208.5	1.37%	15008.6	14705.3	-303.4	-2.02%	15753.63	15008.64	-4.73%	15759.41	14705.26	-6.69%
		Utility Based High	9.69	15753.6	15759.4	5.8	0.04%	15415.7	15382.5	-33.2	-0.22%	14858.8	14955.5	96.7	0.65%	15753.63	14858.80	-5.68%	15759.41	14955.50	-5.10%
	FD(l)	Clear Sky w/Hg	9.67	15472.8	15788.4	315.6	2.04%	15319.2	15336.7	17.5	0.11%	14946.9	14811.5	-135.4	-0.91%	15472.79	14946.86	-3.40%	15788.37	14811.49	-6.19%
	6	Clear Sky wo/Hg	9.67	15519.9	15662.4	142.5	0.92%	15303.1	15147.2	-155.9	-1.02%	14671.1	15096.3	425.2	2.90%	15519.85	14671.09	-5.47%	15662.36	15096.31	-3.61%
		NAAQS	9.67	15727.6	15710.0	-17.6	-0.11%	15359.9	15312.5	-47.4	-0.31%	14840.7	14867.4	26.7	0.18%	15727.62	14840.72	-5.64%	15710.02	14867.37	-5.36%
		Utility Based (Coal)	9.67	15833.8	15761.6	-72.2	-0.46%	15353.7	15181.0	-172.7	-1.12%	15192.4	14905.5	-286.8	-1.89%	15833.80	15192.39	-4.05%	15761.61	14905.55	-5.43%
		Utility Based High	9.67	15833.8	15761.6	-72.2	-0.46%	15169.1	15309.6	140.6	0.93%	14960.4	14674.1	-286.3	-1.91%	15833.80	14960.40	-5.52%	15761.61	14674.07	-6.90%
	S(s)	Clear Sky w/Hg	9.19	5229.0	5221.7	-7.2	-0.14%	5220.9	5226.7	5.8	0.11%	5145.6	5180.6	35.0	0.68%	5228.95	5145.56	-1.59%	5221.73	5180.56	-0.79%
	7	Clear Sky wo/Hg	9.19	5188.3	5228.4	40.1	0.77%	5176.0	5187.7	11.7	0.23%	5094.9	5122.2	27.3	0.54%	5188.33	5094.93	-1.80%	5228.43	5122.24	-2.03%
		NAAQS	9.19	5201.6	5264.4	62.7	1.21%	5142.1	5138.2	-3.9	-0.08%	5149.3	5112.3	-37.0	-0.72%	5201.62	5149.32	-1.01%	5264.35	5112.33	-2.89%
		Utility Based (Coal)	9.19	5216.4	5251.5	35.1	0.67%	5152.6	5206.2	53.6	1.04%	5115.0	5122.6	7.6	0.15%	5216.41	5114.98	-1.94%	5251.49	5122.58	-2.45%
		Utility Based High	9.19	5216.4	5251.5	35.1	0.67%	5141.9	5187.9	46.0	0.89%	5138.6	5164.8	26.2	0.51%	5216.41	5138.64	-1.49%	5251.49	5164.82	-1.65%
	S(l)	Clear Sky w/Hg	9.76	16365.7	16417.5	51.7	0.32%	16126.2	16110.5	-15.7	-0.10%	15673.2	15756.8	83.6	0.53%	16365.73	15673.16	-4.23%	16417.48	15756.75	-4.02%
	8	Clear Sky wo/Hg	9.76	16254.6	16346.5	91.9	0.57%	16023.6	15949.1	-74.5	-0.46%	15502.8	15745.3	242.5	1.56%	16254.57	15502.82	-4.62%	16346.52	15745.32	-3.68%
		NAAQS	9.76	16398.2	16604.0	205.8	1.25%	15946.9	15932.0	-14.9	-0.09%	15351.1	15553.3	202.3	1.32%	16398.19	15351.06	-6.39%	16603.98	15553.31	-6.33%
		Utility Based (Coal)	9.76	16353.1	16378.2	25.1	0.15%	15867.8	15844.0	-23.8	-0.15%	15559.0	15489.5	-69.5	-0.45%	16353.07	15559.04	-4.86%	16378.17	15489.54	-5.43%
		Utility Based High	9.76	16353.1	16378.2	25.1	0.15%	15840.0	15853.5	13.5	0.08%	15608.4	15609.8	1.4	0.01%	16353.07	15608.39	-4.55%	16378.17	15609.76	-4.69%
	SB(s)	Clear Sky w/Hg	4.59	45.2	48.1	3.0	6.53%	47.6	47.9	0.3	0.56%	44.1	43.8	-0.3	-0.66%	45.18	44.08	-2.44%	48.13	43.79	-9.02%
	14	Clear Sky wo/Hg	4.59	46.4	44.7	-1.7	-3.68%	45.7	48.3	2.6	5.69%	42.0	42.6	0.6	1.52%	46.40	42.01	-9.47%	44.70	42.65	-4.59%
		NAAQS	4.59	47.5	46.9	-0.6	-1.24%	45.4	44.1	-1.3	-2.77%	40.7	44.5	3.8	9.27%	47.53	40.72	-14.33%	46.94	44.49	-5.22%
		Utility Based (Coal)	4.59	48.2	47.0	-1.2	-2.58%	46.4	43.1	-3.4	-7.23%	43.9	43.6	-0.4	-0.80%	48.20	43.91	-8.91%	46.96	43.55	-7.24%
		Utility Based High	4.59	48.2	47.0	-1.2	-2.58%	43.3	43.7	0.4	0.86%	43.8	43.2	-0.5	-1.24%	48.20	43.75	-9.22%	46.96	43.21	-7.98%

TABLE 24
Smithland Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010 Without Project HSI Units	2010 With Project HSI Units	2010 Delta	2010 % Delta	2040 Without Project HSI Units	2040 With Project HSI Units	2040 Delta	2040 % Delta	2070 Without Project HSI Units	2070 With Project HSI Units	2070 Delta	2070 % Delta	2010-2070 Without Project 2010	2010-2070 Without Project 2070	2010-2070 % Delta	2010-2070 With Project 2010	2010-2070 With Project 2070	2010-2070 % Delta
Smithland	ES(s)	Clear Sky w/Hg	4.79	1826.217	1822.304	-3.9	-0.21%	1805.714	1806.248	0.5	0.03%	1814.638	1804.251	-10.4	-0.57%	1826.22	1814.64	-0.63%	1822.30	1804.25	-0.99%
	1	Clear Sky wo/Hg	4.79	1815.755	1813.467	-2.3	-0.13%	1799.958	1796.177	-3.8	-0.21%	1784.449	1791.653	7.2	0.40%	1815.76	1784.45	-1.72%	1813.47	1791.65	-1.20%
		NAAQS	4.79	1814.576	1824.204	9.6	0.53%	1802.461	1800.166	-2.3	-0.13%	1787.847	1783.847	-4.0	-0.22%	1814.58	1787.85	-1.47%	1824.20	1783.85	-2.21%
		Utility Based (Coal)	4.79	1814.106	1809.537	-4.6	-0.25%	1798.582	1799.942	1.4	0.08%	1792.99	1786.177	-6.8	-0.38%	1814.11	1792.99	-1.16%	1809.54	1786.18	-1.29%
		Utility Based High	4.79	1814.106	1809.537	-4.6	-0.25%	1799.426	1805.846	6.4	0.36%	1784.757	1786.734	2.0	0.11%	1814.11	1784.76	-1.62%	1809.54	1786.73	-1.26%
	ES(f)	Clear Sky w/Hg	2.15	466.3759	464.621	-1.8	-0.38%	462.0236	462.5175	0.5	0.11%	458.5298	458.8051	0.3	0.06%	466.38	458.53	-1.68%	464.62	458.81	-1.25%
	2	Clear Sky wo/Hg	2.15	463.3846	463.9663	0.6	0.13%	458.9324	458.9129	0.0	0.00%	457.7385	454.8922	-2.8	-0.62%	463.38	457.74	-1.22%	463.97	454.89	-1.96%
		NAAQS	2.15	464.9638	463.7005	-1.3	-0.27%	460.2909	461.458	1.2	0.25%	456.537	459.1613	2.6	0.57%	464.96	456.54	-1.81%	463.70	459.16	-0.98%
		Utility Based (Coal)	2.15	463.0967	464.828	1.7	0.37%	456.573	458.3861	1.8	0.40%	456.1021	454.511	-1.6	-0.35%	463.10	456.10	-1.51%	464.83	454.51	-2.22%
		Utility Based High	2.15	463.0967	464.828	1.7	0.37%	459.9038	460.1533	0.2	0.05%	453.4504	451.1066	-2.3	-0.52%	463.10	453.45	-2.08%	464.83	451.11	-2.95%
	P(s)	Clear Sky w/Hg	4.11	4259.064	4266.117	7.1	0.17%	4230.027	4234.176	4.1	0.10%	4230.373	4227.63	-2.7	-0.06%	4259.06	4230.37	-0.67%	4266.12	4227.63	-0.90%
	3	Clear Sky wo/Hg	4.11	4243.923	4256.393	12.5	0.29%	4233.926	4234.72	0.8	0.02%	4198.947	4207.937	9.0	0.21%	4243.92	4198.95	-1.06%	4256.39	4207.94	-1.14%
		NAAQS	4.11	4249.292	4272.675	23.4	0.55%	4222.01	4228.886	6.9	0.16%	4202.053	4202.07	0.0	0.00%	4249.29	4202.05	-1.11%	4272.68	4202.07	-1.65%
		Utility Based (Coal)	4.11	4262.116	4262.821	0.7	0.02%	4234.94	4230.872	-4.1	-0.10%	4221.022	4213.716	-7.3	-0.17%	4262.12	4221.02	-0.96%	4262.82	4213.72	-1.15%
		Utility Based High	4.11	4262.116	4262.821	0.7	0.02%	4218.283	4220.116	1.8	0.04%	4214.992	4207.947	-7.0	-0.17%	4262.12	4214.99	-1.11%	4262.82	4207.95	-1.29%
	P(l)	Clear Sky w/Hg	4.33	7075.217	7024.292	-50.9	-0.72%	6897.942	6907.108	9.2	0.13%	6721.316	6726.247	4.9	0.07%	7075.22	6721.32	-5.00%	7024.29	6726.25	-4.24%
	4	Clear Sky wo/Hg	4.33	7037.58	7042.289	4.7	0.07%	6759.43	6788.013	28.6	0.42%	6589.741	6588.184	-1.6	-0.02%	7037.58	6589.74	-6.36%	7042.29	6588.18	-6.45%
		NAAQS	4.33	7049.443	6974.981	-74.5	-1.06%	6721.196	6801.226	80.0	1.19%	6518.486	6559.542	41.1	0.63%	7049.44	6518.49	-7.53%	6974.98	6559.54	-5.96%
		Utility Based (Coal)	4.33	7008.953	6999.777	-9.2	-0.13%	6673.474	6761.188	87.7	1.31%	6558.891	6491.521	-67.4	-1.03%	7008.95	6558.89	-6.42%	6999.78	6491.52	-7.26%
		Utility Based High	4.33	7008.953	6999.777	-9.2	-0.13%	6712.07	6681.105	-31.0	-0.46%	6423.581	6452.69	29.1	0.45%	7008.95	6423.58	-8.35%	6999.78	6452.69	-7.82%
	FD(a)	Clear Sky w/Hg		3826.408	3825.099	-1.3	-0.03%	3823.141	3823.191	0.1	0.00%	3822.101	3821.896	-0.2	-0.01%	3826.41	3822.10	-0.11%	3825.10	3821.90	-0.08%
	5	Clear Sky wo/Hg		3826.261	3826.645	0.4	0.01%	3821.959	3823.075	1.1	0.03%	3821.169	3821.171	0.0	0.00%	3826.26	3821.17	-0.13%	3826.65	3821.17	-0.14%
		NAAQS		3824.979	3824.67	-0.3	-0.01%	3822.781	3823.131	0.4	0.01%	3820.855	3820.164	-0.7	-0.02%	3824.98	3820.85	-0.11%	3824.67	3820.16	-0.12%
		Utility Based (Coal)		3825.38	3824.848	-0.5	-0.01%	3822.668	3824.046	1.4	0.04%	3822.448	3821.328	-1.1	-0.03%	3825.38	3822.45	-0.08%	3824.85	3821.33	-0.09%
		Utility Based High		3825.38	3824.848	-0.5	-0.01%	3823.309	3823.462	0.2	0.00%	3821.302	3821.44	0.1	0.00%	3825.38	3821.30	-0.11%	3824.85	3821.44	-0.09%
	FD(l)	Clear Sky w/Hg	4.34	6907.001	7039.453	132.5	1.92%	6866.102	6881.832	15.7	0.23%	6676.89	6622.976	-53.9	-0.81%	6907.00	6676.89	-3.33%	7039.45	6622.98	-5.92%
	6	Clear Sky wo/Hg	4.34	6993.638	7036.966	43.3	0.62%	6801.078	6740.473	-60.6	-0.89%	6515.724	6649.378	133.7	2.05%	6993.64	6515.72	-6.83%	7036.97	6649.38	-5.51%
		NAAQS	4.34	7035.66	7036.692	1.0	0.01%	6834.2	6823.561	-10.6	-0.16%	6668.4	6548.395	-120.0	-1.80%	7035.66	6668.40	-5.22%	7036.69	6548.39	-6.94%
		Utility Based (Coal)	4.34	7105.234	7050.931	-54.3	-0.76%	6788.9	6765.756	-23.1	-0.34%	6669.358	6568.155	-101.2	-1.52%	7105.23	6669.36	-6.13%	7050.93	6568.15	-6.85%
		Utility Based High	4.34	7105.234	7050.931	-54.3	-0.76%	6609.332	6677.736	68.4	1.03%	6464.663	6412.819	-51.8	-0.80%	7105.23	6464.66	-9.02%	7050.93	6412.82	-9.05%
	S(s)	Clear Sky w/Hg	3.03	1739.231	1743.893	4.7	0.27%	1730.757	1734.513	3.8	0.22%	1699.65	1706.117	6.5	0.38%	1739.23	1699.65	-2.28%	1743.89	1706.12	-2.17%
	7	Clear Sky wo/Hg	3.03	1722.232	1730.519	8.3	0.48%	1704.915	1706.937	2.0	0.12%	1691.745	1696.572	4.8	0.29%	1722.23	1691.75	-1.77%	1730.52	1696.57	-1.96%
		NAAQS	3.03	1729.096	1740.651	11.6	0.67%	1706.223	1697.484	-8.7	-0.51%	1704.414	1691.013	-13.4	-0.79%	1729.10	1704.41	-1.43%	1740.65	1691.01	-2.85%
		Utility Based (Coal)	3.03	1737.714	1738.946	1.2	0.07%	1711.812	1719.082	7.3	0.42%	1698.743	1701.052	2.3	0.14%	1737.71	1698.74	-2.24%	1738.95	1701.05	-2.18%
		Utility Based High	3.03	1737.714	1738.946	1.2	0.07%	1703.759	1710.418	6.7	0.39%	1692.83	1697.683	4.9	0.29%	1737.71	1692.83	-2.58%	1738.95	1697.68	-2.37%
	S(l)	Clear Sky w/Hg	4.31	7109.828	7189.193	79.4	1.12%	7010.78	7033.937	23.2	0.33%	6845.961	6876.845	30.9	0.45%	7109.83	6845.96	-3.71%	7189.19	6876.84	-4.34%
	8	Clear Sky wo/Hg	4.31	7104.787	7140.935	36.1	0.51%	6943.976	6924.15	-19.8	-0.29%	6696.058	6785.461	89.4	1.34%	7104.79	6696.06	-5.75%	7140.93	6785.46	-4.98%
		NAAQS	4.31	7152.077	7222.869	70.8	0.99%	6895.584	6920.716	25.1	0.36%	6661.862	6749.551	87.7	1.32%	7152.08	6661.86	-6.85%	7222.87	6749.55	-6.55%
		Utility Based (Coal)	4.31	7147.951	7182.247	34.3	0.48%	6858.808	6829.088	-29.7	-0.43%	6712.326	6714.358	2.0	0.03%	7147.95	6712.33	-6.09%	7182.25	6714.36	-6.51%
		Utility Based High	4.31	7147.951	7182.247	34.3	0.48%	6786.255	6737.684	-48.6	-0.72%	6650.807	6621.769	-29.0	-0.44%	7147.95	6650.81	-6.96%	7182.25	6621.77	-7.80%
	CC(y)	Clear Sky w/Hg		252.6596	252.6489	0.0	0.00%	252.6155	252.6196	0.0	0.00%	252.665	252.6607	0.0	0.00%	252.66	252.67	0.00%	252.65	252.66	0.00%
	9	Clear Sky wo/Hg		252.6797	252.6429	0.0	-0.01%	252.632	252.6172	0.0	-0.01%	252.6594	252.6518	0.0	0.00%	252.68	252.66	-0.01%	252.64	252.65	0.00%
		NAAQS		252.6439	252.6249	0.0	-0.01%	252.6732	252.674	0.0	0.00%	252.6657	252.6475	0.0	-0.01%	252.64	252.67	0.01%	252.62	252.65	0.01%
		Utility Based (Coal)		252.6513	252.6638	0.0	0.00%	252.7104	252.6694	0.0	-0.02%	252.6787	252.6761	0.0	0.00%	252.65	252.68	0.01%	252.66	252.68	0.00%
		Utility Based High		252.6513	252.6638	0.0	0.00%	252.6258	252.6445	0.0	0.01%	252.7016	252.6827	0.0	-0.01%	252.65	252.70	0.02%	252.66	252.68	0.01%
	BC(s)	Clear Sky w/Hg		80.06569	80.08036	0.0	0.02%	79.80183	79.72027	-0.1	-0.10%	79.8055	79.89992	0.1	0.12%	80.07	79.81	-0.32%	80.08	79.90	-0.23%
	10	Clear Sky wo/Hg		79.85235	79.64496	-0.2	-0.26%	80.20712	79.85856	-0.3	-0.43%	79.76649	79.99541	0.2	0.29%	79.85	79.77	-0.11%	79.64	80.00	0.44%
		NAAQS		80.03089	80.01593	0.0	-0.02%	80.05003	80.23842	0.2	0.24%	79.82193	80.16659	0.3	0.43%	80.03	79.82	-0.26%	80.02	80.17	0.19%
		Utility Based (Coal)		79.739	80.22461	0.5	0.61%	79.73562	80.07919	0.3	0.43%	80.0537	79.87132	-0.2	-0.23%	79.74	80.05	0.39%	80.22	79.87	-0.44%
		Utility Based High		79.739	80.22461	0.5	0.61%	80.12109	79.76339	-0.4	-0.45%	80.11665	79.83674	-0.3	-0.35%	79.74	80.12	0.47%	80.22	79.84	-0.48%
	BC(f)	Clear Sky w/Hg		81.92156	81.93554	0.0	0.02%	81.88215	81.86133	0.0	-0.03%	81.86633	81.8753	0.0	0.01%	81.92	81.87	-0.07%	81.94	81.88	-0.07%
	11	Clear Sky wo/Hg		81.89116	81.82753	-0.1	-0.08%	81.94239	81.87691	-0.1	-0.08%	81.86412	81.89731	0.0	0.04%	81.89	81.86	-0.03%	81.83	81.90	0.09%
		NAAQS		81.9157	81.9044	0.0	-0.01%	81.91921	81.943	0.0	0.03%	81.88451	81.93369	0.0	0.06%	81.92	81.88	-0.04%	81.90	81.93	0.04%
		Utility Based (Coal)		81.8345	81.9527	0.1	0.14%	81.86062	81.90445	0.0	0.05%	81.92342	81.8877	0.0	-0.04%	81.83	81.92	0.11%	81.95	81.89	-0.08%
		Utility Based High		81.8345	81.9527	0.1	0.14%	81.91133	81.86218	0.0	-0.06%	81.90536	81.86723	0.0	-0.05%	81.83	81.91	0.09%	81.95	81.87	-0.10%
	BC(j)	Clear Sky w/Hg		1242.827	1242.798	0.0	0.00%	1242.685	1242.663	0.0	0.00%	1242.553	1242.49	-0.1	-0.01%	1242.83	1242.55	-0.02%	1242.80	1242.49	-0.02%
	12	Clear Sky wo/Hg		1242.762	1242.71	-0.1	0.00%	1242.598	1242.594	0.0	0.00%	1242.431	1242.586	0.2	0.01%	1242.76	1242.43	-0.03%	1242.71	1242.59	-0.01%
		NAAQS		1242.754	1242.793	0.0	0.00%	1242.664	1242.661	0.0	0.00%	1242.41	1242.554	0.1	0.01%	1242.75	1242.41	-0.03%	1242.79	1242.55	-0.02%
		Utility Based (Coal)		1242.847	1242.669	-0.2	-0.01%	1242.628	1242.587	0.0	0.00%	1242.581	1242.617	0.0	0.00%	1242.85	1242.58	-0.02%	1242.67	1242.62	0.00%
		Utility Based High		1242.847	1242.669	-0.2	-0.01%	1242.585	1242.621	0.0	0.00%	1242.556	1242.427	-0.1	-0.01%	1242.85	1242.56	-0.02%	1242.67	1242.43	-0.02%
	BC(a)	Clear Sky w/Hg		1860.825	1860.872	0.0	0.00%	1860.661	1860.602	-0.1	0.00%	1860.358	1860.366	0.0	0.00%	1860.83	1860.36	-0.03%	1860.87	1860.37	-0.03%
	13	Clear Sky wo/Hg		1860.832	1860.709	-0.1	-0.01%	1860.538	1860.418	-0.1	-0.01%	1860.205	1860.255	0.1	0.00%	1860.83	1860.21	-0.03%	1860.71	1860.26	-0.02%
		NAAQS		1860.86	1860.922	0.1	0.00%	1860.509	1860.527	0.0	0.00%	1860.25	1860.329	0.1	0.00%	1860.86	1860.25	-0.03%	1860.92	1860.33	-0.03%
		Utility Based (Coal)		1860.764	1860.795	0.0	0.00%	1860.507	1860.548	0.0	0.00%	1860.418	1860.459	0.0	0.00%	1860.76	1860.42	-0.02%	1860.80	1860.46	-0.02%
		Utility Based High		1860.764	1860.795	0.0	0.00%	1860.536	1860.556	0.0	0.00%	1860.249	1860.319	0.1	0.00%	1860.76	1860.25	-0.03%	1860.80	1860.32	-0.03%
	SB(s)	Clear Sky w/Hg	1.73	23.63872	25.06976	1.4	6.05%	24.81292	24.56551	-0.2	-1.00%	24.29506	23.88075	-0.4	-1.71%	23.64	24.30	2.78%	25.07	23.88	-4.74%
	14	Clear Sky wo/Hg	1.73	24.25266	23.70867	-0.5	-2.24%	24.0194	24.06708	0.0	0.20%	22.87096	23.14224	0.3	1.19%	24.25	22.87	-5.70%	23.71	23.14	-2.39%
		NAAQS	1.73	24.11122	24.59181	0.5	1.99%	23.62626	23.4746	-0.2	-0.64%	23.12634	23.22481	0.1	0.43%	24.11	23.13	-4.08%	24.59	23.22	-5.56%
		Utility Based (Coal)	1.73	25.16856	24.75636	-0.4	-1.64%	23.58706	23.38065	-0.2	-0.88%	23.67835	23.08099	-0.6	-2.52%	25.17	23.68	-5.92%	24.76	23.08	-6.77%
		Utility Based High	1.73	25.16856	24.75636	-0.4	-1.64%	22.72559	22.58817	-0.1	-0.60%	22.61423	22.51721	-0.1	-0.43%	25.17	22.61	-10.15%	24.76	22.52	-9.04%
	SB(j)	Clear Sky w/Hg		590.8089	590.7903	0.0	0.00%	590.7173	590.702	0.0	0.00%	590.7958	590.7686	0.0	0.00%	590.81	590.80	0.00%	590.79	590.77	0.00%
	15	Clear Sky wo/Hg		590.7675	590.7571	0.0	0.00%	590.7945	590.8378	0.0	0.01%	590.7524	590.7528	0.0	0.00%	590.77	590.75	0.00%	590.76	590.75	0.00%
		NAAQS		590.7597	590.7513	0.0	0.00%	590.7476	590.7616	0.0	0.00%	590.8146	590.8173	0.0	0.00%	590.76	590.81	0.01%	590.75	590.82	0.01%
		Utility Based (Coal)		590.8009	590.8189	0.0	0.00%	590.737	590.7171	0.0	0.00%	590.7569	590.7681	0.0	0.00%	590.80	590.76	-0.01%	590.82	590.77	-0.01%
		Utility Based High		590.7805	590.7411	0.0	-0.01%	590.8146	590.8173	0.0	0.00%	590.7225	590.7094	0.0	0.00%	590.78	590.72	-0.01%	590.74	590.71	-0.01%

TABLE 25
Lock Dam 52 Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
L&D 52	ES(s)	Clear Sky w/Hg	0.96	342.7	340.8	-1.8	-0.54%	338.7	339.3	0.5	0.15%	343.5	341.5	-2.0	-0.59%	342.67	343.55	0.25%	340.83	341.53	0.21%
	1	Clear Sky wo/Hg	0.96	340.6	339.5	-1.1	-0.33%	338.4	340.7	2.3	0.67%	336.7	338.5	1.9	0.56%	340.62	336.66	-1.16%	339.50	338.55	-0.28%
		NAAQS	0.96	340.2	341.7	1.5	0.43%	339.4	337.4	-2.0	-0.59%	336.6	335.2	-1.4	-0.41%	340.21	336.60	-1.06%	341.67	335.21	-1.89%
		Utility Based (Coal)	0.96	340.9	341.7	0.8	0.24%	339.7	338.3	-1.3	-0.39%	339.2	338.9	-0.3	-0.09%	340.91	339.23	-0.49%	341.74	338.91	-0.83%
		Utility Based High	0.96	340.9	341.7	0.8	0.24%	340.3	339.9	-0.4	-0.11%	336.7	339.4	2.7	0.80%	340.91	336.66	-1.25%	341.74	339.35	-0.70%
	ES(f)	Clear Sky w/Hg	0.67	151.1	151.0	-0.1	-0.06%	150.8	150.9	0.1	0.08%	150.8	150.8	0.0	0.00%	151.08	150.78	-0.20%	150.99	150.78	-0.14%
	2	Clear Sky wo/Hg	0.67	151.0	151.0	0.1	0.06%	150.8	150.7	-0.2	-0.11%	150.7	150.6	-0.1	-0.05%	150.95	150.67	-0.19%	151.05	150.60	-0.30%
		NAAQS	0.67	151.0	151.0	0.0	-0.02%	150.8	150.8	0.0	-0.02%	150.7	150.8	0.1	0.09%	150.98	150.69	-0.19%	150.96	150.82	-0.09%
		Utility Based (Coal)	0.67	150.8	151.0	0.2	0.11%	150.8	150.7	-0.1	-0.04%	150.7	150.7	0.0	-0.01%	150.84	150.70	-0.09%	151.01	150.68	-0.22%
		Utility Based High	0.67	150.8	151.0	0.2	0.11%	150.9	150.9	0.0	-0.02%	150.5	150.5	0.0	-0.02%	150.84	150.50	-0.22%	151.01	150.48	-0.35%
	P(s)	Clear Sky w/Hg	3.17	3256.4	3248.0	-8.3	-0.26%	3240.0	3240.8	0.8	0.02%	3234.5	3230.1	-4.4	-0.14%	3256.35	3234.48	-0.67%	3248.03	3230.09	-0.55%
	3	Clear Sky wo/Hg	3.17	3250.2	3256.2	5.9	0.18%	3243.0	3226.7	-16.3	-0.50%	3213.7	3220.4	6.7	0.21%	3250.23	3213.68	-1.12%	3256.17	3220.39	-1.10%
		NAAQS	3.17	3248.7	3255.3	6.6	0.20%	3237.2	3226.8	-10.4	-0.32%	3217.4	3219.6	2.1	0.07%	3248.70	3217.42	-0.96%	3255.30	3219.56	-1.10%
		Utility Based (Coal)	3.17	3255.7	3254.7	-0.9	-0.03%	3241.5	3233.1	-8.3	-0.26%	3232.5	3227.2	-5.3	-0.16%	3255.69	3232.46	-0.71%	3254.74	3227.16	-0.85%
		Utility Based High	3.17	3255.7	3254.7	-0.9	-0.03%	3224.1	3226.0	1.9	0.06%	3233.8	3221.4	-12.5	-0.39%	3255.69	3233.85	-0.67%	3254.74	3221.37	-1.03%
	P(l)	Clear Sky w/Hg	3.02	5034.3	5012.1	-22.2	-0.44%	4937.1	4938.9	1.8	0.04%	4838.3	4834.9	-3.4	-0.07%	5034.29	4838.29	-3.89%	5012.08	4834.91	-3.53%
	4	Clear Sky wo/Hg	3.02	5021.8	5027.2	5.3	0.11%	4874.6	4889.0	14.4	0.30%	4795.4	4786.3	-9.2	-0.19%	5021.82	4795.42	-4.51%	5027.15	4786.25	-4.79%
		NAAQS	3.02	5041.8	5006.9	-34.8	-0.69%	4861.3	4896.2	34.9	0.72%	4759.0	4769.4	10.4	0.22%	5041.76	4759.00	-5.61%	5006.93	4769.43	-4.74%
		Utility Based (Coal)	3.02	5006.7	5010.2	3.4	0.07%	4838.5	4877.1	38.6	0.80%	4773.2	4755.5	-17.8	-0.37%	5006.75	4773.24	-4.66%	5010.20	4755.47	-5.08%
		Utility Based High	3.02	5006.7	5010.2	3.4	0.07%	4850.8	4840.9	-9.8	-0.20%	4719.1	4733.1	14.1	0.30%	5006.75	4719.07	-5.75%	5010.20	4733.15	-5.53%
	FD(l)	Clear Sky w/Hg	3.03	4992.0	5032.6	40.6	0.81%	4947.6	4948.5	0.9	0.02%	4829.2	4814.5	-14.7	-0.30%	4991.98	4829.23	-3.26%	5032.60	4814.55	-4.33%
	6	Clear Sky wo/Hg	3.03	5007.1	5047.6	40.5	0.81%	4897.4	4874.7	-22.8	-0.46%	4758.0	4824.7	66.7	1.40%	5007.11	4757.98	-4.98%	5047.60	4824.72	-4.42%
		NAAQS	3.03	5030.5	5051.7	21.2	0.42%	4910.1	4921.1	11.0	0.22%	4823.4	4781.6	-41.8	-0.87%	5030.46	4823.35	-4.12%	5051.66	4781.56	-5.35%
		Utility Based (Coal)	3.03	5078.9	5038.7	-40.2	-0.79%	4907.9	4885.7	-22.2	-0.45%	4839.8	4779.3	-60.5	-1.25%	5078.90	4839.77	-4.71%	5038.72	4779.25	-5.15%
		Utility Based High	3.03	5078.9	5038.7	-40.2	-0.79%	4841.9	4860.0	18.1	0.37%	4742.3	4731.0	-11.3	-0.24%	5078.90	4742.33	-6.63%	5038.72	4731.03	-6.11%
	S(s)	Clear Sky w/Hg	2.49	1498.1	1504.2	6.1	0.40%	1492.9	1498.7	5.8	0.39%	1479.6	1485.8	6.2	0.42%	1498.10	1479.57	-1.24%	1504.17	1485.81	-1.22%
	7	Clear Sky wo/Hg	2.49	1486.5	1493.0	6.5	0.44%	1469.1	1474.4	5.3	0.36%	1473.9	1479.4	5.6	0.38%	1486.54	1473.88	-0.85%	1493.02	1479.44	-0.91%
		NAAQS	2.49	1492.9	1502.8	10.0	0.67%	1475.7	1472.3	-3.4	-0.23%	1480.5	1472.6	-7.9	-0.53%	1492.89	1480.52	-0.83%	1502.84	1472.60	-2.01%
		Utility Based (Coal)	2.49	1495.1	1504.7	9.6	0.64%	1489.5	1490.7	1.2	0.08%	1479.3	1484.5	5.2	0.35%	1495.12	1479.33	-1.06%	1504.72	1484.52	-1.34%
		Utility Based High	2.49	1495.1	1504.7	9.6	0.64%	1482.0	1485.2	3.2	0.22%	1474.4	1476.6	2.2	0.15%	1495.12	1474.37	-1.39%	1504.72	1476.57	-1.87%
	S(l)	Clear Sky w/Hg	3.07	5240.5	5271.1	30.6	0.58%	5163.3	5169.1	5.8	0.11%	5073.8	5090.3	16.4	0.32%	5240.47	5073.85	-3.18%	5271.08	5090.26	-3.43%
	8	Clear Sky wo/Hg	3.07	5248.9	5245.8	-3.1	-0.06%	5138.9	5123.7	-15.2	-0.30%	5026.1	5056.2	30.1	0.60%	5248.90	5026.09	-4.24%	5245.77	5056.21	-3.61%
		NAAQS	3.07	5245.8	5296.2	50.4	0.96%	5102.8	5106.8	4.0	0.08%	5010.2	5043.4	33.1	0.66%	5245.76	5010.24	-4.49%	5296.19	5043.38	-4.77%
		Utility Based (Coal)	3.07	5244.2	5269.1	24.8	0.47%	5094.2	5085.7	-8.5	-0.17%	5026.9	5023.0	-3.9	-0.08%	5244.24	5026.92	-4.14%	5269.08	5023.00	-4.67%
		Utility Based High	3.07	5244.2	5269.1	24.8	0.47%	5079.1	5054.2	-24.8	-0.49%	5008.6	5002.5	-6.1	-0.12%	5244.24	5008.62	-4.49%	5269.08	5002.53	-5.06%
	SB(s)	Clear Sky w/Hg	1.61	40.2	41.3	1.1	2.77%	41.4	41.1	-0.4	-0.87%	40.1	40.0	-0.1	-0.29%	40.21	40.10	-0.27%	41.33	39.99	-3.24%
	14	Clear Sky wo/Hg	1.61	40.6	40.0	-0.6	-1.53%	40.3	40.2	-0.1	-0.30%	39.4	39.4	-0.1	-0.14%	40.62	39.42	-2.97%	40.00	39.36	-1.61%
		NAAQS	1.61	40.8	40.8	0.0	0.12%	39.0	39.7	0.7	1.67%	39.5	40.0	0.5	1.37%	40.80	39.48	-3.22%	40.84	40.02	-2.02%
		Utility Based (Coal)	1.61	40.6	40.7	0.1	0.33%	40.0	39.6	-0.3	-0.82%	39.6	39.5	-0.1	-0.31%	40.61	39.58	-2.53%	40.74	39.46	-3.14%
		Utility Based High	1.61	40.6	40.7	0.1	0.33%	39.6	39.2	-0.4	-1.09%	39.3	39.3	0.0	-0.10%	40.61	39.30	-3.24%	40.74	39.26	-3.65%

TABLE 26
Lock Dam 53 Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
L&D 53	ES(s)	Clear Sky w/Hg	0.88	336.0	336.0	0.0	-0.01%	336.8	335.6	-1.2	-0.36%	341.7	339.9	-1.8	-0.52%	335.99	341.65	1.68%	335.96	339.87	1.16%
	1	Clear Sky wo/Hg	0.88	336.1	336.9	0.8	0.25%	335.6	336.4	0.9	0.25%	334.4	335.4	1.0	0.29%	336.07	334.41	-0.49%	336.90	335.38	-0.45%
		NAAQS	0.88	337.6	336.2	-1.4	-0.41%	336.6	337.9	1.2	0.37%	334.9	333.9	-1.0	-0.31%	337.57	334.93	-0.78%	336.19	333.88	-0.69%
		Utility Based (Coal)	0.88	336.1	337.3	1.2	0.35%	338.6	338.2	-0.4	-0.11%	335.5	337.9	2.4	0.71%	336.10	335.51	-0.18%	337.30	337.88	0.17%
		Utility Based High	0.88	336.1	337.3	1.2	0.35%	336.5	339.4	2.9	0.86%	335.8	334.2	-1.6	-0.46%	336.10	335.76	-0.10%	337.30	334.21	-0.91%
	ES(f)	Clear Sky w/Hg	1.17	262.9	262.8	0.0	-0.02%	262.6	262.6	0.0	0.00%	262.3	262.3	0.0	0.01%	262.85	262.31	-0.21%	262.80	262.35	-0.17%
	2	Clear Sky wo/Hg	1.17	262.8	262.9	0.1	0.03%	262.5	262.5	0.0	-0.01%	262.4	262.3	-0.1	-0.04%	262.78	262.41	-0.14%	262.86	262.29	-0.22%
		NAAQS	1.17	262.9	262.8	-0.1	-0.04%	262.6	262.7	0.1	0.05%	262.3	262.4	0.1	0.06%	262.90	262.26	-0.24%	262.78	262.41	-0.14%
		Utility Based (Coal)	1.17	262.7	262.8	0.1	0.03%	262.4	262.5	0.1	0.04%	262.3	262.3	0.0	-0.01%	262.70	262.32	-0.15%	262.78	262.29	-0.19%
		Utility Based High	1.17	262.7	262.8	0.1	0.03%	262.5	262.6	0.1	0.03%	262.3	262.2	-0.1	-0.02%	262.70	262.28	-0.16%	262.78	262.21	-0.22%
	P(s)	Clear Sky w/Hg	5.75	6071.0	6065.1	-5.9	-0.10%	6039.2	6041.1	1.9	0.03%	6013.7	6016.8	3.1	0.05%	6071.02	6013.74	-0.94%	6065.14	6016.79	-0.80%
	3	Clear Sky wo/Hg	5.75	6060.9	6057.9	-3.0	-0.05%	6039.9	6034.6	-5.3	-0.09%	6009.3	6001.8	-7.5	-0.12%	6060.85	6009.29	-0.85%	6057.85	6001.80	-0.93%
		NAAQS	5.75	6054.6	6071.7	17.2	0.28%	6031.0	6026.1	-4.8	-0.08%	5989.9	6007.8	17.9	0.30%	6054.56	5989.90	-1.07%	6071.74	6007.81	-1.05%
		Utility Based (Coal)	5.75	6069.2	6065.8	-3.4	-0.06%	6038.1	6030.9	-7.2	-0.12%	6006.3	6007.8	1.5	0.02%	6069.21	6006.33	-1.04%	6065.79	6007.79	-0.96%
		Utility Based High	5.75	6069.2	6065.8	-3.4	-0.06%	6037.2	6018.8	-18.4	-0.30%	6006.2	6010.6	4.3	0.07%	6069.21	6006.24	-1.04%	6065.79	6010.56	-0.91%
	P(l)	Clear Sky w/Hg	5.36	9178.9	9131.4	-47.5	-0.52%	9025.2	9026.6	1.4	0.02%	8821.9	8824.2	2.3	0.03%	9178.87	8821.93	-3.89%	9131.41	8824.21	-3.36%
	4	Clear Sky wo/Hg	5.36	9172.7	9176.3	3.6	0.04%	8974.1	8975.7	1.7	0.02%	8838.0	8813.4	-24.6	-0.28%	9172.69	8838.04	-3.65%	9176.33	8813.42	-3.95%
		NAAQS	5.36	9200.5	9144.7	-55.8	-0.61%	8972.3	9008.1	35.8	0.40%	8768.5	8780.4	11.9	0.14%	9200.54	8768.53	-4.70%	9144.73	8780.43	-3.98%
		Utility Based (Coal)	5.36	9115.3	9133.4	18.1	0.20%	8919.8	8966.1	46.3	0.52%	8783.3	8762.3	-21.0	-0.24%	9115.33	8783.28	-3.64%	9133.39	8762.26	-4.06%
		Utility Based High	5.36	9115.3	9133.4	18.1	0.20%	8939.6	8930.4	-9.2	-0.10%	8733.9	8739.5	5.6	0.06%	9115.33	8733.91	-4.18%	9133.39	8739.55	-4.31%
	FD(l)	Clear Sky w/Hg	5.37	9122.6	9136.5	13.9	0.15%	9058.5	9048.1	-10.4	-0.11%	8810.9	8777.3	-33.6	-0.38%	9122.55	8810.91	-3.42%	9136.47	8777.34	-3.93%
	6	Clear Sky wo/Hg	5.37	9143.0	9199.8	56.8	0.62%	8977.0	8932.1	-44.9	-0.50%	8770.3	8843.9	73.7	0.84%	9142.98	8770.25	-4.08%	9199.83	8843.93	-3.87%
		NAAQS	5.37	9159.8	9184.9	25.1	0.27%	9012.2	9002.9	-9.4	-0.10%	8874.7	8854.7	-20.0	-0.23%	9159.80	8874.69	-3.11%	9184.90	8854.71	-3.59%
		Utility Based (Coal)	5.37	9221.3	9167.3	-54.0	-0.59%	9005.1	8939.9	-65.2	-0.72%	8872.9	8749.7	-123.2	-1.39%	9221.29	8872.94	-3.78%	9167.32	8749.72	-4.56%
		Utility Based High	5.37	9221.3	9167.3	-54.0	-0.59%	8956.2	8952.1	-4.2	-0.05%	8741.4	8733.9	-7.5	-0.09%	9221.29	8741.40	-5.20%	9167.32	8733.88	-4.73%
	S(s)	Clear Sky w/Hg	3.83	2278.9	2288.9	10.1	0.44%	2267.8	2268.5	0.7	0.03%	2246.9	2246.7	-0.2	-0.01%	2278.88	2246.92	-1.40%	2288.94	2246.70	-1.85%
	7	Clear Sky wo/Hg	3.83	2256.3	2264.3	8.0	0.36%	2239.0	2246.8	7.8	0.35%	2246.0	2253.8	7.8	0.35%	2256.32	2246.02	-0.46%	2264.34	2253.81	-0.46%
		NAAQS	3.83	2270.3	2284.4	14.1	0.62%	2250.3	2243.0	-7.3	-0.32%	2248.8	2234.4	-14.4	-0.64%	2270.30	2248.81	-0.95%	2284.38	2234.41	-2.19%
		Utility Based (Coal)	3.83	2266.4	2268.4	2.0	0.09%	2258.7	2262.3	3.6	0.16%	2243.3	2240.1	-3.2	-0.14%	2266.42	2243.26	-1.02%	2268.43	2240.08	-1.25%
		Utility Based High	3.83	2266.4	2268.4	2.0	0.09%	2246.0	2261.0	15.1	0.67%	2248.3	2237.8	-10.5	-0.47%	2266.42	2248.28	-0.80%	2268.43	2237.78	-1.35%
	S(l)	Clear Sky w/Hg	5.45	9637.9	9662.9	25.0	0.26%	9495.8	9492.5	-3.4	-0.04%	9313.6	9333.8	20.2	0.22%	9637.92	9313.61	-3.36%	9662.91	9333.76	-3.41%
	8	Clear Sky wo/Hg	5.45	9637.8	9626.6	-11.1	-0.12%	9528.3	9456.9	-71.4	-0.75%	9317.1	9361.5	44.5	0.48%	9637.76	9317.06	-3.33%	9626.62	9361.53	-2.75%
		NAAQS	5.45	9634.0	9708.4	74.4	0.77%	9434.8	9430.6	-4.2	-0.04%	9271.2	9318.8	47.7	0.51%	9633.97	9271.18	-3.77%	9708.38	9318.83	-4.01%
		Utility Based (Coal)	5.45	9606.2	9626.0	19.8	0.21%	9417.3	9404.1	-13.2	-0.14%	9271.6	9258.6	-13.0	-0.14%	9606.18	9271.61	-3.48%	9625.95	9258.63	-3.82%
		Utility Based High	5.45	9606.2	9626.0	19.8	0.21%	9413.3	9418.2	4.9	0.05%	9303.6	9290.2	-13.4	-0.14%	9606.18	9303.58	-3.15%	9625.95	9290.16	-3.49%
	SB(s)	Clear Sky w/Hg	1.76	17.7	18.8	1.1	6.34%	19.2	19.1	-0.2	-0.85%	17.4	17.3	-0.1	-0.58%	17.71	17.38	-1.86%	18.83	17.28	-8.24%
	14	Clear Sky wo/Hg	1.76	18.0	17.7	-0.2	-1.22%	17.7	17.4	-0.2	-1.37%	16.9	16.6	-0.3	-1.73%	17.96	16.93	-5.72%	17.74	16.64	-6.21%
		NAAQS	1.76	18.7	18.4	-0.3	-1.49%	16.7	17.0	0.2	1.32%	16.8	17.5	0.7	4.10%	18.68	16.82	-9.98%	18.40	17.50	-4.88%
		Utility Based (Coal)	1.76	18.0	17.5	-0.5	-2.75%	17.7	16.5	-1.1	-6.39%	16.8	16.5	-0.3	-2.04%	18.02	16.83	-6.63%	17.52	16.48	-5.95%
		Utility Based High	1.76	18.0	17.5	-0.5	-2.75%	16.8	16.6	-0.2	-1.24%	16.0	16.4	0.4	2.43%	18.02	16.00	-11.21%	17.52	16.39	-6.48%

TABLE 27
Open River
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Open River	ES(s)	Clear Sky w/Hg	0.34	131.0	131.2	0.3	0.20%	130.0	129.8	-0.2	-0.16%	131.4	131.8	0.5	0.36%	130.95	131.37	0.32%	131.21	131.85	0.48%
	1	Clear Sky wo/Hg	0.34	130.2	130.8	0.6	0.43%	129.9	130.0	0.1	0.10%	130.6	130.5	-0.1	-0.07%	130.20	130.57	0.29%	130.76	130.48	-0.22%
		NAAQS	0.34	131.8	130.4	-1.3	-0.99%	130.4	130.2	-0.1	-0.11%	130.3	130.1	-0.2	-0.12%	131.75	130.26	-1.14%	130.44	130.10	-0.27%
		Utility Based (Coal)	0.34	131.2	130.4	-0.8	-0.62%	130.1	130.1	0.0	-0.01%	131.3	131.7	0.4	0.32%	131.22	131.26	0.03%	130.40	131.69	0.98%
		Utility Based High	0.34	131.2	130.4	-0.8	-0.62%	130.2	130.6	0.3	0.25%	130.8	130.9	0.1	0.06%	131.22	130.80	-0.32%	130.40	130.88	0.36%
	ES(f)	Clear Sky w/Hg	0.27	61.6	61.6	0.0	-0.01%	61.6	61.6	0.0	0.02%	61.5	61.5	0.0	0.01%	61.64	61.54	-0.16%	61.63	61.55	-0.14%
	2	Clear Sky wo/Hg	0.27	61.6	61.6	0.0	0.00%	61.6	61.6	0.0	-0.04%	61.6	61.6	0.0	0.00%	61.63	61.55	-0.13%	61.63	61.55	-0.13%
		NAAQS	0.27	61.6	61.6	0.0	-0.01%	61.6	61.6	0.0	0.05%	61.5	61.6	0.0	0.03%	61.64	61.55	-0.14%	61.63	61.57	-0.11%
		Utility Based (Coal)	0.27	61.6	61.6	0.0	0.02%	61.6	61.6	0.0	0.04%	61.5	61.5	0.0	-0.01%	61.63	61.54	-0.15%	61.64	61.53	-0.18%
		Utility Based High	0.27	61.6	61.6	0.0	0.02%	61.6	61.6	0.0	0.01%	61.5	61.5	0.0	0.02%	61.63	61.52	-0.17%	61.64	61.54	-0.17%
	P(s)	Clear Sky w/Hg	3.02	3018.7	3018.0	-0.8	-0.02%	3002.8	2999.6	-3.1	-0.10%	2987.7	2989.6	1.9	0.06%	3018.71	2987.71	-1.03%	3017.96	2989.62	-0.94%
	3	Clear Sky wo/Hg	3.02	3015.5	3014.4	-1.1	-0.04%	3002.8	2995.6	-7.1	-0.24%	2981.3	2979.6	-1.7	-0.06%	3015.49	2981.31	-1.13%	3014.37	2979.60	-1.15%
		NAAQS	3.02	3011.0	3024.2	13.2	0.44%	3000.7	2999.2	-1.5	-0.05%	2976.0	2991.8	15.8	0.53%	3011.03	2975.96	-1.16%	3024.24	2991.77	-1.07%
		Utility Based (Coal)	3.02	3023.7	3013.9	-9.8	-0.32%	2997.2	2993.1	-4.1	-0.14%	2979.3	2983.5	4.2	0.14%	3023.68	2979.29	-1.47%	3013.93	2983.46	-1.01%
		Utility Based High	3.02	3023.7	3013.9	-9.8	-0.32%	2999.4	2990.4	-9.1	-0.30%	2985.4	2983.8	-1.6	-0.06%	3023.68	2985.40	-1.27%	3013.93	2983.75	-1.00%
	P(l)	Clear Sky w/Hg	2.94	4919.9	4892.1	-27.8	-0.57%	4816.9	4821.8	4.9	0.10%	4690.9	4686.7	-4.2	-0.09%	4919.89	4690.93	-4.65%	4892.09	4686.74	-4.20%
	4	Clear Sky wo/Hg	2.94	4920.3	4922.7	2.4	0.05%	4783.7	4775.7	-8.0	-0.17%	4700.3	4688.6	-11.7	-0.25%	4920.30	4700.31	-4.47%	4922.70	4688.59	-4.76%
		NAAQS	2.94	4935.2	4899.6	-35.6	-0.72%	4775.8	4796.8	21.0	0.44%	4646.4	4668.4	22.0	0.47%	4935.17	4646.41	-5.85%	4899.56	4668.41	-4.72%
		Utility Based (Coal)	2.94	4875.2	4892.5	17.2	0.35%	4757.3	4779.4	22.1	0.47%	4657.9	4646.4	-11.5	-0.25%	4875.23	4657.93	-4.46%	4892.46	4646.40	-5.03%
		Utility Based High	2.94	4875.2	4892.5	17.2	0.35%	4764.7	4763.3	-1.3	-0.03%	4630.0	4626.2	-3.7	-0.08%	4875.23	4629.98	-5.03%	4892.46	4626.23	-5.44%
	FD(l)	Clear Sky w/Hg	2.94	4892.9	4893.1	0.2	0.00%	4837.7	4823.8	-13.9	-0.29%	4687.5	4658.6	-28.9	-0.62%	4892.86	4687.52	-4.20%	4893.06	4658.63	-4.79%
	6	Clear Sky wo/Hg	2.94	4905.4	4941.8	36.4	0.74%	4790.1	4753.9	-36.2	-0.76%	4662.1	4708.9	46.8	1.00%	4905.44	4662.09	-4.96%	4941.82	4708.92	-4.71%
		NAAQS	2.94	4913.2	4931.6	18.4	0.38%	4812.5	4809.9	-2.6	-0.05%	4733.8	4714.5	-19.4	-0.41%	4913.18	4733.84	-3.65%	4931.62	4714.46	-4.40%
		Utility Based (Coal)	2.94	4953.9	4915.3	-38.6	-0.78%	4802.0	4775.7	-26.3	-0.55%	4726.8	4641.7	-85.0	-1.80%	4953.90	4726.76	-4.59%	4915.28	4641.74	-5.57%
		Utility Based High	2.94	4953.9	4915.3	-38.6	-0.78%	4780.0	4782.5	2.5	0.05%	4641.7	4632.2	-9.5	-0.20%	4953.90	4641.66	-6.30%	4915.28	4632.18	-5.76%
	S(s)	Clear Sky w/Hg	1.02	641.8	642.3	0.5	0.07%	637.0	637.7	0.7	0.11%	635.9	636.5	0.6	0.10%	641.80	635.89	-0.92%	642.28	636.52	-0.90%
	7	Clear Sky wo/Hg	1.02	639.1	639.2	0.1	0.01%	633.3	632.3	-0.9	-0.15%	636.0	637.5	1.4	0.23%	639.11	636.05	-0.48%	639.18	637.50	-0.26%
		NAAQS	1.02	638.6	642.4	3.8	0.60%	635.1	633.0	-2.2	-0.34%	636.8	634.9	-1.9	-0.30%	638.58	636.76	-0.29%	642.42	634.88	-1.17%
		Utility Based (Coal)	1.02	636.6	638.8	2.3	0.36%	635.8	638.2	2.4	0.38%	634.9	634.6	-0.3	-0.04%	636.59	634.92	-0.26%	638.85	634.64	-0.66%
		Utility Based High	1.02	636.6	638.8	2.3	0.36%	635.3	637.3	2.0	0.31%	636.5	634.6	-1.9	-0.30%	636.59	636.51	-0.01%	638.85	634.58	-0.67%
	S(l)	Clear Sky w/Hg	2.99	5191.2	5207.1	15.9	0.31%	5094.2	5092.7	-1.5	-0.03%	4975.0	4987.5	12.5	0.25%	5191.21	4975.03	-4.16%	5207.09	4987.53	-4.22%
	8	Clear Sky wo/Hg	2.99	5193.5	5186.1	-7.4	-0.14%	5109.1	5064.4	-44.7	-0.87%	4978.1	5009.7	31.6	0.64%	5193.52	4978.08	-4.15%	5186.15	5009.72	-3.40%
		NAAQS	2.99	5188.5	5241.7	53.2	1.03%	5050.8	5043.6	-7.2	-0.14%	4952.2	4985.3	33.1	0.67%	5188.52	4952.16	-4.56%	5241.74	4985.31	-4.89%
		Utility Based (Coal)	2.99	5168.8	5184.7	15.9	0.31%	5041.6	5037.1	-4.4	-0.09%	4942.9	4937.4	-5.5	-0.11%	5168.78	4942.86	-4.37%	5184.68	4937.36	-4.77%
		Utility Based High	2.99	5168.8	5184.7	15.9	0.31%	5040.1	5046.7	6.6	0.13%	4967.8	4959.9	-7.9	-0.16%	5168.78	4967.83	-3.89%	5184.68	4959.94	-4.33%
	SB(s)	Clear Sky w/Hg	0.63	6.3	6.7	0.4	5.60%	6.1	6.2	0.1	2.37%	6.2	5.9	-0.4	-5.80%	6.35	6.25	-1.52%	6.70	5.89	-12.15%
	14	Clear Sky wo/Hg	0.63	6.3	6.4	0.0	0.78%	6.2	6.1	-0.1	-1.53%	6.1	6.1	0.1	1.00%	6.32	6.07	-3.91%	6.36	6.13	-3.70%
		NAAQS	0.63	6.3	6.4	0.1	1.45%	5.9	6.0	0.1	2.40%	5.9	6.1	0.2	3.60%	6.26	5.89	-5.84%	6.35	6.11	-3.85%
		Utility Based (Coal)	0.63	6.3	6.3	0.0	0.01%	6.2	6.0	-0.2	-2.49%	6.0	5.7	-0.2	-3.91%	6.31	5.96	-5.56%	6.31	5.73	-9.26%
		Utility Based High	0.63	6.3	6.3	0.0	0.01%	5.8	5.7	-0.1	-1.58%	6.0	6.2	0.2	3.35%	6.31	5.96	-5.57%	6.31	6.16	-2.41%

Upstream Fish-Passage Opportunities at Ohio River Mainstem Dams

Completion Report: MIPR Number W36XDD11102054

Prepared for
U.S. Army Corps of Engineers
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December 2003

Cover photo: Arial photograph of the Belleville Dam on the Ohio River near Reedsville, Ohio. File Photo U.S. Army Corps of Engineers.

Suggested citation:

Knights, B. C., J. H. Wlosinski, J. A. Kalas, and S. W. Bailey. 2003. Upstream fish passage opportunities at Ohio River mainstem dams. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, November 2003. 95 pp. Appendixes A-B.

Abstract

Mainstem dams on the Ohio River may affect the bioproduction and biodiversity of native fishes by imposing restrictions to natural longitudinal movements. Literature on native fishes in the Ohio River suggests that many of these species are migratory during the reproductive phase of their life cycles or move longitudinally between feeding and overwintering areas at other times. If mainstem dams pose restrictions to these migrations or movements, populations may be affected by failed or reduced reproduction and increased mortality related to poor habitat. As well, increased isolation of subpopulations and reduced habitat availability brought about by restricted movements can negatively affect metapopulations of large river fishes by increasing the likelihood of local extinctions and reducing re-establishment rates. The objective of our study was to assess upstream fish-passage opportunities through Ohio River mainstem dams by relating historical hydraulic conditions at these dams to swimming capabilities of select native and non-native fishes to determine if these dams are restricting upstream movements of fishes. Additionally, abundance and distribution of target species were examined in relation to upstream fish-passage opportunities at mainstem dams to determine if restricted fish passage might influence these factors. Fish species included in this study were selected based on consultation with the Ohio River Mainstem Study-Environmental Team and review of pertinent literature on the migratory behaviors of native and non-native fish species in the Ohio River. A comparison of the swimming speeds of target fishes with estimated water velocities through the gates of mainstem dams during various conditions, and reports of upstream movement of target fishes through dams suggest that upstream fish passage opportunities generally occur during open-river rather than controlled conditions at dams. Open river is the condition when the dam gates have been lifted clear of the water and are no longer controlling water levels behind the dam; at open river, the water surface elevation immediately downstream of the dam (i.e., tailwater) is about equal to the water surface elevation immediately upstream of the dam (i.e., headwater). An analysis of historical water elevation data at Ohio River mainstem dams revealed that the frequency of open river by calendar week and hence the potential for fish passage varied spatially along the river by dam and temporally with discharge. The general spatial pattern of open river indicated that the potential for fish passage is low to high at dams in the Louisville District, low to moderate at Huntington District dams, and low at Pittsburgh District dams. In general, open-river conditions were more frequent during winter and spring (i.e., high-flow period; December through June) and generally nonexistent during summer and fall (i.e., low-flow period). Pre- and post-dam abundance and distribution information for target species, along with life history information suggest that some species are affected by mainstem dams on the Ohio River. Uncertainty as to the role of mainstem dams in the reduction in abundance and distribution of target species remains because of the qualitative nature of the data and because concomitant stressors have acted upon these species. However, there is a growing recognition that efforts will need to go beyond species- and site-specific management to restore the natural bioproductivity and biodiversity of large regulated rivers. River systems are large complex ecosystems necessitating restoration efforts at comparable scales and complexities followed by long-term assessment and adaptive management. To be successful, these efforts will need to focus on systemic issues including the restoration of more natural flow regimes, floodplain connectivity, water and substrate quality, and fish passage.

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Introduction

The Ohio River has 20 mainstem dams (Figure 1) that influence the ecology of the river. Recent literature on ecological concepts for large rivers suggests that longitudinal connectivity is an important feature in regards to ecosystem structure and function (e.g., Vannote et al. 1980; Ward and Stanford 1995), and hence restoration of large rivers (Stanford et al. 1996). This is obviously true in regards to the restoration of large river fishes with life-stage specific habitats that are spatially separated along a river system, or when metapopulation structure is important for sustaining a species in a system (Stanford et al. 1996). A well-touted example of the consequence of dams to fish populations in large rivers is the loss of salmon stocks in the Columbia River Basin, where more than 200 stocks of anadromous salmonids have become extinct (Bergkamp et al. 2000).

Numerous studies indicate that longitudinal connectivity may be equally important to some species of non-salmonid, both potadromous and diadromous, fishes inhabiting large floodplain rivers (e.g., sturgeons, paddlefish *Polyodon spathula*, and herrings; Auer 1996; Johnson et al. 1997; Bergkamp et al. 2000). If these fish are intermittently or completely denied access to spawning habitats or delayed from reaching these habitats because of dams, variable recruitment and possibly extirpation of existing stocks may result. Pearson and Pearson (1989) stated that the Ohio River mainstem dams eliminated the spring run of Alabama shad *Alosa alabamae* and seriously impaired movements of other fishes. The degree to which loss of longitudinal connectivity affects population levels of large-river, non-salmonid fishes is probably species and system specific, and is generally unknown because of the difficulty in assessing population levels and because other factors (e.g., habitat alterations and pollution) concomitantly influence these populations.

Longitudinal movements of fish within a large river system may serve other ecological functions. One example is that fish movement serves as a dispersal mechanism for juvenile freshwater mussels. Freshwater mussels, including those in the Ohio River Basin, are recognized as one of the most threatened fauna in North America. Eleven of 127 species of freshwater mussels in the Ohio River have gone extinct since the turn of the 19th century; 46 of the remaining species are considered endangered or species of concern (Neves 1999). In general, freshwater mussels have an obligate parasitic stage during which they are attached to the gills of a specific host fish species. If fishes are prevented from moving upstream during critical life stages of mussels then this mechanism of development and dispersal is disrupted and can lead to complete recruitment failure for affected species and possibly extirpation. For example, Upper Mississippi River dams are thought to have contributed to the decline of the ebony shell *Fusconaia ebena* and elephant ear *Elliptio crassidens* mussel by blocking movements of the skipjack herring *Alosa chrysochloris*, a primary host species for the two mussel species (Becker 1983; U.S. Fish and Wildlife Service 1999).

Anecdotal and scientific information suggest that some fish species (e.g., paddlefish and sauger *Stizostedion canadense*) pass upstream through Ohio River mainstem dams (Johnson et al. 1997; Conover and Grady 2000; Henley et al. 2001; C. O'Bara, West Virginia Department of Natural Resources, Parkersburg, West Virginia, personal communications). As well, numerous fish species that are common to the Ohio and Mississippi Rivers are known to pass upstream through Mississippi River dams (Holland et al. 1984) that are similar in design in terms of pathways for upstream fish passage to Ohio River dams. To pass upstream through Ohio River dams, fish must move through one of the major sections of the dam, that is through

the controlled (i.e., gated) section, over the uncontrolled section (i.e., fixed weir), or through one of the lock chambers. Fish passage opportunities probably change temporally with discharge because hydraulic conditions, that is lift and water velocity, at or through these dam sections change with discharge. Lift is the difference between water surface elevation immediately upstream (headwater) and immediately downstream (tailwater) of the dam. Also discharge, lift, and dam section dimensions vary among Ohio River mainstem dams probably resulting in spatial variation in fish-passage opportunities along the river.

Wilcox et al. (unpublished report) examined the temporal and spatial patterns of fish-passage opportunities at Mississippi River navigation dams (27 mainstem dams) by comparing fish swimming abilities with hydraulic conditions at these dams. Their study concluded that water velocities through the dam gates probably impede fish moving upstream during most of the year, and that the best opportunity for fish passage occurs when dam gates are completely out of the water, that is during open river. Their study suggests that fish-passage opportunities are species and dam specific and that operational or structural modifications should be investigated to determine if fish-passage opportunities can be enhanced.

A systematic evaluation of fish-passage opportunities at the 20 navigation dams along the 1,578-km length of the Ohio River has not been conducted, but is warranted given the findings of Wilcox et al. (unpublished report). The Ohio River differs from the Upper Mississippi River in regards to fish fauna, mainstem dam dimensions, channel morphology, and discharge regime. Thus, the findings of Wilcox et al. (unpublished report) are not wholly applicable to the Ohio River.

The objective of our study was to assess upstream fish-passage opportunities through Ohio River mainstem dams by relating historical hydraulic conditions at these dams to migration timing and swimming capabilities of select native and non-native fishes. Additionally, migratory behavior and post-dam abundance and distribution of these species were examined in relation to fish-passage opportunities. Fish species included in this study (Table 1) were selected based on consultation with the Ohio River Mainstem Study (ORMSS)-Environmental Team (i.e., biologists familiar with the fish and fisheries in the Ohio River) and review of pertinent literature on the migratory behaviors of native and non-native fish species in the Ohio River.

Study Area

The Ohio River flows 1,578 km from its source at the confluence of the Allegheny and Monongahela Rivers near Pittsburgh, Pennsylvania to its confluence with the Mississippi River near Cairo, Illinois (Figure 1). At the upper end near Sewickley, Pennsylvania, the mean discharge ranges from about 400 m^3/s in October to 2,200 m^3/s in March (Figure 2; raw data from the U.S. Geological Survey database at www.water.usgs.gov/nwis/discharge). At the lower end near Metropolis, Illinois, the mean discharge ranges from about 2,600 m^3/s in September to 15,800 m^3/s in March. As well, channel and floodplain width and stream gradient vary substantially from source to mouth (Table 2; after Pearson 1992).

Frost and Mitsch (1989) described the modern day Ohio River with its navigation dams as resembling a series of connected lakes more than a river. The navigation pools (i.e., impoundments) formed behind the mainstem dams range in length from about 11 km (Dashields Pool) to more than 180 km (Cannelton Pool; Tables 3a–3c). The upper ten pools (Emsworth to R. C. Byrd Pools) average 48 km (range 11 to 72 km) in length, while the remaining downstream pools, excluding pools for Dams 52 and 53 (each about 30 km long),

average 126 km (90 to 183 km) in length (8 pools). Water velocities in these navigation pools are reduced at normal discharges as compared to the predammed river and may be negligible during low-water periods (Taylor 1989) in some pools. Van Hassel et al. (1988) noted that this conversion of lotic areas to lentic areas is an important factor that has influenced fish communities in the Ohio River. Numerous tributaries flow into the navigation pools of the Ohio River along its 1,578 km course (Table 4; also see Henley et al. 2001). The largest tributaries are in the lower reach of the river and include the Tennessee, Cumberland, and Wabash Rivers. The reservoirs on the tributaries impact the discharge and water quality of the mainstem Ohio River. Pearson (1992) summarized the three major effects as (1) water storage that reduces the maximum seasonal flow rates and lengthens the duration of bank-full stages (2) low flows during droughts are nearly twice those before impoundment and (3) the water released to the mainstem from the reservoirs is often less turbid than before.

Significant system modifications to accommodate commercial navigation on the mainstem of the Ohio River have included snag removal, dredging, and construction of wing dikes, back channel dikes, and canals in the early to mid-1800s; construction of low-lift dams (more than 50 dams, mostly removable wicket-type) in the late 1800s and early 1900s; and most recently (i.e., 1920s to 1980s) completion or modification of 18 high-lift dams and associated locks (Tables 3a-3c; Pearson and Krumholz 1984; Frost and Mitsch 1989; U.S. Army Corps of Engineers 2002). At present, 20 mainstem dams (18 high-lift and two movable low-lift, wicket type) with lifts ranging from 3.3 to 12.3 m are in place on the Ohio River mainstem (Figure 1). The 20 existing dams, in conjunction with dredging, help maintain a minimum 2.7-m navigation channel throughout the Ohio River. A new high-lift dam (i.e., Olmstead Dam) is being constructed at ORKm 1,552 (Ohio River Kilometer measured from the source of the Ohio River at the confluence of the Allegany and Monongahela Rivers) to replace the two remaining wicket dams (i.e., Dams 52 and 53). This new dam will have a lift of 8 m and is scheduled for completion in 2010.

Mainstem Dams

Design characteristics—The 20 mainstem dams on the Ohio River were completed over a 60-year period (i.e., 1921 to 1980) and are dispersed along a 1,500-km reach of a heterogeneous river channel. Thus, the features of these dams differ in terms of lift, total span, and span and type of controlled (i.e., gated) and uncontrolled (i.e., fixed-weir) sections (Tables 3a-3c). The "typical" high-lift dam includes a gated and fixed-weir section on the main channel of the river, along with a pair of locks (Figure 3). The span of the dams, including gated and fixed-weir sections perpendicular to the main flow, locks, and hydropower facilities (excluding islands), varies from about 360 to 800 m. The gated sections of the dams span about 285 to 425 m, and usually consist of multiple (i.e., 4 to 12) tainter gates (e.g., Figure 4) with individual widths of 30.5 to 33.5 m. The gated sections of two dams, Emsworth and Montgomery Dams, have Sydney-type gates (e.g., Figure 5; 14 and 10 gates, respectively) with gate-widths of 30.5 m. Emsworth Dam includes a gated section in the main (8 gates) and back channel (6 gates). The R. C. Byrd Dam differs from the typical high-lift dam in that it has a gated section consisting of eight roller gates (e.g., Figure 5) with widths of 38.1 m, and no fixed-weir section. Other high-lift dams that lack a fixed weir include Markland, Racine, and New Cumberland Dams. Conversely, Dashshields Dam is a fixed weir (483.1 m long) without a gated section. Fixed-weir sections (e.g., Figure 6) on the main channel of the other high-lift dams, excluding McAlpine

Dam, have spans of 10.5 to 682.4 m. The 2,500-m fixed weir at McAlpine Dam includes a 2,000-m section that parallels the main flow and surrounds the Falls of Ohio Wildlife Conservation Area. The lock chambers for this dam are also non-typical in that they are located in a canal that was originally built in 1830 to bypass the Falls of Ohio rather than in the main channel. The fixed-weir sections of the Smithland, J. T. Myers, and Newburgh Dams are navigable fixed weirs that can be traversed by vessels during high river stages (Tables 3a-3c). This is not so for other dams that have non-navigable fixed weirs.

The two remaining mainstem dams, Dams 52 and 53, are low-lift, movable-wicket dams. These dams consist of a controlled section about 1,000 m wide and a set of locks. The controlled portion of these dams consist of a series of movable sections (i.e., wickets; Figure 6) that are lifted to a vertical position by a manned vessel and crane system during low-water periods to form a low-head dam across the channel. Vessels traveling on the river when this low-head dam is present (i.e., wickets in vertical position) must use the lock system. When water levels are high, that is deep enough to allow navigation above that point on the river without a low-head dam, the wickets are laid down horizontally onto the river bottom. When the wickets are in this horizontal position, vessels can travel up and down the river by passing directly over the wickets, thus bypassing the locks.

Fish passage through dams—At low to moderate discharges, that is normal-flow conditions, there is a lift at the dam. For typical Ohio River mainstem dams under normal-flow conditions, most water passes under the dam gates. This type of flow is submerged-orifice flow, and the discharge and water velocity through this submerged-orifice is dependent on the size and character (e.g., sharp or rounded entrance) of the gate opening, and the amount of lift at the dam (Alexander 1992; Corsi and Schuler 1995). Under normal-flow conditions, fish must swim through these gate openings to pass upstream through the dam, or alternatively must move through the locks. Upstream fish passage is probably precluded at the fixed weir under normal-flow conditions because of the lift at the dam. With lift at the dam, either there is no flow or cascading flow over the weir depending on the elevation of the weir crest relative to the normal controlled pool elevation above the dam.

As discharge increases to high-flow conditions, the lift at a typical dam approaches a minimum (i.e., tailwater elevation nearly equal to headwater elevation), and the gates of the controlled section are lifted completely out of the water; this condition is commonly referred to as open river. During open river, fish must swim through the now open, gated section or over the fixed weir to pass the dam. Under these conditions, fish passage is probably dependent on the water velocities through the open gates or over the fixed weir. The magnitudes of these velocities are dependent on the slope of the water across the dam and characteristics of the weir, rather than on the lift and gate opening characteristics as with submerged-orifice flow. As water elevation continues to rise with discharge past the initial open-river point, other areas (i.e., inundated floodplain) become available for fish passage.

Notable exceptions to the typical Ohio River dam include Dams 52 and 53 (wicket dams) and Dashields Dam (fixed weir only). When lift is present at these dams, the only route for fish passage is through the lock chambers because there is no gated section; during open river (i.e., essentially no lift) fish must pass over the navigable-pass (Dams 52 and 53) or fixed-weir (Dashields Dam) sections. As well, at low discharges at dams with hydroelectric facilities (Tables 3a-3c), most water passes through the turbines rather than under the gates.

Fish passage through locks during normal operations probably occurs at normal and high flows, but is not likely a major passageway for fish given unsuitable flow patterns through and around the lock chambers during normal operations (Wilcox et al. unpublished report). That is, the flow patterns are not conducive for attracting fish into or leading them out of the lock chamber under normal operations. Methods to successfully attract fish into the lock chamber by manipulating the lock gates and the fill and drain system to establish attractant flow patterns have been demonstrated (Ohio River Valley Water Sanitation Commission {ORSANCO} 1962). However, the efficiency (i.e., ratio of the number of fish entering the chamber from downstream to the number of fish moving upstream out of the lock chamber) of these methods to pass fish through the dams has not been determined.

Methods

Fish passage opportunities—A comparison of fish swimming speeds to water velocities in the gate openings was made to determine the hydraulic conditions, that is the critical lift, that allows target fish to pass through the gates of Ohio River mainstem dams. As an index of fish-passage opportunities at each dam, the frequency of occurrence of critical lift was determined by examining historical water-surface elevation (i.e., headwater and tailwater) data for each dam.

***Life history information*—**To assess swimming abilities and passage opportunities of target fishes during spawning-migration periods, pertinent life history information was extracted from relevant literature. Life history information, including adult sizes and spawning temperatures, was obtained largely from fishery textbooks; data from proximal sources such as Trautman (1981), Wallus et al. (1990), Clay (1975), Smith (1979), and Forbes and Richardson (1920) were examined first to obtain Ohio River-specific information. Median adult size was recorded as the median total length reported for mature fish across sources. Spawning temperatures of target fishes were defined as the range of temperatures reported in the literature for ripe, spawning, or nest guarding individuals.

Spawning-migration periods were estimated for target fishes based on season and reported water temperatures during spawning. The migration periods for target species were defined as the spawning periods (i.e., the period when water temperatures in the Ohio River were equal to the reported spawning temperatures) and the four weeks before the spawning period. The weekly average water temperature at Ohio River dams was determined with data from four sites on the Ohio River including Evansville, Indiana; South Heights, Pennsylvania; Joppa, Illinois; and Wheeling, West Virginia (Table 5). Mean temperature for each calendar week was determined for these four sites and then used to estimate weekly average water temperatures at each dam by linearly interpolating between sites by river kilometer.

Swimming speeds—Literature searches to obtain swimming speed information were conducted on Web-based sources including a fish-passage bibliography (Ickes et al. 2001), Cambridge Scientific Abstracts (2003), and FishBase (2003). Ickes et al. (2001) contains nearly 500 citations relevant to fish passage in large floodplain rivers. Cambridge Scientific Abstracts includes coverage of the Aquatic Science and Fisheries Abstracts Series that monitors more than 5,000 publications. FishBase (2003) includes referenced information on more than 26,000 fish species.

Many techniques have been used to quantify fish swimming speeds; Bainbridge (1958) and Videler (1993) give details on many of these. Fish swimming speeds are usually expressed as sustained, prolonged, or burst speeds. Generally, sustained speeds are considered speeds that a fish can maintain for greater than 200 min and entail the use of red muscle fibers and aerobic metabolism by fish (Jones 1982). Burst speeds are the maximum speed a fish can maintain for about 15 s before exhaustion (Blake 1983). Burst swimming is an anaerobic process that generally entails the use of white muscle fibers (Blake 1983). Prolong swimming speeds generally fall between sustained and burst speeds. This type of swimming entails red and white muscle fiber use and requires aerobic and anaerobic metabolism (Blake 1983). Like burst swimming trials, experiments to establish prolonged speeds end with complete exhaustion of the fish. Prolonged swimming speeds are often referred to as critical swimming speeds (Brett 1964), and are commonly expressed as $Ucrit_{10,}$ where $Ucrit_{10}$ is the speed a fish can maintain for 10 min before exhaustion.

Information on prolonged and burst swimming speeds was summarized from the literature. If species-specific information on prolonged and burst swimming speed of target fishes was not available, then information from morphologically similar species (i.e., a surrogate) was used if available. Often times swimming speed data reported in the literature are based on subadult fish or water temperatures differing from migration temperatures. For this study, direct observations and empirically derived models were interpreted to estimate swimming speeds for median adult-sized fish at median migration temperatures when possible.

To obtain an estimate of burst swimming speed for all target species at the median adult length and spawning-migration temperature, maximum swimming speeds (U_{max}) were calculated with the method derived by Winter and Van Densen (2001). They used U_{max} as a proxy for burst swimming speed for a variety of fishes when estimating fish passage opportunities through weirs in the River Vecht. U_{max} was determined with

$$U_{max} = SlF_{max} \qquad (1)$$

where S is the stride length or the maximum distance a fish travels in one tail beat expressed as a proportion of the fish's total length, l is the total length of the fish, and F_{max} is maximum tail beat frequency in beats per second (Blake 1983; Videler 1993). For example, the estimated burst swimming speed for a 0.20-m fish with a stride length of 0.7, and F_{max} of 15 is 2.1 m/s.

The two kinematic variables controlling U_{max} in fishes are S and F_{max}. While species-specific kinematic data are not available for most fish species, it seems reasonable that S and F_{max} data from other species with similar morphology and thus swimming form could be used to estimate these parameters for species lacking data (Winter and Van Densen 2001). Videler (1993) found that stride length varies little among fishes with carangiform and subcarangiform swimming modes, which are the modes used by most Ohio River target species. Based on Videler (1993) and Winter and Van Densen (2001), 0.7 was used as an estimate of stride length for most target species in our study; exceptions included angullids, esocids, and gars (Table 6).

Maximum tail beat frequency (F_{max}) is species, size, and temperature dependent (Videler 1993). Target species in our study were placed into one of three general F_{max} groups based on species after Winter and Van Densen (2001) including (1) high F_{max} (i.e., 25 Hz), includes the rheophilic catostomids, clupeids, piscivorous percids, esocids, percicthyids, and hiodontids (2) intermediate F_{max} (i.e., 20 Hz), includes ictalurids, centrarchids, and sciaenids or (3) low F_{max}

(i.e., 15 Hz), includes high-bodied cyprinids and catostomids, anguillids, polydontids, and acipenserids (Table 6). These F_{max} values are for a standard water temperature of 15°C and standard fish size of 9, 8, and 7 cm, respectively for the three groups (i.e., 25, 20, and 15 Hz). The F_{max} values were adjusted for species-specific median adult length and median water temperature during migration periods with

$$F_{lt} = F_{xy}\,(0.87^{(l-x)/10})(2^{(t-y)/10}) \qquad (2)$$

where F_{lt} is length and temperature adjusted F_{max}, and F_{xy} is F_{max} for a target species based on the group (i.e., 15, 20, or 25 Hz). In accordance with this equation, F_{max} doubles for each 10°C increase in temperature and decreases by a factor of 0.87 for each 10-cm increase in total length. Some researchers have noted that burst speeds do not change with water temperature (Blaxter 1969; Peake et al. 1997), thus F_{max} was also calculated for each species at 15°C (i.e., without adjusting for migration temperature).

Water velocities through dam gates—The average water velocity through gate openings at various lift across the dam was estimated with a standard hydraulic equation (Equation 3). For submerged-orifice flows, this equation assumes that flow is uniform through the gate opening and that mass and energy are balanced between the approach-section and the section just downstream of the gate (Alexander 1992). Water velocity estimates through gate openings were made for Ohio River mainstem dams in which complete gate schedules were available from the U.S. Army Corps of Engineers (i.e., Emsworth, Montgomery, New Cumberland, Pike Island, Hannibal, and Greenup Dams). Gate schedules included the hydraulic variables needed to solve the standard equation. This equation incorporates the dimensions of water flow through the dam gates and the total discharge to estimate average water velocity through the gates as

$$V = Q/(h*w) \qquad (3)$$

where V is average water velocity in the gate openings, Q is the total discharge through the dam, h is the sum of the all gate opening heights, and w is the average width of the gates. Where gate schedules indicated that the gates were fully open, individual gate opening height was assumed to be equal to the normal pool elevation minus gate sill elevation (i.e., the height of water flowing through the open gate) rather than the assumed opening height given on the gate schedule.

For comparison, water velocities through gates at a mainstem dam on the Upper Mississippi River (i.e., Lock and Dam 7) were also determined with Equation 3, except that the discharges through individual gates were estimated with the two-point, current-meter method (Corsi and Schuler 1995), rather than from gate schedules. In this method, V in Equation 3 is the average water velocity through the gate, h is the height of the gate opening, and w is the width of the gate opening. Additionally, information from two hydraulic studies of Upper Mississippi River dams (Alexander 1992; Osvalt and Grace unpublished data) was used to describe magnitudes and patterns of water velocities through gate bays.

Frequency of open river—Synthesis of information on fish swimming speeds and magnitudes and patterns of water velocities through gates indicated that the lift most likely to allow fish to pass through dams was the minimum lift (see Results). This minimum lift, known as swellhead, occurs at a dam during open river when gates are lifted completely out of the water. Lift

remaining at open river results from the slope of the riverbed between the tailwater and headwater gages, and any backup of the water at the dam structure because of a reduction in the effective channel width.

As an index of fish-passage opportunities by week of year, the daily tailwater elevation data (Table 7) for each Ohio River mainstem dam were analyzed to determine the proportion of years a particular calendar week was at open river. For example, if 5 of the 20 years of historical data for week 14 (i.e., about the second week in April, 1981 to 2000) indicate that the dam was open, then the proportion of years in which suitable fish-passage conditions existed at that dam for week 14 is 25%. For a week to be considered as an open-river week in the frequency analysis, the dam had to be open for at least one day during the week. A dam was assumed to be at open river on a given day if the tailwater elevation at that dam was greater than or equal to the normal pool elevation minus an estimate of swellhead for that dam. A jump in the cumulative frequency distribution for lift just above zero is indicative of swellhead (Figures 7a-7c). However, for many dams swellhead could not be determined because of infrequent open-river conditions at the dams; in these instances, a value of 0.153 m was used as an estimate of swellhead (Table 7).

Daily water-surface elevation data were available for 20 to 26 years (post-dam completion) for all dams except Emsworth Dam (Table 7). Water elevation data for Emsworth Dam were available for 1995 to 2000. Some daily headwater or tailwater elevation data were missing for other dams during these periods. Missing tailwater values for a particular dam, including values for Emsworth Dam between 1980 and 1994, were estimated with linear regression analysis on available elevation data for that dam and concurrent data from an upstream or downstream dam. For example, missing tailwater elevation data for Emsworth Dam were estimated by determining the relation between Emsworth Dam tailwater elevations 1995 to 2000 and Dashields Dam tailwater elevations 1995 to 2000, and then interpreting this relation to estimate missing Emsworth Dam tailwater elevations from 1980 to 1994. Headwater (i.e., pool) elevations are controlled within a specified range at normal flows and thus missing values could not be estimated in a similar manner as tailwater elevations. Tailwater elevation data for Dams 52 and 53 were missing on numerous days for the period of record; missing daily values for tailwater elevation from these dams were assumed to signify that the dams were at open-river condition on those days when values were missing based on communications with Bill Byron, U.S. Army Corps of Engineers, Louisville District.

Abundance and distribution of target fishes—Spatial and temporal abundance and distribution information and information on swimming and migratory behaviors were collected for target species from relevant literature. In addition, literature from a bibliography compiled by the ORMSS-Environmental Team on natural resources of the Ohio River was used to obtain references on agency reports and unpublished data pertinent to abundance and distribution of target species. Pearson and Pearson (1989; update to Pearson and Krumholz 1984) summarized abundance and distribution information by river reach (upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) and period (1900 to 1969 and 1970 to 1988) for all target species. To assess more recent (i.e., 1989 to 2001) abundance and distribution, two data sets with catch information (i.e., ORSANCO unpublished data; Ohio Environmental Protection Agency [OEPA] unpublished data) were analyzed to determine frequency of occurrence of target species in samples. Occurrence classes included common (i.e., occurs in >50% of samples); occasional (i.e., occurs in >15% to =50% of samples;

uncommon (i.e., occurs in ≤15% of samples); or absent (i.e., did not occur in any samples). For this analysis, lock rotenone samples (ORSANCO unpublished data) from a given lock were considered to be from that dam's navigation pool, and night electrofishing samples (OEPA unpublished data) from the same navigation pool during a given year were considered as one sample. For the results and discussion sections of this report, we adopted Pearson and Pearson's (1989) definitions of river reaches (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) unless otherwise specified.

Results

Swimming speeds—Prolonged swimming speeds of median-size adults derived from species-specific observations or empirical models were available for 15 of 44 target species (Table 8). The range of prolonged speeds for these species was 0.45 to 0.88 m/s. Information from seven surrogate species (six target, one nontarget; see Appendix A for scientific names of nontarget surrogates) were used to estimate prolonged speed for 28 target species. The prolonged swimming speed of the American eel *Anguilla rostrata* was not estimated because information was not available. Prolonged swimming speeds including surrogate-derived estimates ranged from 0.45 to 1.02 m/s with only one value exceeding those from species-specific information (i.e., 1.02 m/s for blue sucker *Cycleptus elongates*; longnose sucker *Catostomus catostomus* surrogate). Only four species had estimated prolonged swimming speeds of less than 0.60 m/s, including northern pike *Esox lucius* (0.45 m/s), silver redhorse *Moxostoma anisurum* (0.54 m/s), longnose gar *Lepisosteus osseus* (0.45 m/s), and shortnose gar *Lepisosteus platostomus* (0.45 m/s).

Estimates of burst speeds derived from species-specific observations or empirical models were made for 6 of 44 target species (Table 8). Estimates ranged from 1.00 to 4.73 m/s. Two estimates of burst speed were available for northern pike (i.e., 2.50 and 4.68 m/s) and common carp *Cyprinus carpio* (1.17 and 1.75 m/s). Excluding the two highest burst speeds for northern pike (i.e., 4.68 m/s) and alewife *Alosa pseudoharengus* (i.e, 4.73 m/s), values ranged from 1.00 to 2.50 m/s. Eight surrogate species (four target and four nontarget) were used to estimate burst speeds of 32 target species. The range of burst speeds including surrogate-derived estimates was the same as that for species-specific estimates (i.e., 1.00 to 4.73 m/s). Estimates of burst speed were not made for seven target species because information was not available. Estimates of maximum swimming speed from Equation 1 (i.e., proxy for burst speed; U_{max}; Winter and Van Densen 2001) were made for all target species (Table 8). These values ranged from 1.55 to 5.22 m/s at a standard temperature of 15°C ($U_{max\text{-}15}$) and 1.00 to 7.38 m/s at median temperature during spawning migrations ($U_{max\text{-}t}$).

Water velocities through dam gates—Average water velocities, estimated with Equation 3, through gates of Ohio River mainstem dams (i.e., Emsworth, Montgomery, Pike Island, New Cumberland, Hannibal and Greenup Dams) ranged from 2.14 m/s at 0.31 m of lift to 13.67 m/s at 8.14 m of lift (Figure 8); the minimum and maximum estimated water velocities occurred at the Greenup Dam. The minimum water velocities through the gate openings occurred at the minimum lift when gates were completely out of the water (i.e., open river). Water velocities at minimum lift for these six mainstem dams averaged 2.68 m/s (standard deviation = 0.51 m/s) and ranged from 2.14 to 3.58 m/s. Excluding Emsworth and Montgomery Dams, where minimum head at open river was relatively high (i.e., 1.80 and 0.67 m, respectively) minimum water

velocities ranged from 2.14 to 2.68 m/s at lift of 0.23 to 0.34 m. Estimated water velocities through roller and tainter gates at Lock and Dam 7 on the Upper Mississippi River were similar to velocities at Ohio River dams and ranged from 2.6 m/s at 0.4 m of lift to 7.7 m/s at 2 m of lift (Figure 8). Water velocities through other Ohio River mainstem dams were not estimated with Equation 3 because complete gate schedules were not available for those dams. However, the magnitude of water velocities through gates at various lifts for other Ohio River mainstem dams are assumed to be similar to those with estimates based on similarities in estimates among dams including Lock and Dam 7 on the Upper Mississippi River.

Equation 3 estimates the average water velocity in the plane of the gate opening and assumes a uniform flow. During submerged-orifice flow conditions when gates are in the water, the plane of highest velocity actually occurs downstream of the gate opening because of flow contraction. Based on a maximum contraction of 0.6, water velocities just downstream of the gate opening can be up to 66% higher than the velocities in the gate opening (Wilcox et al. unpublished report). As the gate opening increases, the flow-contraction factor decreases, and the magnitude of the water velocity in the gate opening approaches the maximum velocity. When the dam is at open river (i.e., gates out of the water), the plane of the gate opening is probably the plane of maximum velocity because of negligible flow contraction.

Based on a model of Lock and Dam 8 on the Upper Mississippi River (Osvalt and Grace unpublished data) water velocities through gate openings during open river are nonuniform, and lower than predicted by Equation 3 in some areas. For example, some velocity estimates in the upper portion of the gate opening based on the physical model were about 1 m/s, while values predicted by Equation 3 under the same conditions were 2.1 m/s. In contrast during submerged-orifice flow (i.e., gates in the water), the physical model generally indicated that water velocities immediately downstream of the gate openings were more uniform and nearly the same as or greater than those predicted by Equation 3. Low velocity areas and even back eddies were present 4.88 m directly downstream from the roller gate opening at relatively high lifts. However, fish would still encounter the relatively high water velocities in the gate opening when passing upstream.

The total length of the dam sill (gate sill + stilling basin) for Ohio River mainstem dams is generally in excess of 30 m (Tables 3a-3c; Figure 4). However, the portion of that distance affected by water velocities near the maximum velocity is uncertain, but important in regards to fish passage. A study by Alexander (1992) for example, found that water velocities measured about 8.5 m upstream of the tainter gate openings at Dam 24 on the Upper Mississippi River when lift was 3.6 m were only 7% of the estimated water velocities (Equation 3) in the gate opening. At low lift (i.e., 0.6 m), measured upstream water velocities were 64% of estimated velocities. Similarly, the physical model for Lock and Dam 8 on the Upper Mississippi River (Osvalt and Grace unpublished data) indicated that water velocities 4.88 m upstream of the gate centerline were substantially lower than gate opening velocities predicted by Equation 3, particularly at high lift. Directly downstream of the gate openings (i.e., 1.5 m [tainter gate] and 4.88 m [roller gate]), water velocities were generally equal to or greater than those predicted by Equation 3 during controlled and open-river conditions. These observations suggest that the entire sill is not affected by high flows and that fish moving through the dam encounter the highest velocities immediately downstream of the gate opening, with substantially lower velocities just upstream. However, the portion of the dam sill affected by water velocities near those estimated by Equation 3 could not be determined from these hydraulic studies; thus,

uncertainty remains as to the distance a fish would have to swim at relatively high water velocities to pass a dam.

Critical lift—A comparison of fish swimming speeds (Table 8) and estimated water velocities through the gate openings (Figure 8) revealed that water velocities were always even at the open river (i.e., minimum lift possible), in excess of the prolonged swimming speeds of target fishes. This indicates that target fish swimming at prolonged speeds cannot pass through the gates of Ohio River mainstem dams unless substantially lower than average water velocities are present in the gate openings because of nonuniform flow. However, if the physical model for Lock and Dam 8 on the Upper Mississippi River (Osvalt and Grace unpublished data) reflects conditions at Ohio River dams, and nonuniform flows provide areas with reduced water velocity (i.e., <1 m/s), then the prolonged swimming speeds of some target fishes may be adequate to pass through the dam during open river. Fish swimming at prolonged speeds probably could not swim through gates during controlled flow conditions because of more uniform high water velocities in excess of 2 m/s (Figure 8).

If fish can pass upstream through the gate opening within the duration of their burst swimming speed performances (i.e., 10 to 20 s before reaching exhaustion) by using areas of average velocity (i.e., Equation 3) or less (i.e., as predicted in the Upper Mississippi River model; Osvalt and Grace unpublished data), then some target species may be able to move through these dams during open river or even during low-lift conditions. However as previously noted, uncertainty remains as to the distance a fish must swim at burst speeds through high water velocities to pass the dam. Assuming that fish must pass through water velocities equal to those predicted by Equation 3 (Figure 8) for 10 m to get through the dam and that fish can maintain their burst speed for at least 10 seconds without reaching exhaustion, then a fish's burst swimming speed must exceed the water velocity by 1 m/s to pass the dam (i.e., 1 m/s $*$ 10 s = 10 m). Thus, an estimated burst swimming speed of =3.14 m/s (i.e., 2.14 m/s + 1 m/s) would be required to pass through the dam with the minimum water velocity at open river (i.e., Greenup Dam; Figure 8). Using this same logic, a burst swimming speed of 3.68 m/s would be required by fish to swim through dams with the average minimum water velocity. Burst speeds of this magnitude were generally not observed or estimated from empirical models for target species (Table 8). However, estimated burst speed based on maximum swimming speed (U_{max}; Equation 1) for target species often exceeded 3.50 m/s (i.e., 23 of 44 target species; Table 8); this suggests that passage may be possible for some species at some dams if 10 m is a reasonable estimate of the portion of the sill affected by high water velocities.

At open river, water velocities through gate openings may be nonuniform and reduced in magnitude in some areas (Osvalt and Grace unpublished data). As well, average water velocity through the gate openings is the least at minimum head (i.e., open river; Figure 8). This suggests that fish swimming at burst or prolonged speeds should have better opportunities to pass through the dams at open river as compared to controlled conditions. Given that average water velocities at open river are already near the upper limit of burst speeds observed and estimated for target species (Figure 8; Table 8), the likelihood of passing these dams with lift greater than the minimum lift (i.e., open river) is doubtful, particularly considering flow contraction and the more uniform flow through a submerged orifice (i.e., a gate opening under controlled conditions).

This comparison of fish swimming speeds and water velocities through gate openings during open-river and controlled-flow conditions suggests that critical lift (i.e., the minimum lift that allows fish passage) is probably equivalent to open river. Fish passage through Ohio River

dams during controlled-flow conditions seems unlikely given the high magnitude of the water velocities and the uniform flow pattern. Conversely, the lower magnitude and nonuniform pattern of water velocities during open river may provide fish swimming at prolonged or burst speeds the opportunity to pass through the dam. Based on these deductions, the frequency of critical lift was assumed to be equivalent to the frequency of open river for all Ohio River mainstem dams.

Frequency of open river—The frequency of open river by week and hence the potential for fish passage varied spatially along the river by dam and temporally with discharge (Table 9). The general spatial pattern of open river suggests that the potential for fish passage is low to high at dams in the Louisville District, low to moderate at Huntington District dams, and low at Pittsburgh District dams. In general, open-river conditions were more frequent during winter and spring (i.e., high-flow period; December through June) and generally nonexistent during summer and fall (i.e., low-flow period). The open-river period generally narrowed with the distance of the dam upstream from the mouth of the Ohio River (Table 9).

In the Louisville District (i.e., Dam 52 through Markland Dam; eight dams), the two wicket dams were at open river most weeks (Table 9). During the high-flow period, Smithland Dam was at open river 15% to 45% of years by week, but generally less than 35%. The J. T. Myers and Newburgh Dams had similar patterns of open river during high-flow periods with a range of 15% to 80% of years by week for both dams. These dams had periods of 13 to 18 weeks where frequencies of open river were greater than 50% of years. The next two dams, Cannelton and McAlpine Dams, had patterns of open river during peak flow periods that were similar to Smithland Dam. The last dam in the Louisville District, Markland Dam, was rarely at open river (=15% of years by week) even during the high-flow period.

In the Huntington District, the first four dams (i.e., Meldahl, Greenup, R. C. Byrd, and Racine Dams) had open-river conditions between 0% and 50% of years by week during the high-flow period, but generally less than 30%. The remaining two dams in the District, Belleville and Willow Island Dams, had only two or three calendar weeks (i.e., weeks 8, 9, or 10) during the high-flow period when open-river frequencies were about 10% to 20% of years; otherwise frequencies were generally less than 5% of years by week.

The mean number of days a given dam was at open river during an open-river week varied by dam (Table 10), with a general decreasing trend going upstream. Recall that to be considered an open-river week in the frequency analysis, the dam had to be at open river only one day during the week. For Dams 53 through McAlpine (i.e., seven dams), the mean number of days that these dams were open during open-river weeks ranged from 3.5 to 6.8 days. For Markland through Racine Dams (i.e., five dams), the mean number of days that these dams were open per open-river week ranged from 2.3 to 3.0 days. For the remaining dams, Belleville through Emsworth Dams (i.e., eight dams), the mean number of days that these dams were open per open-river week was less than 2.0 days.

Spawning-migration periods relative to open river—Weekly average water temperature for a given calendar week varied about 2°C over the length of the Ohio River with higher temperatures in the lower reaches as compared to the upper reaches (Table 11). This low variability in temperatures across navigation pools resulted in low spatial variation in estimated spawning-migration period for a given species across pools (Appendix B). In general, the comparison of the timing of open river to fish spawning-migration periods revealed that fish that

migrate at low temperatures (e.g., walleye *Stizostedion vitreum*; Appendix B) encounter the greatest opportunity for moving through the dams because the high-flow period (i.e., open-river period) on the Ohio River occur in late winter to early spring, whereas fish spawning at warmer temperatures (e.g., channel catfish *Ictalurus punctatus*; Appendix B) tend to miss the greatest opportunities. This is even more likely the scenario at upstream dams as compared to downstream dams, because the period of open river narrows going upstream (Table 9) and migration periods for a given species do not vary much by navigation pool.

Life history, abundance, and distribution of target species—Life history characteristics relevant to fish passage, and abundance and distribution of the 44 target species by reach (upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) are summarized in Table 12. Abundance and distribution of the 44 target species by navigation pool and reach are summarized in rows two through four in the migration period tables in Appendix B. A more detailed account of life history, distribution, abundance, and fish-passage considerations for the species or groups of species identified by the ORMSS–Environmental Team (i.e., paddlefish, skipjack herring, hiodontids, ictiobids, moronids, sauger, walleye, lake sturgeon *Acipenser fulvescens*, shovelnose sturgeon *Scaphirhynchus platorynchus*, American eel, blue sucker, blue catfish *Ictalurus furcatus*, silver carp *Hypophthalmichthys molitrix*, and bighead carp *H. nobilis*) appear in the Species of Special Interest section that follows the general discussion.

General Discussion

Fish passage at open river—Circumstantial evidence suggests that fish passage upstream through the gates of mainstem dams on the Ohio River may be possible when dams are at open river. This evidence includes reports of upstream movement of fishes through these dams and through dams of similar design on the Mississippi River during open river (Holland et al. 1984; Johnson et el. 1997; Henley et al. 2001; Knights et al. 2002; Zigler et al. 2003; C. O'Bara, West Virginia Department of Natural Resources, Parkersburg, West Virginia, personal communications). As well, the comparison of fish swimming speeds and average water velocities through dam gates suggests that many fish species swimming at burst speeds may be able to pass through these dams at open river if the length of the affected sill does not exceed about 10 m. Additionally, a hydraulic study on a dam of similar design to those on the Ohio River suggested that areas of relatively low water velocity exist in the upper portion of the water column in the gate openings during open river (Osvalt and Grace unpublished data); thus, fish swimming through these areas at prolonged or burst speeds may be able to pass upstream through the dams during open river.

Fish passage over the fixed weir when the dam is at open river may be possible, but information was not available to assess the water velocities and hence the potential for passage. Likewise, fish passage through the navigable-passes at Dams 52 and 53 could not be assessed but may be possible during open river because of near natural flow dimensions when wickets are positioned horizontally. Information needed to determine the water velocities over the fixed weirs and navigable-passes include the discharge and the dimensions of water flowing over the weir. An additional pathway for fish passage may be available as the river elevation rises above bankfull during open river; the complex structure and bottom contour of the flooded landscape probably creates areas with low water velocity suitable for fish passage.

Fish passage at normal flow—Fish passage through the gate openings during normal-flow conditions seems unlikely based on the uniform nature and high magnitude of water velocities predicted by flow dimensions and discharge (Figure 8) and demonstrated with the Upper Mississippi River Lock and Dam 8 physical model (Osvalt and Grace unpublished data). In addition, submerged-orifice flow (present under controlled-flow conditions) results in water velocities greater than those predicted by Equation 3 because of flow contraction. This flow contraction results in water velocities just downstream of the gate opening up to 66% greater than those velocities estimated in the gate opening with Equation 3. Additionally, Monk et al. (1989) found that American shad avoided submerged-orifices in a full-scale model of a section of a fish ladder. The degree to which other species may avoid submerged orifices is unknown.

Fixed weirs are probably impassable by fish during normal-flow conditions because either water does not flow over them (i.e., normal pool elevation less than weir elevation; e.g., Pike Island Dam; Tables 3a-3c) or lift across the weir creates cascading flows impassable by non-jumping fishes (i.e., probably most target species). Some passage over the fixed weir may be possible as the tailwater elevation approaches the normal pool elevation (i.e., approaching open river), but again information to assess passage under these conditions was not available.

Frequency of fish-passage opportunities—Upstream fish passage at Ohio River mainstem dams with gated sections (i.e., all dams except Dashields Dam, Dam 52, and Dam 53) may be possible for many of the target fishes during open river. Passage also seems possible at Dams 52 and 53 during open river given the more natural flow dimensions present at these dams when wickets are positioned horizontally; conversely, restricted flow dimensions over the fixed weir at the Dashields Dam may result in higher water velocities not as conducive to upstream fish passage as compared to Dam 52 and 53. The frequency and duration of open river, and hence fish-passage opportunities, were not consistent among dams, generally increasing with ORKm (i.e., going downstream from the source). The first eight dams from the source, including Emsworth, Dashields, Montgomery, New Cumberland, Pike Island, Hannibal, Willow Island, and Belleville Dams, rarely attain open river and thus upstream fish passage through gates or over fixed weirs at these dams is probably rare. Generally, any fish passage at these dams probably occurs through the lock chamber. As discussed before, passage through the lock chamber during normal operations is probably not a viable (in the population sense) means of fish passage because of non-conducive flow patterns, which may confuse fish trying to move upstream.

Other dams, including Racine, R. C. Byrd, Greenup, Meldahl, McAlpine, Cannelton, Newburgh, J. T. Myers, and Smithland Dams, provide low to high opportunities for upstream fish passage based on open-river frequencies and durations. Of these nine dams, Newburgh and J. T. Myers Dams provide the greatest opportunity with the frequency of open river exceeding about 50% of years for a period of 13 and 18 weeks, respectively, during the high-flow period in winter and early spring. If fish can pass through Dams 52 and 53 during open river, these dams provide abundant opportunity nearly year-round. Conversely, Markland Dam is rarely open and thus probably presents fish with few opportunities for upstream passage.

Capabilities of fishes to pass dams—Fishes with the greatest prolonged and burst speeds and with behavioral or morphological characteristics conducive to passing through high and variable flows are probably the most capable to pass upstream though mainstem dams. For example, the

clupeids (i.e., Alabama shad, and skipjack herring), hiodontids (goldeye *Hiodon alosoides* and mooneye *Hiodon tergisus*), and larger moronids (i.e., striped bass *Morone saxatilis*, white bass *Morone chrysops*, and yellow bass *Morone mississippiensis*) had relatively high prolonged (~0.8 m/s) and maximum burst speeds (~4 m/s; Table 8) suggesting that they may be more capable of passing upstream through gates of mainstem dams than fish with lower swimming speeds. As well these species are pelagic or benthopelagic (Table 12), a characteristic that may be advantageous as compared to benthic because the areas of lowest water velocity through the dam gates may occur near the water surface with increasing water velocity toward the bottom (Osvalt and Grace unpublished data). Other relatively strong swimmers that are pelagic or benthopelagic and may be able to take advantage of lower velocities in the upper portion of the water column include paddlefish, common carp, grass carp *Ctenopharyngodon idella*, silver carp, bighead carp, carp suckers, white sucker *Catostomus commersoni*, ictiobids, moxostomids, largemouth bass *Micropterus salmoides*, sauger, walleye, and freshwater drum *Aplodinotus grunniens* (Tables 8 and 12).

Other strong swimmers that may be at a slight disadvantage because of their benthic tendencies as compared to pelagic fishes include the blue sucker, spotted sucker *Minytrema melanops*, channel catfish, and blue catfish. However, some benthic fishes are known to demonstrate substrate appression (e.g., shovelnose sturgeon; Adams 1997). Substrate appression is the ability of a fish to hold its position on the bottom in high water velocities by flexing its pectoral and pelvic fins or body to generate a downward thrust from the passing water (Mitchell 1989). This behavior may allow benthic fish to alternate between burst swimming and resting to pass through high velocity areas, whereas pelagic fishes would have to continually swim through these areas (Mitchell 1989). Substrate appression may be enhanced by morphological features such as a flattened head, for example as seen with shovelnose sturgeon, blue catfish, and channel catfish.

Fishes with elongated bodies (sturgeon and northern pike) have generally lower estimated swimming speeds as compared to other fishes, thus potentially making these elongated forms less capable of passing upstream through the gates of mainstem dams. Additionally, sturgeon and gar may be at a disadvantage to scaled fishes because they have hardened scutes. Webb (1986) calculated that the drag per unit area for lake sturgeon is 3.5 times that of a similar size trout; he suggested that this was probably because of a "pressure drag penalty" for having scutes. Despite this apparent increased drag, lake sturgeon are known to move upstream through mainstem dams in the Upper Mississippi River during open river (Knights et al. 2002). Further research on the swimming capabilities, behaviors, and morphological features of fishes relative to passing through areas with high and variable water velocities, such as those found in the gate bays of Ohio River mainstem dams, is needed to reduce the uncertainty in assessing fish passage by target fishes.

Abundance and distribution of target species relative to fish passage—Synthesis of the abundance and distribution information (Table 12; Appendix B) and the frequency of fish-passage opportunities at mainstem dams (Table 9 and Appendix B) suggest that at least half of the target species do not need to move upstream through mainstem dams to persist in the Ohio River across broad reaches. This includes species that are generally common in all three reaches (i.e., longnose gar, mooneye, skipjack herring, common carp, river carpsucker *Carpiodes carpio*, quillback *Carpiodes cyprinus*, smallmouth buffalo *Ictiobus bubalus*, channel catfish, white bass, largemouth bass, sauger, walleye, and freshwater drum). As well, species that are generally

common in the middle or upper reach but not in the lower reach (i.e., spotted sucker, silver redhorse, river redhorse *Moxostoma carinatum*, black redhorse *Moxostoma duquesnei*, golden redhorse *Moxostoma erythrurum*, shorthead redhorse *Moxostoma macrolepidotum*, and smallmouth bass *Micropterus dolomieu*) may not be dependent on passage to persist. The common status of these fishes in the upper- or middle-reach pools, where opportunities for fish passage are rare, suggests that local populations or upstream populations are providing recruitment in these navigation pools. The absence or low abundance of some of these species in the lower reaches may just suggest that habitat or environmental conditions are not suitable for these species, rather than any limitation imposed by fish passage.

Most of the Ohio River target fishes are known to migrate (Table 12). Many of these migrations are upstream to spawning areas in flowing water (e.g., many of the fluvial-dependent and fluvial-specialist species; Table 12), presumably followed by dispersal back downstream to resting and feeding areas. Even though many species of Ohio River fishes are reported to make upstream migrations, the importance of inter-pool migrations, in terms of maintaining abundance and distribution, is difficult to assess and probably variable among species. For example, all of the life history requirements of a species may be adequately met within a given pool; suitable substrates and conditions for adults to spawn may be present, and eggs and larvae may find or drift to suitable areas within a pool. As well, adequate feeding, resting, and wintering areas may be available within the pool. Alternatively, the presence of a species in a particular navigation pool may be sustained because populations in upstream pools or tributaries are the sole or at least a supplemental source of recruitment for the downstream pool, thus negating the need for this species to pass upstream through dams.

Conversely, navigation dams may be limiting the abundance and distribution of species that are generally only found in the lower reach or have been extirpated from the system (i.e., lake sturgeon, shovelnose sturgeon, shortnose gar, Alabama shad, bighead carp, blue sucker, bigmouth buffalo *Ictiobus cyprinellus*, blue catfish, and yellow bass; Table 12). Likewise, the distribution of species found in the lower and middle reaches but not generally in the upper reach (i.e., paddlefish, goldeye, American eel, grass carp, silver carp, highfin carpsucker *Carpiodes velifer*, white catfish *Ameiurus catus*, and striped bass; Table 12) suggests that dams may limit these species. This deduction is substantiated by the generally broader distribution and greater abundance of at least some of these species before the construction of mainstem dams (e.g., most obviously, lake sturgeon, shovelnose sturgeon, paddlefish, American eel, blue sucker; see Species of Special Interest section).

For species that are known to make long-distance migrations (e.g., anadromous species, paddlefish, and lake sturgeon; Table 12), movements upstream through dams may be particularly important because their evolutionary history may require very specific conditions, not met within a single pool, to ensure successful mating, and survival of the young. As well, paddlefish and lake sturgeon are known to range broadly, yet at times home to wintering, feeding, and spawning habitats (Auer 1996; Jennings and Zigler 2000; Knights et al. 2002; Zigler et al. 2003). The combination of these characteristics (nomadic and homing) probably makes upstream movement through dams a prerequisite to viable populations. As well, Auer (1996) suggested that egg maturation may occur during the migration of lake sturgeon, thus alterations in the distance, and hence duration, of migrations resulting from dams may negatively affect reproductive success.

However, even when evidence suggests that the abundance and distribution are reduced (e.g., shovelnose sturgeon, paddlefish, American eel, and blue sucker) or that species have been extirpated (e.g., lake sturgeon and Alabama shad), it is difficult to establish that lack of fish

passage is the cause of these losses because other historical, concomitant stressors, such as habitat changes, introduction of exotics, overharvest, and degraded water quality, may play a role in population declines (Pearson and Krumholz 1984). Many target species, particularly those that are widely distributed, are considered tolerant of pollution (Table 12), potentially suggesting the entire system is degraded or that sensitive species have not recovered from previous assaults. Pearson (1992), along with numerous others, have noted that some fishes are only recently showing signs of expanded ranges into the upper 160 km of the Ohio River (mid-Hannibal through Emsworth Pool) following severe pollution before 1970. As well, species that have been extirpated from one system with dams may still be present in other systems with dams (e.g., lake sturgeon in the Upper Mississippi River System but not in the Ohio River System and skipjack herring in the Ohio River System but not the Upper Mississippi River System; see Species of Special Interest section), again leaving uncertainty as to the role of dams.

Much uncertainty as to the effects of dams on fishes inhabiting large river systems will remain despite the efforts of researchers and managers to elucidate the issue. These uncertainties will remain because past and present stressors on large river systems have acted or act concurrently with dams to affect fish populations. As well, population assessments at the level of detail necessary to elucidate changes in abundance and distribution were not conducted particularly before dams in the Ohio River and thus any comparisons between pre- to post-dam periods become qualitative. Finally, system-specific research on the life history characteristics of Ohio River fishes is lacking, thus making assessments of the importance of longitudinal movements by these fishes difficult.

Despite uncertainties, recent literature on the ecological structure and function of large rivers indicates that longitudinal connectivity is important to river biota in many respects, and particularly so for fishes. Large river fish populations evolved under conditions that were less restrictive in terms of longitudinal movement as compared to present conditions. Thus, restrictions imposed by mainstem dams probably affect the distribution, abundance, and productivity of these populations by imposing limitations on life cycle completion and metapopulation dynamics. Our analyses of critical lift and frequency of open river suggest that fishes in the Ohio River are now probably more restricted longitudinally as compared to pre-dam conditions. The information on abundance and distribution for some species, particularly those that are highly migratory (e.g., Alabama shad, lake sturgeon, paddlefish, American eel), lend credence to the assertion that restricted longitudinal movement negatively impacts these fishes.

Dams on large rivers may negatively impact metapopulations of native fishes by reducing available habitat and immigration between subpopulations, thus making them less resilient to disturbances and more vulnerable to extinction. Francis (2003) surmised that coho salmon *Oncorhynchus kisutch* populations in Oregon are less productive and less resilient than historically because anthropogenic factors, like dams, have reduced life history variability necessary in an inconsistent and unpredictable environment. Restricted fish passage at mainstem dams has probably had similar effects on populations of anadromous and potadromous fishes in the Ohio River, but because of the qualitative nature or lack of information on abundance and distribution and because of concurrent stressors, these effects are difficult to verify.

Recommendations

The Ohio River System has been significantly modified by dams resulting in drastically altered physicochemical properties and disruption of longitudinal connectivity. Ecological principles

concerning metapopulation dynamics suggest that the biodiversity and bioproduction of native fishes in large rivers will be negatively affected by the reduced immigration and loss of habitat associated with dams (Stanford et al. 1996; Hanski 1998); after decades with dams, these consequences seem evident in the fish fauna of the Ohio River. As well, the inability of some species to complete their life cycle because required habitats are separated by generally impassable dams has undoubtedly affected abundance and distribution of these fishes in the Ohio River. These negative effects of dams mandate that restoration and enhancement efforts for fishes in the Ohio River include fish passage in conjunction with habitat restoration to be fully successful. Although most fish species present now will probably persist and some will possibly increase under present conditions, others will probably decline and possibly become extirpated if broader restoration efforts that include fish passage are not undertaken. At a minimum, most species will not reach their bioproduction potential without consideration of fish passage. As well, reintroductions of extirpated fishes that were probably most impacted by the loss of longitudinal connectivity given their life histories will be limited without addressing passage and habitat connectivity issues.

A myriad of issues surround the implementation of fish-passage improvements at mainstem dams on the Ohio River including target species, operational versus structural passage measures, cost-benefit, funding, invasive species, and the effects on other waterway users (i.e., municipal, commercial, and recreational). A thorough analysis of these issues has been completed on the Upper Mississippi River as part of the Navigation Study (D. Wilcox, U.S. Army Corps of Engineers, St. Paul, Minnesota, personal communications) and will undoubtedly benefit any future efforts by managers on the Ohio River. Issues concerning target species include which species, habitat requirements and connectivity, importance of tributaries, prioritization of dams, operational or structural measures, and type of structures. Obviously, target species should include those migratory species that have apparently been most affected by the disruption of longitudinal connectivity including Alabama shad, lake sturgeon, American eel, and paddlefish. However many other species, including small-bodied forms not covered in this report will probably benefit from connectivity of subpopulations under the principles of metapopulation dynamics (Hanski 1998; Jungwirth 1998) and should be considered in efforts to improve fish passage at mainstem dams.

Operational as well as structural measures to improve fish passage at mainstem dams on the Ohio River should be considered. For example, increasing the frequency and duration of open river by altering operational procedures used by dam operators to control water levels, or operating the locks in such a manner as to pass fish when not being used for navigation should be investigated. While less expensive than structural measures, operational measures are generally untested and may provide only limited improvements.

In the Upper Mississippi River, nature-like (i.e., rock-ramp) fishways are being seriously considered to improve fish passage at mainstem dams because of their applicability to a wide array of fish species, fish sizes, and hydrologic conditions (Gebler et al. 1998; Harris 1998). Although more conventional passage structures (e.g., vertical slot and Denil) have been designed primarily to pass adult salmonid species (Schwalme and Mackay 1985) and can be relatively expensive, they should be included in assessments of alternatives in the Ohio River because they can pass non-salmonid species (Schwalme and Mackay 1985; Bunt et al. 1999, 2001) and may be more applicable to high-lift dams or where space is limiting (Gebler 1998; Parasiewicz et al. 1998) as compared to nature-like fishways. Although similar in basic design (i.e., gated, fixed-weir, and lock sections) to Mississippi River mainstem dams, the dams on the Ohio River

tend to have greater lift that will probably make implementation of operational and structural measures more challenging and costly.

Finally, any assessment of restoration efforts will have to include a cost-benefit analysis and a determination of how to best spend limited monies for restoration. As stated previously, operational measures may be less expensive but at the same time are unproven and possibly less effective than structural measures. With limited dollars available, habitat restoration within pools and associated tributaries to accommodate the full array of life history requirements for some species may be the only affordable alternative albeit limited. Preliminary estimates for nature-like fishways at mainstem dams on the Upper Mississippi River are in the tens of millions of dollars; probably a high proportion of what is typically available for restoration. As well, assessing the effectiveness of fishways and putting a dollar value on the benefits of improved fish passage will be fraught with difficulties because of the nature of the perceived benefit (i.e., bioproduction and biodiversity of native fishes).

However, there is a growing recognition that efforts will need to go beyond species- and site-specific management to restore the natural bioproductivity and biodiversity of large regulated rivers (Stanford et al. 1996). River systems are large complex ecosystems necessitating restoration efforts at comparable scales and complexities followed by long-term assessment and adaptive management. To be successful, these efforts will need to focus on systemic issues including the restoration of more natural flow regimes, floodplain connectivity, water and substrate quality, and fish passage.

Species of Special Interest

The ORMSS-Environmental team identified some species or groups of species that were of particular concern based on abundance and distribution, as well as on ecological and economic considerations. These included widely distributed species or groups including paddlefish, skipjack herring, hiodontids, ictiobids, moronids, sauger, and walleye; species with restricted distribution including lake sturgeon, shovelnose sturgeon, American eel, blue sucker, and blue catfish; and several nonnative (potentially nuisance) species including silver carp and bighead carp. The life history characteristics, swimming abilities, abundance and distribution information, and fish-passage issues for these species or groups are discussed in the sections that follow (in phylogenetic order).

Lake sturgeon are considered a benthic large-river species that are fluvial dependent, generally requiring flowing water for reproduction. They are nonguarder litho-pelagophils (i.e., spawn over rock or gravel, larvae drift after hatching), and spawning takes place in the spring at water temperatures of 8 to 21°C (14 to15 C° seems optimal) in areas with water velocities of 0.1 to 0.15 m/s (Wallus et al. 1990; Jennings 1991). Spawning occurs in areas of swift water or rapids, outside bends of riverbanks where current is upwelling, at low falls, or near dams that preclude upstream movement (Wallus et al. 1990; Fortin et al. 1993; Bruch 1999). Eggs are demersal and attach to the substrate. Larvae hatch and drift downstream, presumably to nursery areas. Males reach sexual maturity at an age 8 to 22 years and at total lengths of 752 to 1,270 mm; females mature at age 12 to 33 years and at total lengths of 800 to 1,400 mm (Lee et al. 1980; Wallus et al. 1990; Jennings 1991). The majority of males are thought to spawn at least every other year and females every 4 to 7 years (Wallus et al. 1990; Lyons and Kempinger 1992).

Lake sturgeon are known to migrate long distances between spawning, feeding, and wintering areas (Wallus et al. 1990; Fortin et al. 1993; Auer 1996; Rusak and Mosindy 1997; Bruch 1999; Knights et al. 2002). Often times these migrations are from rivers or lakes into tributary streams. Wallus et al. (1990) cited one tagging study where lake sturgeon migrated up to 400 km and males returned to the same spawning location in subsequent years. In his review on lake sturgeon, Jennings (1991) suggested that lake sturgeon may home to natal spawning sites. Knights et al. (2002) reported median maximum extent of movement from tagging sites of adult-sized lake sturgeon from two groups in the Upper Mississippi River to be 56 and 97 km. They noted extensive movements of lake sturgeon during spring, summer, and fall between a core area in the mainstem of the Mississippi River and a large tributary, and between another core area in the mainstem and other mainstem reaches. These movements suggested a homing behavior to core feeding and wintering sites. During this 18-month study, lake sturgeon moved upstream (10 fish, 19 passages) and downstream (13 fish, 35 passages) through navigation dams on the Upper Mississippi River a total of 54 times (Knights et al. 2002). Most upstream passage events occurred during open river or during a period that included open-river and controlled-flow conditions, thus leaving uncertainty as to what conditions actually existed at the time of passage, but suggesting upstream passage during open river. Wallus et al. (1990) suggested that nonspawning movements in spring, summer, and fall were associated with selection of favorable water temperatures by lake sturgeon. Knights et al. (2002) and Bruch (1999) suggested that some movements by lake sturgeon from feeding areas in the summer or fall to tributaries may be associated with spawning that will occur the following spring.

Prolonged (U_{crit10}) and burst (10 s duration) swimming speeds of adult-sized (101 cm median total length) lake sturgeon were estimated as 0.82 and 1.55 m/s, respectively (Peake et al. 1997). The prolonged speed for lake sturgeon is near the upper end of those reported for target species. However, burst swimming speed is relatively low given the median size of adult lake sturgeon. Webb (1986) calculated that the drag per unit of wetted surface area for lake sturgeon is 3.5 times that of a similar size trout; he suggested that this was probably because of a "pressure drag penalty" for having hardened scutes rather than scales. The U_{max} estimates derived with the methods of Winter and Van Densen (2001) were 2.4 and 2.86 m/s, but may also overestimate maximum speed because of the added drag associated with scutes.

The lower Ohio River System is at the southern extent of the native range of lake sturgeon (Lee et al. 1980). Pearson and Krumholz (1984) stated that lake sturgeon were once abundant throughout the Ohio River, generally citing Trautman (1981) as the source of this information. In a later review of literature and data, Pearson and Pearson (1989) noted that lake sturgeon had been reported in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) between 1800 and 1969, but that no recent (post-1969) reliable records exist (Appendix B). Pearson and Krumholz (1984) suggest that the validity of a recent report from the middle reach (ORKm 785 in the Markland Pool in 1971) by Trautman (1981) should be doubted. Pearson and Pearson (1989) indicated that the lake sturgeon should be considered extirpated from the Ohio River and implicated navigation dams as a probable reason for their absence.

Trautman (1981) cites several sources that lake sturgeon were present, and even abundant in some instances, in the Ohio River as far east as western Pennsylvania in the 1800s and early 1900s. Trautman (1981) also cites early sources (i.e., pre-impoundment) that noted the occurrence of lake sturgeon in the Muskingum River, which enters the present day Belleville Pool just below Willow Island Dam (i.e., upper reach), and in the Scioto River, which enters the

present day Meldahl Pool just below Greenup Dam (i.e., upper margin of middle reach). The report of lake sturgeon in the Scioto River noted that they commonly migrated as far upstream as Circleville and that "stragglers" were as far upstream as Columbus, Ohio, and in several small tributaries of the Scioto River. Trautman (1981) stated that after 1916 (post-impoundment), the numbers of lake sturgeon in the Ohio River declined sharply. He goes on to suggest that the decline of lake sturgeon in Ohio waters, presumably including the Ohio River, appeared to have been caused by dams that block spawning migrations; destruction of spawning habitat by siltation, pollution, and drainage; and destruction of mollusk food resources.

In a species account, Wallus et al. (1990) cited Burr and Warren (1986) indicating that lake sturgeon were formerly present in the Ohio, Tennessee, and Cumberland Rivers of Kentucky. As well, Wallus et al. (1990) cited Eagar and Hatcher (1980) that lake sturgeon were formerly widespread in large rivers of Tennessee, with three confirmed recent reports (i.e., 1960s or 1970s) from the Cumberland and Tennessee Rivers. Smith (1979) noted that a commercial fisherman from Darwin, Illinois, reportedly captured a lake sturgeon in the Wabash River, but the date of capture was not given. Lake sturgeon were not collected in night electrofishing and lock rotenone sampling conducted between 1989 and 2001 (ORSANCO unpublished data; OEPA unpublished data); however, lake sturgeon may not be susceptible to these capture methods or may be too rare to be detected.

Whether lack of fish passage at mainstem dams is the cause of the apparent extirpation of lake sturgeon in the Ohio River System is uncertain. More likely a combination of factors, for example, overharvest, poor water quality, siltation, and blockage of spawning migration routes by dams, are to blame (Trautman 1981; Pearson and Krumholz 1984; Pearson and Pearson 1989). Several life history characteristics of lake sturgeon, including that they are benthic, highly migratory, exhibit site fidelity to spawning and feeding areas, generally spawn in flowing water over rock substrates, and produce larvae that drift downstream to nursery areas, suggest that lake sturgeon may be negatively affected by lack of upstream passage opportunities at mainstem dams.

The benthic nature of adult lake sturgeon suggests that they may be less capable of moving through open dams because they would be unable to take advantage of the lowest current velocities in the upper portion of the gate openings. However, if lake sturgeon are capable of substrate appression, as observed in shovelnose sturgeon (Adams et al. 1997), then their benthic nature may be an advantage. Knights et al. (2002) found that radio-tagged lake sturgeon moved upstream through navigation dams in the Upper Mississippi River and in most instances, these movements probably occurred during open river. Given the similarities in estimated water velocities through gate openings between Mississippi and Ohio River mainstem dams during open river (Figure 8), and the evidence of upstream passage at Ohio River dams by other fish species, it is likely that lake sturgeon could pass upstream through Ohio River dams during open river.

The literature suggests that lake sturgeon move long distances during spring, summer, and fall and that these movements are associated with spawning, feeding, or overwintering requirements (Fortin et al. 1993; Auer 1996; Rusak and Mosindy 1997; Bruch 1999; Knights et al. 2002). Auer (1996) went as far as to suggest that 250 to 300 km of barrier-free habitat be considered as a minimum for supporting self-sustaining lake sturgeon populations. Our analysis of critical lift and frequency of open river at Ohio River dams suggests that mainstem dams would impede the long distance upstream movements commonly noted for lake sturgeon. Ohio River mainstem dams that open most frequently (i.e., Louisville District dams;

Table 9) may not impede lake sturgeon during spring migrations. However, if lake sturgeon are dependent on summer or fall upstream movements for reproduction, feeding, or overwinter survival, then lower reach dams would probably be a limiting factor because they infrequently open during these periods. In general, upper and middle reach dams (i.e., Huntington and Pittsburgh District dams) open even less frequently than lower reach dams (Table 9), and thus probably act as an even greater impediment to upstream movements by lake sturgeon.

One factor that may have contributed to the extirpation of lake sturgeon and other species from the upper reach of the Ohio River was the notoriously poor water quality that occurred in that reach and its tributaries until about 1970 (Pearson 1992). Other pollution sensitive species (e.g., blue sucker, highfin carpsucker, and mooneye) apparently persisted in the lower reaches of the Ohio River during this period; these populations expanded their range back into the upper reaches after the water quality improved (Pearson 1992). Conversely, the lower reach of the Ohio River may not have been a suitable long-term refuge from poor water quality for lake sturgeon populations because the lower reach may lack suitable hard substrates necessary for successful lake sturgeon spawning. As well, the lower reach of the Ohio River defines the southern fringe of the lake sturgeon's native range (Lee et al. 1980); this suggests that habitat or physicochemical conditions (e.g., summer water temperatures) may be marginal for lake sturgeon in this reach. Alternatively, other factors (e.g., overharvest) may have contributed to the extirpation of lake sturgeon systemwide, thus re-establishment from remnant populations in the Ohio River was not possible despite improvements in water quality conditions.

The persistence of lake sturgeon in the Upper Mississippi River System, which like the Ohio River has a series of mainstem navigation dams and numerous dams on its tributaries, suggests the potential for successful reintroduction of lake sturgeon into the Ohio River. However, upstream passage opportunities (i.e., open-river conditions) are generally more frequent at dams in the reach where lake sturgeon still occur in the Upper Mississippi River as compared to the middle and upper reach dams on the Ohio River (Wilcox et al. unpublished report; Table 9). Even in the Upper Mississippi River, managers suspect that the lack of upstream fish passage is a limitation to the remnant populations of lake sturgeon. As noted previously, the potential lack of suitable spawning substrate in the lower reach of the Ohio River and the marginal habitat conditions in the lower reach as reflected by the lake sturgeon's native range argues for reintroduction into the middle and upper reaches rather than the lower reach. Thus, any reintroduction plan for lake sturgeon in the Ohio River would need to consider upstream fish-passage issues because of the lake sturgeons migratory nature and life stage-specific habitat requirements.

Shovelnose sturgeon are a benthic, fluvial specialists requiring flowing water to meet all of their life history requisites including reproduction and feeding (Keenlyne 1997; Galat and Zweimüller 2001). They are considered to be characteristic of large rivers (Pflieger 1971 in Simon and Emery 1995) and often congregate below dams or at the mouth of tributaries (Keenlyne 1997). Trautman (1981) noted that shovelnose sturgeon feed over clean sand and gravel bottoms in current. They are thought to be nonguarder litho-pelagophils (Wallus et al. 1990) that spawn from April to early July at water temperatures of 15.5 to 21.5°C, possibly cued by increased stream-flow (Forbes and Richardson 1920; Pflieger 1975; Becker 1983; Wallus et al. 1990). Shovelnose sturgeon are known to move upriver to spawn in tailwaters, at rock structures, or in tributaries (Keenlyne 1997). Males reach sexual maturity at age 5 and at a median total length of 551 mm; females reach maturity at age 7 and at a median total length of 645 mm (Forbes and

Richardson 1920; Becker 1993; Wallus et al. 1990). Most (65% to 70%) mature males are thought to spawn in a given year, while females may spawn only every 2 to 3 years (Wallus et al. 1990).

Hurley et al. (1987) noted that most movement by radio-tagged shovelnose sturgeon between April and September in Pool 13 of the Upper Mississippi River occurred during May and July, with the least movements in April and June. They noted movements of up to 17 km between activity centers, with "homing" by 8 of 22 radio-tagged fish to these activity centers. Aside from movements between activity centers, radio-tagged shovelnose sturgeon were largely sedentary during the study (Hurley et al. 1987). Additionally, Hurley et al. (1987) and Curtis et al. (1997) found that shovelnose sturgeon in the Upper Mississippi River generally used the upstream portion of navigation pools (i.e., riverine portion) rather than the downstream, impounded areas. Curtis et al. (1997) reported that 15% of locations of radio-tagged shovelnose sturgeon occurred in the tailwaters of Dam 12. Hurley et al. (1987) noted that of 146 tag returns from 2,385 tagged shovelnose sturgeon, one fish moved upstream 43 km passing through one navigation dam, and four fish moved downstream 182 to 190 km passing through four navigation dams; the other 141 recaptures occurred in the navigation pool where fish were originally tagged. Moos (1978 in Wallus et al. 1990; Keenlyne 1997) found that shovelnose sturgeon moved as far as 540 km downstream in the Missouri River and suggested that dams in the upper Missouri River may block migrations of shovelnose sturgeon to traditional spawning grounds.

Estimates of prolonged swimming speeds (U_{crit}) based on work by Adams et al. (1997) and Tunink (1975) range from 0.65 to 0.77 m/s for adult fish. The estimated burst speed of a median adult-sized shovelnose sturgeon based on a lake sturgeon model (Peake et al. 1997) was 1.00 m/s. An estimate of U_{max} derived with the methods of Winter and Van Densen (2001) was 3.00 m/s, but like those for lake sturgeon may be an overestimate of burst speed because of increased drag associated with the fish's scutes (Webb 1986). Shovelnose sturgeon exhibit substrate appression, a behavior that allows them to hold their position on the bottom in high water velocities (Adams et al. 1997); this behavior may enable shovelnose sturgeon to move upstream through mainstem dams if their estimated burst speeds are near 3.00 m/s as predicted by U_{max}, as opposed to 1.00 m/s as predicted by the lake sturgeon model.

The Ohio River defines the eastern limit of distribution for shovelnose sturgeon (Lee et al. 1980). Pearson and Pearson (1989) found that shovelnose sturgeon were present in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle— ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) in an early period (1800 to 1969), and only in the lower two reaches in a recent period (post-1969; Appendix B). Pearson and Krumholz (1984) noted that shovelnose sturgeon populations declined dramatically in numbers between 1900 and 1950. Additionally, they noted only two reports of shovelnose sturgeon in the late 1950s from ORKm 510 to 1,194 (i.e., middle reach; Belleville to Newburgh Pool) and one report of 84 specimens taken between ORKm 1,194 to 1,578 (lower reach; Newburgh Pool to the mouth). Pearson and Krumholz (1984) noted five reports after 1970 of specimens taken between Newburgh Pool and the mouth with the most recent two reports occurring in 1981. Additionally, they noted that William Pearson collected two adult shovelnose sturgeon in the Cannelton Pool at the Falls of Ohio (i.e., lower margin of the middle reach) in 1983. Pearson and Krumholz (1984) suggest that the remnant populations of shovelnose sturgeon in the lower Ohio River are seriously threatened.

Trautman (1981) indicated that shovelnose sturgeon were common in the Ohio River during 1925 to 1950 from the mouth of the Scioto River (enters upper Meldahl Pool; upper

margin of the middle reach) westward. He also noted that according to fishermen, a marked decrease in shovelnose sturgeon abundance had occurred since about 1950 and that work done at the University of Louisville supports this supposition. Bailey and Cross (1954 in Wallus et al. 1990) noted that shovelnose sturgeon were common in the Ohio River in Washington County in eastern Ohio (i.e., the middle portion of the upper reach) until impoundment in 1911, but were rare upstream of Scioto County, Ohio (i.e., upper margin of the middle reach), after the 1950s. Burr and Warren (1986 in Wallus et al. 1990) indicated that shovelnose sturgeon were formerly common in tributaries to the Ohio River in Kentucky including the Licking (enters Markland Pool; middle reach) and Big Sandy (enters Greenup Pool; lower margin of the upper reach) Rivers. They also indicated that shovelnose sturgeon might still be present in the Tennessee, Cumberland, Green, Kentucky, and Licking Rivers (lower and middle reaches). Burr and Warren (1986 in Wallus et al. 1990) also noted that shovelnose sturgeon are occasional to common in the lower Ohio River. Smith (1979) reported that shovelnose sturgeon are more abundant in the Wabash River (enters Smithland Pool; lower reach) than in other rivers in Illinois, but that information was not available to assess their abundance in the lower Ohio River.

Our review of recent data found shovelnose sturgeon to be occasionally to commonly collected in gill nets in the lower-reach tailwaters (i.e., Newburgh Dam tailwaters and below) during the 1980s (Kinman et al. 1989). In an analysis of other recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that no shovelnose sturgeon were collected (Appendix B); however, these surveys did not include typical shovelnose sturgeon habitat (i.e., main channel and tailwater areas with moderate current).

This information suggests a reduction in the distribution or abundance of shovelnose sturgeon in all reaches of the Ohio River, particularly in the middle and upper reaches. This pattern of abundance and distribution suggests that lack of upstream passage at mainstem dams, that open more frequently in the lower reach as compared to the middle and upper reaches (Table 9), may negatively affect shovelnose sturgeon populations. As well, shovelnose sturgeon are known to migrate upstream to spawn suggesting that dams may block migrations to spawning habitats in upstream reaches and tributaries of the Ohio River. However, shovelnose sturgeon are not generally known for long-distance spawning migrations like those of lake sturgeon and may be more sedentary at other times (Hurley et al. 1987). Furthermore, shovelnose sturgeon may successfully spawn in tailwaters of dams (Keenlyne 1997), thus negating the need to move upstream through dams for successful reproduction. Conversely, shovelnose sturgeon larvae are thought to drift downstream to nursery areas; this downstream movement of larvae may necessitate movement back upstream (possibly through dams) by juvenile or adult fish to sustain fish numbers in the upper reaches. The spawning period for shovelnose sturgeon generally occurs after the peak open-river period at dams (Appendix B), particularly in the Huntington District (i.e., middle reach), suggesting that shovelnose sturgeon may have little opportunity for upstream passage during spawning migrations. Likewise, the Pittsburgh District (i.e., upper reach) dams are only rarely open (Appendix B) and thus upstream passage through those dams is probably minimal during all seasons.

Despite a report that indicated that shovelnose sturgeon can move upstream through navigation dams on the Upper Mississippi River (one fish; Hurley et al. 1987), they may not be capable of moving through the gate openings given their relatively low swimming speeds (Table 8). Shovelnose sturgeon would probably have to use substrate appression (Adams et al. 1997) in conjunction with burst swimming close to their estimated U_{max} (i.e., 3.00 m/s; Table 8) to move upstream through the relatively high water velocities in the gate openings of mainstem

dams (Figure 8). However as noted previously, U_{max} may overestimate burst swimming speeds of shovelnose sturgeon because of increased drag associated with scutes (Webb 1986). In general, the studies of shovelnose sturgeon in the Upper Mississippi River (i.e., Hurley et al. 1987; Curtis et al. 1997) indicated that upstream movement through mainstem dams is rare. This supports the hypothesis that movement through gate openings may not be possible for shovelnose sturgeon even during open-river conditions and that another pathway (e.g., through the lock chamber) may have been used in the single instance reported. Conversely, the rare occurrence of upstream passage could suggest that shovelnose sturgeon do not have the propensity to move upstream through dams. As noted previously, radio-tagged shovelnose sturgeon in the Upper Mississippi River predominately moved short distances between activity centers and were otherwise rather sedentary (Hurley et al. 1987).

Although the pattern of abundance and distribution suggests that lack of fish passage may negatively affect shovelnose sturgeon populations in the Ohio River, Pearson and Krumholz (1984) suggest that an environmental change in the Ohio River, rather than harvest or dams (i.e., lack of fish passage), is responsible for the decline of shovelnose sturgeon. In support of this hypothesis, they noted that shovelnose sturgeon were not an important commercial species nor do they undergo extensive spawning migrations. Pearson and Krumholz (1984) suggested that siltation might have reduced available food resources and spawning substrates for shovelnose sturgeon. As well, shovelnose sturgeon are fluvial specialists (Keenlyne1997; Galat and Zweimüller 2001) indicating that they may be severely affected by the conversion of riverine (i.e., lotic) habitats to impoundments (Van Hassel et al. 1988). This is supported by work done on the Upper Mississippi River that found shovelnose sturgeon generally use the upper, riverine portion of the navigation pools rather than the downstream impounded portion (Hurley et al. 1987; Curtis et al. 1997).

Paddlefish are a pelagic, fluvial-dependent species requiring flowing water for reproduction (Balon 1975; Galat and Zweimüller 2001). They are considered to be characteristic of large rivers (Pflieger 1971 in Simon and Emery 1995) and are known to congregate below dams or in other deep areas with slow-moving water (Jennings 1991; Johnson et al. 1997; Henley et al. 2001; Zigler et al. 2003). Paddlefish move upstream to spawn in the spring when water temperatures are about 10 to 16°C and may be cued to spawn by rising water levels (Wallus et al. 1990; Jennings 1991). They are nonguarder litho-pelagophils that spawn over gravel-rubble substrate in water 2 to12 m deep (Wallus et al. 1990). Paddlefish eggs are demersal and larvae drift downstream to nursery areas (Wallus et al. 1990). Males are sexually mature at age 6 to 9 and at total lengths of 1,020 mm to 1,397 mm; females are sexually mature at age 7 to 12 and at total lengths of 1,070 mm to 1,397 mm (Wallus et al. 1990; Jennings 1991).

Paddlefish are known to be highly migratory within large river systems. Smith (1979) indicated that paddlefish move up tributaries to dams that block their migration. Henley et al. (2001) noted that extensive movements are characteristics of all ages of paddlefish and suggested that upriver movement through mainstem dams on the Ohio River may be restricted even at open river. Conversely, documentation of upstream passage through navigation dams was more common than downstream passage for paddlefish tagged as part of a basin-wide (i.e., Mississippi River Basin including the Ohio River) mark-recapture effort (Conover and Grady 2000; Henley et al. 2001). Johnson et al. (1997) found that paddlefish radio-tagged at the mouth of the Scioto River in Meldahl Pool (i.e., upper margin of the middle reach) commonly made extensive downstream and upstream movements (up to 100 km). Eight of 15 radio-tagged paddlefish

moved downstream through the Meldahl Dam, and four of these eight fish eventually moved back upstream through that dam during open river. Johnson et al. (1997) also noted paddlefish movements into several tributaries including the Scioto (up to 30 km), Brush, and Goose Laughery; all of these tributaries enter the Meldahl Pool. Others have noted movements of paddlefish through navigation dams and into large tributaries on the Upper Mississippi River (Southhall and Hubert 1984; Moen et al. 1992; Zigler et al. 2003). Zigler et al. (2003) noted that the extent of movement by radio-tagged paddlefish was up to 420 km, with numerous fish moving in excess of 100 km from tagging sites. As well, they noted 53 instances of paddlefish passing through navigation dams on the Upper Mississippi River during a 3-year study, including 20 instances in the upstream direction and 33 in the downstream direction. Upstream movement through mainstem dams on the Upper Mississippi River by paddlefish was related to lift, with a 7-fold decrease in the likelihood of upstream passage with each 1 m increase in lift (Zigler et al. in press).

Prolonged swimming speeds (U_{crit10}) for paddlefish 37 to 65 cm in length (eye to base of caudal fin) were 54.7 to 65.4 cm/s (Tunink 1975). We used 65 cm/s as an estimate for prolonged speed for adult paddlefish of median size (84 cm eye-to-fork for males); however, this may be low given that the test individuals in Tunink's (1975) work were not of median adult size. An estimate of burst speed for paddlefish based on a lake sturgeon model (Peake et al. 1997) was 1.4 m/s; this however may be low because paddlefish do not have scutes like lake sturgeon, and as noted by Webb (1986) scutes increase drag significantly. Estimates of U_{max} as a proxy for burst speeds were 2.29 and 3.0 m/s at 11 and 15ºC, respectively.

As with shovelnose sturgeon and lake sturgeon, the upper Ohio River defines the eastern native range of paddlefish (Lee et al. 1980). Pearson and Pearson (1989) found that paddlefish were present in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) in an early (1800 to 1969) and recent period (post-1969; Appendix B). Pearson and Krumholz (1984) noted that paddlefish were originally found from the mouth of the Ohio River (ORKm 1,578) to ORKm 153 (in Hannibal Pool; no source given) and that they had not been reported above ORKm 690 (in Meldahl Pool) since 1970. Conversely, Trautman (1981) noted a newspaper article citing an observation of a dead paddlefish in shallow water in a small tributary of the Muskingum River (enters the upper Ohio River at ORKm 276) in 1977. In a more recent review, Pearson and Pearson (1989) indicated an upstream range extension for paddlefish since 1970 to ORKm 549 (presumably Greenup Dam lock chamber); this is supported by Johnson et al. (1997), who recorded locations of radio-tagged paddlefish in the tailwaters of Greenup Dam.

Trautman (1981) cites reports of the presence or abundance of paddlefish before 1900 in the upper reaches and larger tributaries of the Ohio River in Ohio and Pennsylvania, but that soon after impoundment the species decreased markedly. He also noted that before 1880 several sources indicated that paddlefish were abundant in the Scioto River at Columbus, Ohio. Additionally, he stated that paddlefish were reported above Marietta in the Ohio River (near the mouth of Muskingum River in present day Belleville Pool; upper reach) before 1925. Trautman (1981) goes on to state that paddlefish were reduced in abundance in the Ohio River between 1925 and 1950, but that during that period it was most numerous west of Portsmouth (i.e., west of the mouth of the Scioto River). This abundance pattern may have been evident before impoundment as well; for example, Jordan (1882; in Pearson and Krumholz 1984) noted that paddlefish were more abundant in the "lower Ohio River of Ohio" (presumably as compared to the upper Ohio River of Ohio).

Wallus et al. (1990) reported that paddlefish were formerly abundant in the Ohio River and several large tributaries including the Tennessee, Cumberland, and Wabash Rivers. Smith (1979) reported that older commercial fishermen had caught large numbers of paddlefish in the Wabash River, but that they are now rare. Wallus et al. (1990) also noted that paddlefish occur in the Ohio, Great Miami, Scioto, Tennessee, Cumberland, Green, Salt, Kentucky, Licking, Little Sandy, and Kanawha Rivers. Additionally, they noted that paddlefish occur throughout mainstem reservoirs and larger tributaries of the Tennessee and Cumberland River Systems. Henley et al. (2001) reported that paddlefish taken from the Tennessee and Cumberland Rivers represented a large portion of historical harvest.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that paddlefish were collected occasionally in the lower and middle reach pools (i.e., Meyers to Greenup Pool), occasionally in the Racine Pool (upper reach), and uncommonly in the Pike Island Pool (upper reach; Appendix B). These data sets included recent observations of paddlefish above ORKm 690 including observations in the Meldahl (last record 1995; OEPA unpublished data); Greenup (last record 1995; ORSANCO unpublished data); Racine (last record 1997; ORSANCO unpublished data); and Pike Island Pools (last record 1992; ORSANCO unpublished data). The recent records in the upper pools (i.e., Racine and Pike Island Pools) may be a result of the stocking of paddlefish in the upper Ohio and Kanawha Rivers in the early 1990s (Henley et al. 2001). However, reproduction is occurring in the system as indicated by the capture of larval paddlefish in McAlpine Pool in 1977 (Pearson and Krumholz 1984) and in Meldhal Pool in 1994 and 1995 (Johnson et al. 1997). Johnson et al. (1997) suggested that based on developmental stage, the larval that they captured might have originated from Meldahl or possibly Greenup Pool. Abundance of paddlefish in ORSANCO lock rotenone samples was variable during a 45-year period between 1957 and 1997, with relatively high abundance occurring in the late 1950s, late 1970s, and again in the early 1990s (Lowman 2001).

This information suggests that the present distribution of paddlefish in the mainstem Ohio River is similar to the historical distribution (i.e., mouth to about Pike Island Pool); however, abundance is probably reduced and occurrences above the Greenup Dam are rare. Pearson and Krumholz (1984) suggested a downstream shift in the distribution of paddlefish because at the time of their report no paddlefish had been reported above ORKm 690 (in Meldahl Pool) since 1970. They suggested that this shift might have resulted because of pollution in the upper river or because of restricted fish passage at the mainstem dams. Paddlefish may have expanded their range above Meldahl Pool over the past 30 years by a gradual immigration upstream as permitted by improved water quality (Pearson and Pearson 1989). However, stocking of paddlefish in the upper Ohio and Kanawha (enters R. C. Byrd Pool) Rivers in the early 1990s (Henley et al. 2001) may be responsible for the reports of paddlefish in these upper pools. Johnson et al. (1997) suggested that the upper Ohio River is at the fringe of the native range for paddlefish. This suggests that paddlefish abundance in the upper four to six navigation pools (i.e., Pittsburgh District pools) has always been limited. As noted previously, this is also supported by Jordan's (1882; in Pearson and Krumholz 1984) observation that paddlefish were more abundant in the "lower Ohio River of Ohio."

Life history characteristics and recent literature on the movements of paddlefish suggest that they are highly dependent on upstream migrations for successful reproduction and thus probably affected by restricted passage opportunities at mainstem dams. Their estimated swimming capabilities and pelagic nature indicate that they should be able to take advantage of

any low current zones that may exist in the upper portions of the gate bays and thus possibly pass through the mainstem dams during open river. This is supported by several studies that have noted paddlefish movement upstream through navigation dams (Southhall and Hubert 1984; Moen et al. 1992; Johnson et al. 1997; Conover and Grady 2000; Zigler et al. 2003), including the Meldahl Dam on the Ohio River; many of these studies also suggest that upstream movement through dams by paddlefish occurs during open river.

Paddlefish migrate and spawn at relatively low water temperatures; this may allow them to take advantage of the peak open-river period at the dams, particularly at lower reach dams that open more frequently (Appendix B). However, open-river frequency and duration and hence passage opportunities are moderate to low at middle and upper reach dams (i.e., Huntington and Pittsburgh District dams). This limited opportunity may have substantial implications for paddlefish populations, particularly so if the middle and upper reaches of the Ohio River and associated tributaries (e.g., Scioto, Muskingum, and Kanawha Rivers) comprise the historical spawning habitat for paddlefish in the system. However, as with other litho-pelagophils that spawn over gravel-cobble substrates in flowing water, the creation of reservoirs and their associated sedimentation and reduction in water velocity may be an equally limiting factor for paddlefish populations because of the loss of spawning habitat (Pearson and Krumholz 1984). Obviously, the consideration of upstream fish passage and availability of spawning habitats must go hand-in-hand when planning restoration efforts for paddlefish in the Ohio River.

Goldeye and mooneye *(hiodontids)* are both pelagic, fluvial-dependent species characteristic of large river systems (Pflieger 1971 in Simon and Emery 1995; Galat and Zweimüller 2001). As well, both species spawn over gravel-rock substrates and their embryos develop as they drift (i.e., nonguarder, litho-pelagophil). Mooneye spawn in fast water in large clear streams and in the tailwaters of dams (Trautman 1981; Wallus et al. 1990). Goldeye may be more generalists in regards to spawning habitat as compared to mooneye. Lee et al. (1980) reports that goldeye spawn in pools of rivers or backwaters of lakes, while others report that goldeye ascend tributary streams and spawn over gravel shoals (Smith 1979; Wallus et al. 1990), or in shallow inshore areas of lakes, pools of turbid rivers, and backwater lakes and ponds of rivers (Wallus et al. 1990). Both species are thought to migrate to spawn in the spring at water temperatures of about 10 to 20°C (Smith 1979; Trautman 1981; Wallus et al. 1990). Mooneye may generally spawn earlier in spring than goldeye as indicated by the lower range of reported spawning temperatures (Table 12).

Estimates of prolonged swimming speed for both species based on observations of goldeye in two separate studies (Jones et al. 1974; Tunink 1975) were 0.8 m/s and 0.6 m/s (Table 8). Burst speeds for both species based on a study of American shad were 3.47 to 4.15 m/s (Weaver 1965). Maximum swimming speed estimates (U_{max}) ranged from 2.56 to 4.20 m/s at temperatures of 9 to 15°C for both species as determined by methods of Winter and Van Densen (2001; Table 8).

The upper Ohio River defines the eastern native range for mooneye and goldeye; however, their range extends north and south of the Ohio River Basin (Lee et al. 1980). In their review of data and literature, Pearson and Pearson (1989) found that goldeye and mooneye were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). Pearson and Krumholz (1984) point out the similarity in abundance and distribution of these two species in the Ohio River and suggested that neither species was

abundant historically. Pearson and Krumholz (1984) also stated that the goldeye are commonly seen but never in abundance. They stated that the goldeye were never as abundant as the skipjack herring and that others suggested that goldeye numbers were reduced. The only recent records (1979 and 1981) they found of goldeye above ORKm 269 (in Belleville Pool) were at ORKm 87 (New Cumberland Lock) and ORKm 124 (in New Cumberland Pool). Pearson and Krumholz (1984) indicated that mooneye were present in the Ohio River upstream to the mouth of the Muskingum River (enters Belleville Pool; ORKm 277) between 1920 and 1969; however, they found no reports of mooneye since 1970 in the reach above ORKm 418 (in R. C. Byrd Pool). Pearson and Pearson (1989), however, indicated that the mooneye appear to be expanding their distribution as demonstrated by occurrences between ORKm 418 and ORKm 87 since 1983.

Henshaw (1888 in Trautman 1981) indicated that goldeye were present in the Ohio River presumably near Cincinnati, Ohio (Markland Pool; about ORKm 750). Trautman (1981) noted that fishermen reported goldeye occasionally present to the Pennsylvania state line (presumably around 1920), particularly during spring. Trautman (1981) described the abundance and distribution of goldeye in Ohio as extending along the entire border; however, he noted that they were most abundant in the Scioto River and in the Ohio River from the mouth of the Scioto River (ORKm 570) westward. He also noted their presence in the Muskingum and Little Miami Rivers. Trautman (1981) suggested that goldeye had become more abundant relative to the mooneye since 1920, possibly because of the goldeye's greater tolerance of high turbidity. He also noted that the distribution of goldeye between 1955 and 1980 did not change relative to their distribution pattern in 1950.

Forbes and Richardson (1908 in Smith 1979) noted that goldeye were formerly common in the Ohio River in Illinois, but rare at the time of their field work. Smith (1979) indicated that goldeye are now uncommon in the Ohio and Wabash Rivers in Illinois. Clay (1975) indicated that goldeye are present in the Ohio River in Kentucky, and in the lower reaches of major tributaries including the Green River (enters J. T. Myers Pool), Salt River (enters Cannelton Pool), Cumberland River (enters Pool 52), and middle fork of Kentucky River (enters McAlpine Pool). Clay (1975) also noted that goldeye had been extirpated from the upper Tennessee and Cumberland Rivers. Wallus et al. (1990) cited two reports that indicated goldeye were commonly present (in small numbers) in samples from the Ohio River collected between 1977 and 1986 from ORKm 418 and ORKm 795, but infrequent in samples from the lower Ohio River. He also cites Etnier and Starnes (no date) indicating that goldeye were found in the upper Tennessee and Cumberland Rivers before impoundment, but have since disappeared.

Kirtland (1847 in Trautman 1981) and Henshall (1888 in Trautman 1981) indicated that mooneye were common in the Ohio River before 1900, but did not give reach-specific information. Trautman (1981) noted that during extensive field work between 1920 and 1935, he collected no mooneye in the Ohio River west of Adams County (Meldahl Pool; middle reach) and that only a few individuals were collected east of Adams County (lower Meldahl and upper Markland Pools). However, he stated that during this period mooneye were still abundant in the lower Scioto River (enters Meldahl Pool; upper margin of the middle reach), but that numbers had markedly declined since 1935. Forbes and Richardson (1908 in Smith 1979) reported that mooneye were formerly common in the Ohio River (presumably along Illinois), but rare at the time of their field work. Smith (1979) indicated that mooneye were presently uncommon in the Ohio and Wabash Rivers in Illinois. Environmental Science and Engineering, Inc. (1987 in Wallus et al. 1990) indicated that mooneye were present in small numbers in gill net samples at

ORKm 418 and ORKm 795 from 1977 to 1986 (all years). Wallus et al. (1990) also noted that mooneye were occasional to rare in the Green River (enters J. T. Myers Pool; lower reach) and occasional to common in the reservoirs of the Tennessee and Cumberland Rivers (enter Pool 52; lower reach). Clay (1975) stated that mooneye were more abundant in the Ohio River in western Kentucky as compared to eastern Kentucky.

Our examination of recent survey data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data) indicated that goldeye were generally occasional to common in samples from Smithland to Markland Pool (lower and middle reaches), and generally absent from R. C. Byrd to Emsworth Pool (upper reach; Appendix B). Analysis of the ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) indicated that the abundance of goldeye was variable across years with no significant trends in any of the three sections of the Ohio River (upper—ORKm 0 to 327; middle—ORKm 327 to 1,134; and lower—ORKm 1,142 to 1,578; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]) and that relatively high catches were noted periodically including in the 1950s, 1970s, and 1990s. In our examination of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found mooneye to be more widely distributed and generally more common than goldeye (Appendix B). Mooneye were generally common in collections from Smithland to Racine Pool (lower and middle reaches and lower margin of the upper reach), and occasional from Belleville to Dashields Pool (upper reach). Analysis of the ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) indicated that mooneye were increasing in all three sections of the Ohio River.

This information suggests that goldeye and mooneye have persisted in the Ohio River System despite the presence of dams. Their apparent greater abundance and wider distribution in the lower reaches of the Ohio River, as compared to the upper reach, suggest that lack of fish passage may adversely affect both species. However, historical information, albeit qualitative, suggests that goldeye and mooneye may have declined before impoundment (Smith 1979; Trautman 1981) probably as a result of increased turbidity and pollution. Recent data suggest that these populations have expanded their range or increased in abundance (Pearson and Pearson 1989; Lowman 2000; Appendix B) probably because of improvements in water quality brought about by the Clean Water Act (Van Hassel et al. 1988; Pearson and Pearson 1989). Again, the qualitative nature and general lack of historical data, along with the concomitant nature of environmental stressors acting on these populations, make it difficult to assess the relative role of fish passage in affecting goldeye and mooneye populations. However, if we accept these historical assessments as correct and take into account the recent expansions in abundance and distribution of these populations, then poor water quality rather than lack of fish passage probably played a larger role in their early declines. Regardless, now that water quality has improved, improvements in upstream fish passage may further benefit goldeye and mooneye populations.

Life history characteristics of goldeye and mooneye (e.g., migratory, drifting embryos, large-river fauna) imply that both species should benefit from upstream passage through mainstem dams. The relatively high swimming speed estimates and pelagic nature of goldeye and mooneye suggest that they should be capable of moving through mainstem dams during open river; however, to our knowledge no information is available that documents such movements. Based on spawning temperatures, both species probably begin to migrate early, but mooneye have a narrower range of reported spawning temperatures (Table 12), thus may be obligated to move sooner than the goldeye. This suggests that both species can take advantage

of the peak open-river period in the lower reaches of the Ohio River to pass through dams, but that mooneye may have a slight advantage over goldeye because mooneye may be more likely to encounter open-river conditions at the dams during earlier migrations (Table 9; Appendix B).

American eel are a benthic catadromous species that migrate from the Mississippi River and other East Coast drainages to the Sargasso Sea in the Atlantic Ocean to spawn in late winter to early spring and then die (Smith 1979; Wallus et al. 1990, Stauffer et al. 1994; Haro et al. 2000). The larvae passively drift back toward the East Coast of North and South America and develop into elvers (Avise et al. 1986 in Haro et al. 2000). After reaching the coast, female elvers migrate far upstream into large river systems to feed and mature, while males remain in the lower reaches (Pflieger 1975; Lee et al. 1980). Females reach sexual maturity in 5 to 20 years and at a total length of about 457 mm (Becker 1983) before migrating out of rivers and back to the Sargasso Sea. The population is thought to be panmictic (i.e., mature adults migrate from numerous watershed, meet in the Sargasso Sea, and spawn together), thus recruitment in a particular watershed, such as the Ohio River Basin, is not necessarily dependent on the production of adults from that watershed (Haro et al. 2000).

We found no species-specific information on the swimming speeds of American eel, but McCleave (1980) reported that European eel elvers would probably not make progress in water velocities >0.5 m/s. Estimated burst speed of adult-sized American eel was based on work with the European eel (Blaxter and Dickson 1958) and was 1.14 m/s. Estimated burst speeds of adult-sized American eel based on the methods of Winter and Van Densen (2001) were 1.81 and 3.63 m/s at 15 and 25°C, respectively. Female eels are known to move over land on wet nights, potentially allowing them to pass obstacles, such as dams (Stauffer et al. 1994).

The Ohio River drainage is central to the native range of the American eel (Lee et al. 1980). However, East Coast watersheds represent the relative stronghold for remaining numbers. Pearson and Pearson (1989) suggest that the historical distribution of American eel in the Ohio River Basin is largely unknown. They found records of the species in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) in an early (1800 to 1969) and recent period (post-1969; Appendix B). Pearson and Krumholz (1984) noted that there were no records of American eel above ORKm 277 (in Belleville Pool) between 1920 and 1969 and that the four recent records (post-1969) represent a return to this reach of the river because of improved physicochemical conditions (presumably from a reduction in pollution).

Rafinesque (1820 in Trautman 1981) noted the presence of American eel as far upstream in the Ohio River as Pittsburgh. Kirtland (1850 in Trautman 1981) stated that American eel ascend the Ohio River drainage to "even its head during spring." Trautman (1981) reported that American eel were "rather numerous" between 1920 and 1950 in the Ohio River as far upstream as Marietta (mouth of the Muskingum), in the lower Scioto River (enters Meldahl Pool), and in the Muskingum River (enters Belleville Pool). He also noted their presence in 1968 and 1969 (as reported to him by H. Ronald Preston) at four of nine collection stations on the Ohio River between Belmont and Clermont counties (Markland through Hannibal Pool; middle to upper reach). Smith (1979) suggests that the American eel are now rare in Illinois and is most often found in large rivers. His map depicting the distribution of American eel indicated that it was reported from the Wabash River and a tributary of the Wabash River, but not from the mainstem of the Ohio River along Illinois. Smith (1979) suggests that the construction of dams has greatly

reduced American eel numbers in Illinois. Clay (1975) noted that American eel enter Kentucky streams from the Ohio River, but that their movements are inhibited by large dams.

Our examination of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data) indicates that American eel are generally collected occasionally from the Smithland to Markland Pool (lower and middle reaches), and generally uncommon to absent in the remaining upstream pools (Appendix B). In the lower reach, American eel were commonly collected in the Smithland Dam lock surveys, with the most recent specimens captured in 1997. The most recent records in the upper reach of the river were from the New Cumberland (in 1988) and Racine (in 1989) lock chambers (ORSANCO unpublished data).

This information on abundance and distribution suggests that dams generally block movements of American eel in the Ohio River and that the resulting cumulative effect of blockage is the general absence of the species in the upper reaches of the system. This hypothesis is supported by the swimming speed and life history information reported for American eel. We found little information regarding the migration period of American eel in the Ohio River, but an early report (Kirkland 1850 in Trautman 1981) suggests an upstream migration in the spring. Although this migration period corresponds to the peak period for open river, the poor swimming ability and benthic nature of the species may prevent them from moving upstream through open dams. As well, they are catadromous, and landlocked populations are not known. Thus, American eel must move through or around dams to be present in the upper reaches of the Ohio River. A recent decline in this species has been noted for a broad geographic area in North America, and obstruction of migratory pathways by dams has been implicated as a probable cause in several watersheds (Haro et al. 2000). However, despite dams, American eel have persisted in regulated rivers, including the Ohio River. Thus, other factors (e.g., harvest, oceanic variation, contaminants, and disease) may be acting in concert with dams to affect population levels (Haro et al. 2000). The recent reports of American eel in the Ohio River may be the result of upstream passage through the locks or movement around these dams on wet surfaces by a few individuals. Given a panmictic population, individuals reported in the Ohio River may be offspring from adults that were reared elsewhere (e.g., the lower portions of the Mississippi River Basin, Gulf Coast streams, or Atlantic Coast streams), rather than from the apparently meager number of American eel now reaching maturity in the Ohio River.

The obvious need for upstream passage in order for American eel to be present in the Ohio River (i.e., recruits must come from the ocean) and the apparent decline in their numbers probably in part because of dams, argues strongly for implementation of measures to improve passage at these dams in order to enhance their population. Although some passage still occurs, directed measures to improve passage could benefit American eel in the Ohio River. Large numbers of American eel and European eel are known to pass through conventional fish and eel-specific passage structures, sometimes with great success (Haro et al. 2000). As well, American eel are habitat generalists and thus would probably be able to meet feeding and overwintering requirements if they are able to move into the impoundments in the Ohio River.

Factors that may counteract population increases despite implementation of passage measures include yet unconfirmed (e.g., overharvest, oceanic variation, contaminants, and disease) or unidentified factors causing the general decline in American eel numbers throughout their native range (East Coast of North America and northern South America; Haro et al. 2000). The relatively recent discovery that the Gulf hypoxic zone is growing may also deter recovery of American eel by blocking access to the Mississippi River. The qualitative nature of the historical

data on abundance and distribution does not provide the level of detail necessary to assess whether or not the Ohio River was ever more than a marginal watershed for the American eel. An examination or understanding of oceanic currents or American eel densities in other Gulf Coast watersheds over time may provide some answers to this question by determining the degree to which these currents are favorable to elver drift into these systems. Given the panmictic nature of the American eel population, one can imagine that under certain oceanic conditions (water currents) Gulf Coast watersheds, including the Ohio River Basin, may have been important sources of adult American eel and thus may have contributed to the relative stability of the population.

Alabama shad are a pelagic, anadromous species that migrate into the Mississippi River Basin and other Gulf Coast rivers to spawn in January to July when water temperatures reach 19 to 22°C (Clay 1975; Smith 1979; Lee et al. 1980; National Oceanic and Atmospheric Administration [NOAA] 2001). Spawning occurs over coarse sand, gravel, and rock substrates in moderate current (Lee et al. 1980; NOAA 2001). Adult fish return to the ocean shortly after spawning. Alabama shad sexually mature at 25 to 45 cm total length (Pflieger 1975). The average age of spawning fish is 2 years, and up to 38% of individuals are thought to be return spawners (NOAA 2001). Young remain in rivers for 6 to 8 months before migrating back to the Gulf of Mexico (NOAA 2001); little is known about their distribution once they return to sea (Clay 1975).

Lee et al. (1980) indicated that Alabama shad were formerly in the mainstem and major tributaries of the lower Mississippi River, but are now considered rare in this drainage possibly because of dams and increased siltation. Their former distribution included reports from the mainstem of the Ohio River at Louisville, Kentucky and in the Cumberland River (Lee et al. 1980). Pearson and Krumholz (1984) noted that the only report of Alabama shad in the Ohio River was by Everman (1902 in Pearson and Krumholz 1984) who reported them at Louisville, Kentucky, in 1897 and 1898. They stated that Alabama shad are not probably present in the Ohio River today. Clay (1975) noted other reports of Alabama shad from the Louisville area in the late 1800s. As well, he noted reports of the Ohio shad (*Alosa ohiensis*), now thought to be the same species as the Alabama shad, as far upstream as the mouth of the Kanawha River (enters R. C. Byrd Pool) in the 1800s. Wallus et al. (1990) reported that Alabama shad were present in large rivers in Tennessee, but that they were "not able to cope with impoundments," suggesting they have been extirpated; however, they do not cite references to support these contentions. The NOAA (2001) reported that Alabama shad supported a commercial fishery in the Ohio River in the 1800s; however, this source does not provide a specific reference for this information. Furthermore, Clay (1975) noted the likelihood of non- or misidentification of "shad" species found in the Ohio River in the 1800s and that American shad (*Alosa sapidissima*) were stocked and supported at least a limited fishery in the Ohio River at that time. The dearth of historical reports for Alabama shad in the Ohio River drainage may imply that the Ohio River was always marginal range for the species. Conversely, the species may have been more abundant than indicated by these reports given the likelihood of non- or misidentification of shad-like species in general (see Clay 1975).

Alabama shad is one of two *Alosa* species native to the Ohio River, the other one being the skipjack herring. However, unlike skipjack herring, Alabama shad cannot complete their entire life cycle in freshwater, and adults and juveniles must return to the ocean to feed and mature. Thus, the presence of adults and juveniles in the Ohio River or its tributaries is

dependent on the adults' ability to move upstream through mainstem dams on a regular basis and the ability of juveniles to pass safely downstream through dams. Estimates of their swimming speed and pelagic and migratory nature suggest that Alabama shad should be capable and motivated to move upstream through mainstem dams on the Ohio River. Their absence despite the continued persistence of other similarly capable and motivated potadromous species (e.g., skipjack herring, goldeye, and mooneye) suggests that upstream passage may be somewhat restricted for all of these species. However, local populations and metapopulation dynamics (Stanford et al. 1996) of the potadromous species are probably responsible for their wide distribution and persistence, whereas Alabama shad need to move through mainstem dams on a regular basis (ideally annually) to persist in the system.

This information suggests that any recovery of Alabama shad would be dependent on measures to improve upstream fish passage in the Ohio River and possibly in its tributaries. However, the general decline of Alabama shad in the lower Mississippi River as noted previously may preclude recovery in the Ohio River. Conversely, if the upper Ohio River was an important traditional spawning area, then improving upstream passage in the Ohio River may provide a mechanism for recovery systemwide, including the lower Mississippi River. In such a scenario, describing the characteristics of spawning habitat used by remaining populations of Alabama shad may help identify traditional areas in the Ohio River or direct construction of artificial spawning habitat. Another consideration in the recovery of the Alabama shad is safe downstream passage. Young reportedly return to the sea within 6 to 8 months of hatching. The consequences of increased mortality or delayed emigration associated with downstream passage through dams are unknown. However, in salmon populations, downstream passage of juveniles is now thought to be as significant as upstream passage of adults in terms of population viability.

Skipjack herring are a pelagic, fluvial-dependent species that are characteristic of large rivers (Pflieger 1971 in Simon and Emery 1995). Skipjack herring occur in high flow areas over gravel and sand in large rivers (Smith 1979), but may avoid turbid water (Trautman 1981). Skipjack herring have a prolonged spawning season (Lee et al. 1980), reportedly between March and June in Tennessee (Wallus et al. 1990). They are thought to be phyto-lithophils preferring to spawn over vegetation, or secondarily over gravel, rock, or logs (Wallus et al. 1990). However, Lee et al. (1980) noted that skipjack herring probably spawn in the depths of the main channel over coarse sand-gravel bars. Skipjack herring in spawning condition have been collected in headwater tributaries, tailwaters, and reservoirs of the Tennessee River (Wallus et al. 1990). Skipjack herring reach sexual maturity in 2 to 3 years and at total lengths of 254 to 381 mm (Clay 1975; Becker 1983; Wallus et al. 1990). They are thought to be highly or at least somewhat migratory (Smith 1979; Lee et al. 1980); several authors have noted that skipjack herring migrate upstream in the spring and gather in large numbers below dams (Clay 1975; Smith 1979; Wallus et al. 1990); however, they generally are not reported in small rivers and streams.

Species-specific information on the swimming speed of skipjack herring was not found. Based on goldeye swimming performance (Tunink 1975), the estimate of prolonged swimming speed (U_{crit10}) for skipjack herring was 0.8 m/s (Table 8). The estimate of skipjack herring burst speed, based on the American shad (Weaver 1965), was 3.47 to 4.15 m/s; these estimates closely match the estimates of maximum swimming speeds (U_{max}) based on the methods of Winter and Van Densen (2001) which were 3.75 and 4.31 m/s at 13 and 15°C, respectively.

The Ohio River Basin is central to the original latitudinal distribution of the skipjack herring; however the upper Ohio River is the eastern limit of its native range (Lee et al. 1980). Pearson and Pearson (1989) found that skipjack herring were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). Pearson and Krumholz (1984) noted that skipjack herring were probably abundant before 1900, and that despite severe pollution in the early to mid-1900s managed to persist throughout the river. Trautman (1981) cited Rafinesque (1820), Kirkland (1851), and Henshaw (1888) noting that skipjack herring were present to abundant in the Ohio River before 1900. Rafinesque (1820 in Trautman 1981) noted that skipjack herring generally were not found as far up river as Pittsburgh and that they do not ascend small streams. Trautman (1981) noted that between 1920 and 1950 skipjack herring were more abundant in the Ohio River below Marietta (mouth of the Muskingum River in Belleville Pool) than in two tributaries (i.e., lower Scioto and Muskingum Rivers) or in the Ohio River above Marietta to Pittsburgh. Trautman (1981) indicated that between 1955 and 1980 the distribution of skipjack herring generally did not change and was presumably similar to the pre-1955 distribution. Smith (1979) indicated that skipjack herring were more common in the Ohio and Wabash Rivers than in the Mississippi and Illinois Rivers. He also noted that skipjack herring are still occasionally taken in the Upper Mississippi River below Pool 25 (i.e., in Pool 26, the pool formed by the downstream-most dam in the system) and in the Illinois River. Coker (1930) stated that skipjack herring were "enormously abundant" at Keokuk, Iowa until the construction of Lock and Dam 19 at Keokuk. Clay (1975) noted that skipjack herring were present as far upstream in the Ohio River as Pennsylvania and that they also occur in the Tennessee, Cumberland, Green, and Little Sandy Rivers in Kentucky. Wallus et al. (1990) noted that adult skipjack herring also occur in large tributaries and mainstem reservoirs of the Tennessee River System.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found skipjack herring to be commonly taken from the mouth of the Ohio River to Belleville Pool and occasionally to commonly collected in the upper seven pools (Appendix B). Our findings are in general agreement with the historical data presented above, in that skipjack herring were more common in the Ohio River below the mouth of the Muskingum River as compared to above this mouth. In analysis of the ORSANCO lock rotenone data (1957 to1997), Lowman (2000) found that skipjack herring showed a significant increasing trend in all three sections of the Ohio River (upper—ORKm 0 to 327; middle—ORKm 327 to 1,134; and lower—ORKm 1,142 to 1,578; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]).

Based on abundance and distribution information, skipjack herring have done and apparently are doing well in the Ohio River despite mainstem dams and historical periods of severe pollution. Skipjack herring are probably capable and motivated to move through open mainstem dams based on their relatively high swimming speeds (Table 8) and life history characteristics (i.e., pelagic, fluvial-dependent, characteristic of large rivers, migrate upstream to spawn, and slightly to highly migratory; Table 12). As well, the literature indicated that they have a prolonged spawning period, which would suggest that they could take advantage of open river periods in the Louisville District (Appendix B). However, movement through dams in the Huntington and Pittsburgh Districts are probably low to non-existent based on the frequency of open-river conditions.

The persistence of skipjack herring in the upper Ohio River versus its apparent extirpation in the impounded reaches of the Upper Mississippi River at first seems contradictive. Coker (1930) noted a substantial decline in the abundance of skipjack herring in the Upper Mississippi River above Lock and Dam 19 after the completion of that dam. Dam 19 rarely opens and thus is thought to be a nearly complete barrier to fish passage (Wilcox et al. unpublished report). This suggests that an analogous decline in skipjack herring should have occurred in the upper and middle reaches of the Ohio River where dams open infrequently (Table 9). However, this decline has not occurred suggesting that successful reproduction of local populations rather than upstream fish passage is responsible for maintaining the abundance and distribution of skipjack herring in the Ohio River. Although skipjack herring could have reproduced above Lock and Dam 19 in the Upper Mississippi River, this species may not persist there because the reach above that dam represents the northern extent of the skipjack herring's native range (Lee et al. 1980). This information suggests that skipjack herring were unable to consistently overwinter in that reach of the river and thus their presence was dependent on upstream movement through dams. In support of that hypothesis, the latitude above Lock and Dam 19 on the Upper Mississippi River is generally greater than the latitude at Pittsburgh (source of the Ohio River). As well, the latitude at Lock and Dam 25 on the Upper Mississippi River, above which skipjack herring rarely occur today, is nearly equivalent to or greater than the latitude at the confluence of the Ohio and Muskingum Rivers; as noted previously, skipjack herring have apparently always been more common in the Ohio River below the mouth of the Muskingum River as compared to above, suggesting that this reach above the mouth of the Muskingum River is approaching their latitudinal limit.

Bighead and silver carp are non-native potentially invasive species that occur in large river systems in their native range in eastern Asia (U.S. Fish and Wildlife Service [USFWS] 2000). Bighead carp are benthopelagic, while silver carp are primarily pelagic. Both species are generally considered filter feeders with bighead carp considered as omnivorous plankton feeders, while silver carp consume primarily phytoplankton (Dong and Li 1994). Bighead carp have also been reported as opportunistic bottom feeders (Opuszynski et al. 1991). Bighead and silver carp feeding habits overlap significantly with several native species of fish (e.g., paddlefish, bigmouth buffalo, and gizzard shad *Dorosoma cepedianum*) and freshwater mussels raising concern about negative impacts (USFWS 2000). The presence of stocked bighead and silver carp was noted as a driving force in determining the structure of copepod communities in a subtropical Chinese lake (Xie and Yang 2000).

Bighead and silver carp migrate upstream in spring to spawn at water temperatures of 18 to 30°C, and eggs and larvae drift until hatching (USFWS 2000) suggesting that these species are pelagophils or litho-pelagophils. Schrank et al. (2001) found that bighead carp spawned in the unimpounded reach of the Missouri River (in Missouri and Kansas) during three distinct periods from mid June to early July in conjunction with rising discharge and water temperatures above 22°C. They suggested that a combination of water temperature and discharge act as a cue for spawning and that these conditions possibly ensure successful hatching. In Missouri, bighead carp reportedly congregate on mud flats and shallow confluences (presumably in preparation for spawning) when waters warm (USFWS 2000). Lin Z (1991 in USFWS 2000) reported that bighead carp spawn in two habitat types, either canyons or river valleys. In canyons, spawning occurs in depths of up to 40 m with water velocities from 1.3 to 2.5 m/s. In river valleys, bighead carp spawn at meanders, sandbars, and rocks extending into the river. Lin Z (1991 in

USFWS 2000) also suggested that bighead and silver carp may be cued to spawn by rising water levels.

Little information was found as to the extent of upstream migrations or as to the importance of these migrations in the success of bighead and silver carp populations. In the Terek Region of the Caspian Basin, non-native bighead and silver carp larvae and fingerlings migrated (presumably in a passive manner) to the coastal areas of the Caspian Sea; after maturing, these fish moved back upstream 125 to 260 km to spawn (Abdusamadov 1986). Yi et al. (1991) noted that native bighead and silver carp in the Yangtze River in China are semi-migratory and that some populations of these fishes were affected by the construction of a mainstem dam between the upper and middle reaches of that river. However, they noted that because of the wide geographic dispersion of 36 spawning sites along this reach of the river (1,695 km), no overall affect to the metapopulation was anticipated. This information suggests that both species can persist in rivers with mainstem dams that prevent upstream migrations when local upstream populations are present.

Prolonged and burst swimming speed estimates for bighead and silver carp are based on the common carp (Videler 1993; Blaxter 1969) and were 0.83 and 1.75 m/s, respectively. The estimate of prolonged swimming speed may be low because it was based on the performance of small common carp (i.e., 15 cm; Videler 1993). As well, the reported water velocities in spawning areas of bighead carp (i.e., 1.3 to 2.5 m/s; Lin Z 1991 in USFWS 2000) suggest that prolonged and burst speed estimates may be low. Further suggesting that these fish are relatively fast swimmers, Wang (1985) noted that adult bighead and silver carp were difficult to capture with trawl nets of traditional mesh size, whereas by switching to a trawl with larger mesh size (presumably allowing for faster tow speeds) success was improved. The maximum swimming speeds (U_{max}) determined with methods of Winter and Van Densen (2001; Equation 1) were 4.5 and 3.1 m/s at 21 and 15°C, respectively for both species (Table 8).

Bighead and silver carp were introduced into the United States in the early 1970s in association with aquaculture and have since become established in the Mississippi River Basin (USFWS 2000). Populations of reproducing bighead or silver carp have been reported in the Illinois, Mississippi, and Missouri Rivers (Tucker et al. 1996; Schank et al. 2001). Pearson and Pearson (1989) found that silver carp were not reported in any reach of the Ohio River before 1970; however, silver carp were present in the lower and middle reaches after 1970. Pearson and Krumholz (1984) noted that one specimen had been collected at the Falls of Ohio (in the Cannelton Pool). No mention of bighead carp appears in Pearson and Pearson (1989) or Pearson and Krumholz (1984), presumably because it did not occur in the Ohio River at the time. The earliest report in the U.S. Geological Survey's Nonindigenous Aquatic Species Database for bighead carp in the Ohio River was in 1997 at Moundsville, West Virginia (Hannibal Pool; U.S. Geological Survey [USGS] 2003). Other reported locations in the Ohio River include McAlpine Pool (1998) and Pike Island Pool (2002). The earliest report in the U.S. Geological Survey's Nonindigenous Aquatic Species Database for silver carp in the Ohio River was in 1984 at the Falls of Ohio in the Cannelton Pool (USGS 2003). Other reported locations in the Ohio River include at the J. T. Myers Dam (1986 and 1991) and in the southeast corner of Indiana (possibly Markland or McAlpine Pool) in 1992. The USFWS (2000) indicated that the silver carp was present from the mouth of the Ohio River to the J. T. Myers Dam, and that bighead carp were present from the mouth to the McAlpine Dam. As well, bighead carp were reported as present in the Cumberland River below Barkley Dam and in the lower Green River below Lock and Dam 3 (USFWS 2000). We found no records of silver carp in the post-1988 lock rotenone

or night electrofishing data sets (ORSANCO unpublished data; OEPA unpublished data); however, bighead carp were collected in the J. T. Myers Pool in 1997.

Bighead and silver carp are probably capable and motivated to move upstream through open navigation dams based on their swimming speeds and life history characteristics (i.e., benthopelagic or pelagic, fluvial-dependent, pelagophil, and semi-migratory to migratory). If their migratory behavior is generally limited to spawning runs, then they have low to moderate opportunities for upstream passage at mainstem dams in the Louisville and Huntington Districts except at Dams 52 and 53 that are generally open (Appendix B). Passage opportunities at Pittsburgh District dams would be nearly non-existent year round (Table 9), except through locks. If spawning temperatures of bighead carp in the Ohio River are similar to those reported in the Missouri River (i.e., 22°C; Schrank et al. 2001), rather than the broad range reported elsewhere (i.e., 18 to 30°C), then the opportunities for upstream passage would be more limited in the Louisville and Huntington districts because open river conditions are less frequent when water temperatures are greater than 22°C as compared to less than 22°C.

Limited opportunities for upstream passage at upper reach dams may slow the spread of Asian carps into these reaches; however given that some upstream passage probably occurs through lock chambers under normal operating conditions, a brood stock of bighead and silver carp probably would become established. Once established in the upper and middle reaches of the Ohio River, reproductive potential of bighead and silver carp may be high based on their success in other regulated systems unless other factors (e.g., climate) are limiting. Under this scenario, provisions for upstream passage to benefit native species may also speed the range expansion of bighead and silver carp in the Ohio River, but should not necessarily be deterred because the likelihood of the eventual spread of these invasive species is good despite the general lack of upstream passage opportunities.

Blue sucker are benthic, fluvial specialists characteristic of large rivers where they are found in deep channels, pools, riffles, and chutes with current (Smith 1979; Trautman 1981). For example, blue sucker were collected in areas of fast current in Pool 20 of the Upper Mississippi River (Rupprecht and Jahn 1980). Several authors suggested that blue sucker may be intolerant of turbid conditions (Smith 1979; Trautman 1981); however, Lee et al. (1980) suggest this may not be true based on their wide distribution in the Missouri River. Blue sucker are thought to be nonguarder litho-pelagophils (i.e., spawn over rock or gravel) that migrate upstream during spring to spawn in riffles (Lee et al. 1980; Smith 1979; Moss et al. 1983). Spawning occurs at water temperatures of 10 to 23°C (Becker 1983; Stauffer et al. 1994). Specifically, Moss et al. (1983) found that blue sucker from the Neosho River in Kansas spawned in May at 20 to 23°C, whereas Rupprecht and Jahn (1980) collected ripe male blue sucker from Pool 20 in the Upper Mississippi River near the end of April in two separate years at water temperatures of 16.4 and 13.4°C. The youngest mature male blue sucker collected by Rupprecht and Jahn (1980) was age 4 and 503 mm total length, whereas the youngest mature female was age 6 and 573 mm total length.

Smith (1979) noted that blue sucker move long distances into streams and suggested that they may be highly migratory. Blue sucker populations (Mississippi River Basin population and Gulf Coast populations) have recently been divided into two separate species with a proposal for further division into three species (Buth and Mayden 2001). Recent studies of *Cycleptus meridionalis*, the species recently distinguished from blue sucker, indicated that it was highly migratory (Scott Mettee, Geological Survey of Alabama, Tuscaloosa, Alabama, personal

communications). As well, Peterson et al. (1999) noted that *Cycleptus meridionalis* populations are seemingly doing well in the Pearl and Pascagoula Rivers in Mississippi and suggested that this status results because spawning migrations are generally less restricted in theses systems as compared to other more heavily modified (for hydropower and navigation) rivers.

The estimated prolonged (U_{crit10}) and burst swimming speeds of blue sucker were 1.02 and 3.30 m/s based on studies on the longnose sucker (Jones et al. 1974) and the western sucker (Blaxter 1969), respectively (Table 8). The maximum swimming speed based on the methods of Winter and Van Densen (2001; Equation 1) was 5.22 m/s at 15°C. Their common occurrence in fast currents of large rivers also suggests that they are strong and fast swimmers.

The Ohio River defines the eastern limit of the natural distribution of blue sucker, but is central to their latitudinal distribution (Lee et al. 1980). Pearson and Pearson (1989) found that blue sucker were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). Pearson and Krumholz (1984) suggested that blue sucker were historically abundant but had declined substantially by 1950 and that a recent (post-1975) increase may have occurred. They found only five records of blue sucker in the Ohio River for the period of 1970 to 1982; these records were for fish observed between ORKm 87 (New Cumberland Dam) and ORKm 1,197 (Newburgh Pool). Between 1981 and 1983, W. D. Pearson observed about 300 specimens of blue sucker at the Falls of Ohio (just below McAlpine Dam) during various occasions (Pearson and Krumholz 1984).

Trautman (1981), based on historical references, noted the presence of blue sucker at Pittsburgh and their common occurrence at Cincinnati before 1900. As well, he stated that between 1925 and 1950 blue sucker were most common in the river between the Indiana state line and Portsmouth (middle reach; Markland and Meldahl Pools) and in the lower reaches of the Great Miami (enters Markland Pool), Scioto, and Muskingum Rivers. Trautman (1981) also noted that blue sucker were present in the Ohio River between Portsmouth and Marietta (potentially Meldahl, Greenup, R. C. Byrd, Racine, and Belleville Pools; middle and upper reaches) between 1925 and 1950 and was even rarely taken from Marietta (upper reach near Willow Island Dam) to the Pennsylvania state line. Trautman (1981) stated that personnel from the University of Louisville captured only five specimens from the Ohio River (all from the lower reach; Clay 1975) in 341 samples collected along the entire length of the river, suggesting a decline in abundance as compared to the earlier period (i.e., 1925 to 1950). Between 1955 and 1980, Trautman (1981) reported that personnel with the Ohio Division of Wildlife occasionally captured blue sucker from the lower reaches of the Scioto and Muskingum Rivers (entering middle and upper reaches, respectively).

Smith (1979) noted the presence of blue sucker in the Ohio and Wabash Rivers along Illinois and also suggested a decline from past abundance. He indicated that this decline has been attributed to the construction of dams, deterioration of water quality, overharvest of adults during spawning migrations, and reduction in channel depth through deposition. Clay (1975) noted additional records along the Ohio River in Kentucky during the 1900s including in the lower reach (1959) and in the Licking River (enters middle reach; 1940 and 1956). As well, he notes a report from the Cumberland River (Woolman 1892 in Clay 1975). Clay (1975) suggested that although the life history requirements of the species are not well known, the probable causes of their apparent decline include siltation, pollution, and possibly conversion of lotic areas to "semi-lentic" areas. This conversion probably eliminated much of the habitat preferred by blue sucker (i.e., deep-channel, high-current areas over sand or gravel substrates).

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that blue sucker were generally absent from samples. Blue sucker were sampled occasionally in the Newburgh and Cannelton Pools and uncommonly in the Markland Pool. However given that blue sucker are typically found in deep channels with fast current, the sampling methods used in the ORSANCO (unpublished data) and OEPA (unpublished data) surveys (lock rotenone sampling and night electrofishing) are probably ineffective at capturing blue sucker. Pearson and Pearson (1989) suggested that the abundance of blue sucker had increased in the upper and middle reaches as compared to 1970 levels. However, whether or not this trend has continued is uncertain because of the noted limitation of the recent data we analyzed.

If accurate despite the limitations of the data, the present distribution of blue sucker in the Ohio River may be related to passage opportunities at dams, with occasional occurrence in the lower pools where passage opportunities exist, and absence from upper pools where passage opportunities are rare (Appendix B). Smith (1979) suggested that dams that block spawning migrations may be one factor responsible for the decline of blue sucker. Conversely, Pearson and Krumholz (1984) concluded that the abundance of lithophils in general (including the blue sucker) has probably declined because of degradation of spawning habitats resulting from siltation of the rock-gravel substrates. Additionally, Clay (1975) noted that the conversion of lentic to semi-lentic conditions by dams altered the preferred habitat of blue sucker and thus may be partly responsible for their decline.

Blue sucker are probably fast swimmers based on information from surrogate species and on their general habitat preferences, suggesting that they should be capable of moving upstream through mainstem dams during open river as observed for other large benthic species (e.g., lake sturgeon). Additionally, blue sucker are probably motivated to move through dams based on their life history characteristics (e.g., migratory, fluvial specialists, lithophils or litho-pelagophils). As well, based on their potential for early spawning migrations (Appendix B), blue sucker should be able to take advantage of peak open-river conditions (i.e., fish-passage opportunities) in the lower pools; however, opportunities at upper dams are minimal.

Increased abundance and distribution of other fishes (e.g., mooneye and skipjack herring) with similar life history traits and swimming abilities as blue sucker following improvements in water quality after 1970 (Pearson and Pearson 1989) suggest that re-establishment of blue suckers in the upper reaches may be possible. However, their continued absence in the upper river suggests that local populations are not sustainable in that reach and that their presence may be dependent on upstream movement through dams. Successful reintroductions in the upper reach without addressing fish passage seems unlikely given that it has not occurred yet despite water quality improvements. Conversely, spawning and feeding habitats in the upper reaches may be degraded by conversion to more lentic conditions and siltation; thus, despite fish-passage improvements, reintroductions into the upper river may fail. In the lower river where blue sucker still persist, spawning and feeding habitat must still be available, at least at some minimal level. The conversion of lotic areas to lentic or semi-lentic areas may be detrimental to fluvial specialists like blue sucker and shovelnose sturgeon that may be reliant on fast current for feeding success. These two fluvial specialists have similar distributions in that they are generally absent in the more lentic upper reaches of the Ohio River System as compared to the lower fluvial reaches. Before investing in fish-passage measures for blue sucker, more research needs to be conducted to determine the relative importance of migratory movements versus general habitat availability in sustaining their populations in the lower river.

Smallmouth, bigmouth, and black buffalo (ictiobids) are all benthopelagic macrohabitat generalists characteristic of large river systems (Smith 1979; Simon and Emery 1995; Lee et al. 1980). Smallmouth buffalo also occasionally occur in lakes, and bigmouth buffalo and black buffalo *Ictiobus nigers* are commonly found in oxbows and bottomlands marginal to large rivers (Smith 1979). Smallmouth buffalo feed on benthic invertebrates and often occupy deep clear channels with moderate to strong currents (Clay 1975; Smith 1979; Lee et al. 1980). Bigmouth and black buffalo are found in similar habitats as smallmouth buffalo but also occupy shallow turbid areas (Clay 1975; Smith 1979; Lee et al. 1980; Trautman 1981). Bigmouth buffalo are generally pelagic filter feeders, but may also feed on benthic invertebrates (Clay 1975; Smith 1979). Black buffalo have a similar feeding strategy as smallmouth buffalo (Smith 1979).

All three of these ictiobids are nonguarders and may generally spawn in backwaters or floodplain areas over vegetation and debris (phytophils or phyto-lithophils; Balon 1975; Clay 1975; Pearson and Krumholz 1984; Moyle and Cech 1988). However, others suggest that smallmouth buffalo may not be dependent on flooded or submersed vegetation for spawning. For example, Smith (1979) stated that smallmouth buffalo spawn in quiet pools or backwaters and that their eggs are "merely dropped over the bottom." As well, Clay (1975) noted that smallmouth buffalo spawn over mud bottoms and vegetation. Simon (1999) classified all three ictiobids as litho-pelagophils indicating that they spawn over rock and gravel and that their larvae are pelagic. Spawning temperature and period (Table 12), and age and size at maturity data overlap for all three species. Smallmouth buffalo have the widest reported range of spawning temperatures (i.e., 15.5 to 27°C) encompassing the range for the other two species (15.5 to 18.3°C for bigmouth buffalo and 18 to 21°C for black buffalo). All three species mature at ages 2 to 4 and at lengths of greater than 300 mm.

Little information was available on the longitudinal movements of ictiobids in large river systems as they relate to life history requirements. Bigmouth and smallmouth buffalo reportedly migrate up small tributaries to spawn in some systems (Becker 1983, Scott and Crossman 1973, Tomelleri and Eberle 1990). Lateral migrations to spawn in backwaters or on the floodplain over vegetation may be important to all three species, whereas the need for longitudinal migrations may depend on the relative location of suitable spawning sites to feeding and resting areas. As well, the movements and habitat requirements of larvae and juveniles are little known. If larvae and juveniles move downstream or upstream during maturation, then they too would need to move longitudinally to spawn and contribute to parental populations.

The prolonged and burst swimming speed estimates for all three ictiobids were 0.83 and 1.75 m/s, respectively, based on studies of the common carp (Videler 1993; Blaxter 1969). The maximum swimming speeds (U_{max}) for these species based on methods of Winter and Van Densen (2001; Equation 1) ranged from 2.34 to 3.69 m/s at median migration temperatures and 2.51 to 3.00 m/s at 15°C.

The Ohio River defines the eastern extent of the native range for all three species of buffalo fishes (Lee et al. 1980). Pearson and Pearson (1989) reported that all three species were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). They also reported a small upstream range extension (i.e., 31 km from ORKm 87 to ORKm 56) for smallmouth buffalo since 1984. Pearson and Krumholz (1984) stated that smallmouth buffalo are probably the most abundant sucker in the Ohio River and are clearly the most abundant ictiobid. They indicated that this species is found throughout the river

but is most abundant below the mouth of the Muskingum River (ORKm 276; Belleville Pool in the upper reach). Raney (1938 in Pearson and Krumholz 1984) remarked that while Rafinesque reported that smallmouth buffalo were present as far upstream as Pittsburgh in 1820, they had not been seen there since that time. Pearson and Krumholz (1984) noted that black buffalo are the least abundant among the three species and are more common in the middle third of the river as compared to elsewhere. They also pointed out that smallmouth buffalo and black buffalo have similar distributions in the Ohio River. Conversely, bigmouth buffalo are more common in the lower Ohio River as compared to the upper river and have been documented only once above ORKm 322 (Pearson and Krumholz 1984).

Ictiobids were historically abundant in the Ohio River and its tributaries (Trautman 1981; Jordan 1882 and Henshall 1888 in Trautman 1981). However, Klippart (1878 in Trautman 1981) noted that smallmouth buffalo were formerly abundant in the Scioto River and other streams emptying into the Ohio River, but by 1878 had become less abundant. Trautman (1981) reported that between 1925 and 1950 all three species were more common in the western portion of the Ohio River in Ohio (Meldahl to Belleville Pool) as compared to the eastern portion and were only occasionally taken above the Belleville Pool. Trautman (1981) reported that the 1925 to 1950 abundance of bigmouth and black buffalo had not changed dramatically as compared to the pre-1925 levels, but indicated that fishermen claimed that smallmouth buffalo abundance declined after dams were constructed. Despite this decline, Trautman (1981) indicated that smallmouth buffalo were the most abundant ictiobid in the Ohio River during this period (i.e., 1925 to 1950), as well as in a more recent period (i.e., 1955 to 1980). Trautman (1981) indicated that the abundance of smallmouth and bigmouth buffalo in the Ohio River between 1955 and 1980 was similar to their abundance observed between 1925 and 1950; however, black buffalo abundance had apparently declined between these periods. Trautman (1981) reported the presence of bigmouth and black buffalo in the lower Muskingum River (enters Belleville Pool) and in the Scioto River, and the presence of smallmouth buffalo in the lower Scioto and Great Miami (enter Markland Pool) Rivers in the 1955 to 1980 period.

Smith (1979) found no evidence documenting temporal changes in the distribution or abundance of ictiobids in Illinois, but did suggest that smallmouth buffalo may have declined since the common carp was introduced. The species distribution maps in Smith (1979) indicated that all three species had been reported in the Wabash River, but that only smallmouth and bigmouth buffalo had been reported in the Ohio River in Illinois. Clay (1975) noted that all three species are found in the Ohio River and the lower portions of its major tributaries in Kentucky. He noted that smallmouth buffalo were more abundant in the western part of Kentucky (includes lower reach) as compared to the eastern part (includes middle reach). Clay (1975) also reported that smallmouth buffalo were the most abundant of the ictiobids followed by bigmouth buffalo and finally black buffalo. Clay (1975) indicated that all three species occurred in the Cumberland River (enters Pool 52) and that the smallmouth and bigmouth buffalo occurred in the Green River (enters Meyer Pool) and Big Sandy River (enters Greenup Pool). The smallmouth and black buffalo were found in the Rough (headwater of the Green River) and Salt Rivers (enters Cannelton Pool).

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that smallmouth buffalo were more widely distributed and generally more commonly collected than the other two species of ictiobids (Appendix B). Smallmouth buffalo were commonly collected in most pools (i.e., Smithland to Montgomery Pools) and only absent from samples taken in Dashields Pool (in the upper reach). Bigmouth buffalo were

commonly collected in the lower reach (i.e., Smithland to Newburgh Pools), occasionally collected in the middle reach (i.e., Cannelton to Meldahl Pool), and generally absent from collections in the upper reach (i.e., Greenup to Emsworth Pool; Appendix B). Black buffalo were more widely distributed than bigmouth buffalo; they were common in samples from J. T. Myers Pool (lower reach) and generally occasionally sampled from the middle reach and lower half of the upper reach (i.e., Cannelton to Pike Island Pool).

Regression analysis of the ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) indicated a significant positive trend in catch-per-unit-of-effort for smallmouth buffalo in all three sections of the Ohio River (upper—ORKm 0 to 327; middle—ORKm 327 to 1,134; and lower—ORKm 1,142 to 1,578; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]). No significant trend was found for bigmouth buffalo in the lower and middle sections, and insufficient data from the upper section precluded an assessment. As well, black buffalo were excluded from the analysis because of insufficient data in all three sections.

Based on abundance and distribution information, smallmouth buffalo have persisted and are apparently increasing in abundance in recent times in the Ohio River despite the presence of mainstem dams. As well, an upstream range shift has recently been observed for this species (Pearson and Pearson 1989). Conversely, historical information suggests that smallmouth buffalo abundance may have declined during the 25-year period following dam construction as compared to a pre-dammed period (Trautman 1981). However, information on the abundance, distribution, and life history characteristics of smallmouth buffalo does not suggest that restricted fish passage was any more likely the cause of this decline than as, for example, was habitat degradation resulting from land-use changes or impoundment. The persistence and expansion of smallmouth buffalo in the Ohio River suggest that upstream passage through these dams is not paramount to their continued presence, rather local populations capable of sustaining the species are probably widespread in the system. Smallmouth buffalo may be benefiting from the impoundment of the system, thus explaining their apparent success in the upper reaches in recent times as compared to the pre-dammed period. Spawning habitats of smallmouth buffalo may be more general than those of bigmouth and black buffalo (Clay 1975; Smith 1979). This difference in spawning requirements may explain the apparent divergent trends among these species. However, that is not to say that smallmouth buffalo populations in the Ohio River would not benefit in terms of higher production from improved fish passage. Further research is needed to help elucidate the life history requirements of smallmouth buffalo to make an informed decision regarding the importance of longitudinal movements and upstream passage through dams.

The restricted distribution or apparent decline in abundance of bigmouth and black buffalo is suggestive that upstream fish passage may be more of a limitation for these species as compared to the smallmouth buffalo. However, to some degree, all three species were apparently limited in the upper reaches even before dams were constructed (Trautman 1981). Contrary to smallmouth buffalo, conditions conducive to the maintenance of bigmouth and black buffalo have apparently degraded in the Ohio River since dams were constructed. Whether these species are more limited by restricted fish passage or by other habitat changes brought about by anthropogenic factors, including dams, is uncertain. Scant data on the life history characteristics of these species make it difficult to assess the relative importance of these variables. For example, bigmouth and black buffalo may be more dependent on flooded vegetation and debris for reproduction as compared to smallmouth buffalo (Clay 1975; Smith 1979), thus available

spawning habitat rather than fish-passage opportunities may be the limiting factor. If longitudinal connectivity was improved by improving fish passage, bigmouth and black buffalo may have access to more spawning habitat along the river corridor.

Blue catfish are a benthic, fluvial specialists characteristic of large rivers and are typically found in deep channels or pools with fast current (Smith 1979; Lee et al. 1980; Trautman 1981; Simon and Emery 1995). Clay (1975) noted that blue catfish only occur in "larger" streams in Kentucky. Blue catfish feed in relatively fast-flowing water over nonsilt substrates and apparently avoid silt substrates in slow-flowing water (Trautman 1981). Blue catfish are omnivorous and exhibit ontogenetic shifts in diet with larger individuals (>300 mm) feeding primarily on fish (Edds et al. 2002). Abundance of blue catfish reportedly did not vary significantly among three habitat types (i.e., dam tailwaters, main channel, and tributary) in regulated rivers in Alabama, but their abundance tended to be greater over pebble-coble substrates (Grussing et al. 1999). Likewise, stock-sized blue catfish were found in similar abundance in three macrohabitat types (i.e., bendways, channels, and tailwaters) in the Tennessee-Tombigbee Waterway (Jackson 1995); however, substock-sized blue catfish were most common in channel areas. Flow and woody debris were also thought to be important for blue catfish in tailrace areas inhabited by other catfish species (Grussing et al. 1999). Blue catfish have been nearly extirpated from the reach of the Missouri River in Nebraska with probable causes listed as overharvest, reduced turbidity, and lack of large woody debris (Hesse 1994). Blue catfish are guarding spelophils (i.e., cavity nester), presumably nesting along banks of rivers and connected backwaters. We found no information on age at maturity for blue catfish. However, Perry and Carver (1977) reported a computed length at maturity for blue catfish of 481 mm in marshes of southwest Louisiana. As well, Pflieger (1975) reported that adult fish are commonly 508 to 1,117 mm and 1.4 to 18.2 kg. Reported spawning temperatures for blue catfish ranged from 21 to 24°C (Harlan and Speaker 1956).

Little information was available on the migratory behaviors of blue catfish, although Coker (1930 in Smith 1979) indicated that the Keokuk Dam on the Upper Mississippi River blocked their upstream migration and that all reports of blue catfish in that region were from summer months. As well, Welter (1938 in Clay 1975) noted that blue catfish were common in the Licking River (enters Markland Pool; middle reach of the Ohio River) at Farmers, Kentucky, in spring, suggesting a migration of considerable distance if one assumes they originated from preferred habitats in the Ohio River; the straight-line distance from the Ohio River to Farmers is about 145 km.

The estimate for prolonged swimming speed for blue catfish was 0.71 m/s based on a study of channel catfish (Tunink 1975). No information was available on observed or modeled burst speed for blue catfish or any other morphologically similar species. However, maximum speeds of median-sized adult blue catfish estimated with methods of Winter and Van Densen (2001; Equation 1) were 5.74 m/s at a median migration temperature of 20°C and 4.10 m/s at 15°C. As well, the flattened head of blue catfish may provide them a mechanism to hold position in high water velocities (i.e., substrate appression), allowing them to alternate between resting and bursting to pass upstream through dams.

The upper Ohio River represents the eastern extent of the native distribution for blue catfish, with populations occurring to the north and south in the Mississippi River System (Lee et al. 1980). Pearson and Pearson (1989) reported that blue catfish were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River

(i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). They also reported that blue catfish abundance increased between 1980 and 1988 in the lower two reaches of the Ohio River, replacing bullheads on the top-10 list of abundant species in ORSANCO lock rotenone samples. Pearson and Krumholz (1984) noted the presence of blue catfish in the Ohio River from the mouth to ORKm 89 (New Cumberland Dam); however, blue catfish were rare in the upper reach and abundance increased going downstream from Pittsburgh. Pearson and Krumholz (1984) also reported that no notable change in the distribution of blue catfish had occurred since 1970, but that abundance was declining in the upper half of the river.

Trautman (1981) concluded that blue catfish were present in the Ohio River in Ohio between the Indiana state line and Belmont County (i.e., middle and upper reaches including Markland to Hannibal Pool) before 1900. He also noted that blue catfish were reportedly more common in the river before impoundment (pre-1911) as compared to after impoundment. Trautman (1981) reported that between 1925 and 1950, he examined more than 20 blue catfish taken from the Indiana state line to Portsmouth, Ohio (Markland to Meldahl Pool; upper half of the middle reach). However, based on reports from 1955 to 1980, blue catfish had become less abundant in the middle and upper reaches of the Ohio River in Ohio as compared to earlier periods (Trautman 1981).

Clay (1975) stated that blue catfish were most abundant in the lower reach of the Ohio River, uncommon between Louisville, Kentucky, and Cincinnati, Ohio (i.e., the lower half of the middle reach), and rare or absent in the upper reach. He also noted that blue catfish occur in the lower reaches of large tributaries to the Ohio River. Interestingly, Clay (1975) did not cite any reports of blue catfish occurring above dams on these large tributaries in Kentucky. Distribution maps in Smith (1979) indicate that blue catfish have been reported in the lower reach of the Wabash River in Illinois.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that blue catfish were generally commonly collected from the lower reach (i.e., ORKm 1,053 to 1,578) of the Ohio River, uncommon in the middle reach (ORKm 527 to 1,052), and absent from the upper reach (i.e., ORKm 0 to 526; Appendix B). Regression analysis of the ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) indicated a significant positive trend in catch-per-unit-of-effort for blue catfish in the lower section of the Ohio River (ORKm 1,142 to 1,578) and a significant negative trend in the middle section (ORKm 327 to 1,134; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]). Insufficient data were available from the upper section (above ORKm 327) to make a trend assessment.

The present abundance and distribution of blue catfish are such that they may be related to fish-passage opportunities. Blue catfish are absent in upper reaches where few or no passage opportunities exist and abundance increases with increasing fish-passage opportunities in the lower reaches. As suggested by their habitat preference for channels with swift currents, relatively high maximum swimming speeds, and flattened head, blue catfish may be able to pass upstream through open dams in the lower and middle reaches of the Ohio River. However, no species-specific swimming speed information or empirical fish-passage data were available for blue catfish, thus leaving some uncertainty as to their capability. The relatively late spawning migration period of blue catfish based on reported spawning temperatures (Appendix B) suggests that they may miss the peak period of open river and thus be more longitudinally restricted than

first seems apparent. As well, little information was available on their migratory behavior, thus leaving uncertainty as to their propensity to move upstream to spawn.

As suggested by the southern nature of their native range (Lee et al. 1980), blue catfish may also be thermally limited and thus restricted to the lower reaches of the Ohio River during winter; their presence in the upper reaches may be dependent on upstream passage during spring or summer. In the Upper Mississippi River, blue catfish were apparently present as far north as Lock and Dam 19 (roughly equivalent latitude as Pittsburgh, Pennsylvania) only after migrations from further south (Coker 1930 in Smith 1979). This suggests that the presence of blue catfish in the middle and particularly in the upper reaches of the Ohio River may also have been a seasonal phenomenon with fish migrating upstream during spring to spawn and returning to the lower reaches in summer or fall to feed and overwinter. However with upstream passage restrictions at upper reach dams, blue catfish may be limited to the lower reaches even during spring and summer.

In addition to fish-passage opportunities and climate, habitat preference probably influences the present distribution of blue catfish in the Ohio River that is now heavily silted and slow-moving in some reaches because of impoundment. The lower reach of the Ohio River may be more similar to blue catfish native habitat (i.e., large rivers with deep pools, substantial current, and nonsilt substrates) as compared to the more lentic and silt-laden upper and middle reaches. To increase the chances of success, restoration efforts for blue catfish populations in the middle and particularly upper reaches of the Ohio River would need to consider habitat requirements as well as fish-passage needs. Managers should also consider that restoration efforts in the upper reach may always be limited by physical habitat characteristics and climate.

White bass, yellow bass, striped bass, and white perch (moronids) are generally considered fluvial-dependent species characteristic of large river systems during at least part of their life cycle (Lee et al. 1980; Simon and Emery 1995; Galat and Zweimüller 2001). White and yellow bass are native to the Ohio River Basin, whereas striped bass and white perch *Morone americana* are naturally anadromous or semi-anadromous species with native distributions extending along the East Coast of North America. Both of these anadromous species have been widely introduced and in some instances have become established in inland systems (Lee et al. 1980; USGS 2003). Adult white bass feed primarily on fish, but also on invertebrates (Smith 1979; Hartman 1998) and generally occupy the pelagic zone of open-water habitats; however, they do move inshore to exploit food resources (Beck and Willis 2000). Conversely, yellow bass and white perch generally prefer more lentic habitats and feed on fish and benthic invertebrates and seasonally on fish eggs (Clay 1975; Smith 1979; Trautman 1981; Driscoll and Miranda 1999; USGS 2003). Adult striped bass in inland systems probably have similar food habits and habitat preferences as white bass.

White bass generally spawn over submerged vegetation or firm bottom substrates in flowing water and eggs attach to the substrate (i.e., nonguarder, phyto-lithophil). Yellow bass may have similar spawning ecology as that of white bass (Smith 1979); however, in contrast to other moronids, yellow bass may be less dependent on flowing water to reproduce and may pair during spawning (Texas Parks and Wildlife 2003). Striped bass also spawn over firm substrates in flowing water but their eggs drift until hatching (i.e., nonguarder, litho-pelagophil; Beasley and Hightower 2000; Maryland Department of Natural Resources [MDNR] 2003). Conversely, Simon (1999) indicates that striped bass have a similar reproductive strategy as other moronids (i.e., phyto-lithophil) with nonpelagic larvae. White perch may be more flexible in their

spawning behavior as compared to white and yellow bass, exhibiting characteristics of either phyto-lithophils or litho-pelagophils depending on whether the system they occupy is lentic or lotic (MDNR 2003). All of these moronids spawn in the spring, but variation exists among the species as to the reported spawning temperatures (Table 12). Males of all four species mature at age 2 to 3; females of the smaller moronids (i.e., white perch, white bass, and yellow bass) mature at age 3 to 4, whereas striped bass females generally mature at age 4 to 6 (Becker 1983; Stauffer et al. 1994; MDNR 2003).

All four species are known to migrate upstream in rivers, streams, or reservoirs to spawn. Schools of white bass are reported to home to shoals in lakes or move into streams to spawn (Lee et al. 1980; Becker 1983). As well, white bass were highly mobile during a tagging study in the Upper Mississippi River (Finke 1966 in Becker 1983); the average distance traveled between captures by 57 tagged fish during that study was 34 km. As well, these white bass congregated in the tailwaters of Lock and Dam 3 in the spring and in some instances moved upstream through that dam and into a major tributary (Finke 1966 in Becker 1983). Similarly, yellow bass congregate in tailwaters of dams that block their migrations and move into tributaries to spawn (Carter 1955 in Clay 1975; Becker 1983). White perch and striped bass in their native range generally migrate in fall or late winter-early spring from coastal areas up large rivers and streams to spawn (Lee et al. 1980; Tomelleri and Eberle 1990; MDNR 2003). Striped bass historically migrated up to 435 km in a river in North Carolina (Beasley and Hightower 2000). In an inland reservoir in Texas (i.e., Lake Whitney), adult striped bass moved upstream and into main tributaries to overwinter before returning to the reservoir in spring (Farquhar and Gutreuter 1989). White perch from Green Bay in Lake Michigan migrated up the Fox River, Wisconsin, to the tailwaters of a dam possibly to spawn (Cochran and Hesse 1994).

The prolonged swimming speed of white bass was estimated at 0.78 m/s based on observations of that species (Tunink 1975). This value was also used as an estimate of the prolonged swimming speed of yellow bass and white perch as no species-specific information was available. The estimated prolonged swimming speed (in this instance U_{crit30} rather than U_{crit10}) of striped bass was 0.86 m/s based on work by Freadman (1981). The estimated range of burst speeds for white and striped bass, based on a study of American shad, was 3.47 to 4.15 m/s (Weaver 1965). Maximum swimming speeds (U_{max}) as determined by the methods of Winter and Van Densen (2001; Equation 1) were 4.05 to 4.66 m/s for white bass, 3.56 to 3.81 m/s for yellow bass, 3.52 to 4.69 m/s for striped bass, and 1.69 to 2.22 m/s for white perch.

The upper Ohio River is the eastern extent of the native range for white bass at that latitude. However, the native range of white bass extends to the northeast in the Great Lakes Basin, and transplanted populations occur to the southeast (Lee et al. 1980). In the summary by Pearson and Pearson (1989), white bass were the only representative of the moronids present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). Pearson and Krumholz (1984) indicated that white bass were most common below ORKm 483 and suggested that their abundance may be increasing in the middle reach of the river possibly because of reduced turbidity.

Trautman (1981) cited Jordan (1882) as having considered the white bass to be uncommon in the Ohio River drainage before impoundment. However, Kirkland (1850 in Trautman 1981) indicated that white bass were very common in the Mahoning River (a tributary of the Beaver River that enters the Ohio River in Montgomery Pool) in 1810. Trautman (1981) also stated that white bass were quite uncommon in the Ohio River from 1920 to 1950

(presumably in the state of Ohio) and that they were found only as far upstream as Lawrence County (Greenup Pool). He also noted that the species was uncommon in the lower Scioto River (enters upper Meldahl Pool) and nearly absent from other streams including the Muskingum River (enters Belleville Pool). White bass had been introduced into many inland impoundments and streams in Ohio since the turn of the 20th century (Trautman 1981). However, before 1955 they had become established in only the larger clear impoundments in Ohio rather than the smaller more turbid ones. Between 1968 and 1969, H. Ronald Preston (in Trautman 1981) reported that white bass were present near dams in the Ohio River between Meigs and Clermont counties (Markland to Racine Pool; middle and lower portions of the upper reach). The species distribution map in Smith (1979) indicates that white bass were present in the Ohio River along the border of Illinois and also in the Wabash River. Clay (1975) reported that white bass occurred throughout the state of Kentucky in medium to large streams and reservoirs including the Big Sandy River (enters Greenup Pool).

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that white bass were commonly collected throughout the length of the Ohio River, with the exception of Emsworth Pool where they were occasionally collected (Appendix B). In an analysis of the ORSANCO lock rotenone data (1957 to 1997), Lowman (2000) found that the abundance of the white bass indicated a few peak years in the late 1980s and early 1990s with a recent return to relatively low levels. Data from all three sections of the Ohio River (upper—ORKm 0 to 327; middle—ORKm 327 to 1,134; and lower—ORKm 1,142 to 1,578; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]) were combined for this analysis.

With the exception of a few introduced populations and populations in the Tennessee River, the lower Ohio River is the eastern extent of the native range for yellow bass, but central to its latitudinal distribution (Lee et al. 1980). Pearson and Pearson (1989) reported that yellow bass were originally present (before 1970) in just the lower reach (ORKm 1,053 to 1,578) of the Ohio River, and recently present (1970 to 1988) in the lower and middle reaches from ORKm 527 to 1,052; this suggested a recent range extension or possibly just improved sampling efficiency (e.g., electrofishing) or increased effort. Jordan (1882 in Pearson and Krumholz 1984) indicated that yellow bass were present in the Ohio River from the mouth upstream to at least the confluence with the Wabash River (enters upper Smithland Pool). Pearson and Krumholz (1984) stated that yellow bass were restricted to the lower half of the Ohio River and were encountered most often in the lower 161 km (i.e., the mouth to the middle of Smithland Pool). As well, Clay (1975) noted that yellow bass were generally restricted to large streams and reservoirs in western Kentucky including those in the Tennessee and Cumberland Rivers (both enter Pool 52). Where they occur in Kentucky, yellow bass are much less abundant than white bass (Clay 1975). However, Clay (1975) believed that the impoundment of large streams may have resulted in increased abundance of yellow bass. Smith (1979) stated that yellow bass are generally rare in the Ohio and Wabash (enters Smithland Pool) Rivers and indicated that high turbidities in some Illinois lakes may have contributed to their general decline. Trautman (1981) makes no reference to yellow bass, probably because they generally do not occur in Ohio waters, including the Ohio River.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that yellow bass were commonly collected in Smithland Pool, occasionally collected in J. T. Myers Pool and uncommonly collected in Meldahl Pool; this species was absent from samples taken in the remaining pools (Appendix B). The occurrence of

yellow bass in the Meldahl Pool is aberrant given its absence from samples in the four pools between Meldahl and J. T. Myers Pool. Analysis of ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) suggested that yellow bass abundance is increasing when data for the entire river are combined; however, the data were insufficient for making conclusions with respect to individual sections.

White perch occur broadly in estuaries and coastal ponds and lakes in their native range along the East Coast of North America (Lee et al. 1980). Trautman (1981) indicated that white perch had been introduced into Lake Erie, but made no mention of them in the Ohio River. He also noted that, in its native range, this species prefers clear waters with low gradients and also noted that white perch often become abundant in areas where they have been introduced. White perch have been introduced into as many as 18 states according to the U.S. Geological Survey's Nonindigenous Aquatic Species Database (USGS 2003); however, this database does not indicate the occurrence of white perch in the Ohio River despite their recent capture (i.e., 1993 to 2000) in the upper reach of that system. In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that white perch were sampled occasionally in R. C. Byrd and Racine Pools and uncommonly in Pike Island Pool (upper reach; Appendix B). The occurrence of white perch in Pike Island Pool is aberrant given its absence from samples taken in the three pools between Pike Island Pool and Racine Pool.

The Ohio River is not within the native range of the striped bass; however, this species has been widely introduced into the basin (Lee et al. 1980). Pearson and Pearson (1989) found that striped bass were present during a recent period (1970 to 1988) in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578), but absent from samples taken before 1970. They also indicated that striped bass abundance may be increasing, but were uncertain as to whether this increase was the result of stocking or natural reproduction. Pearson and Pearson (1989) also documented an upstream range extension for this species since 1983 with the upper limit moving from ORKm 203 to ORKm 21. Pearson and Krumholz (1984) stated that striped bass have been stocked in the Ohio River since 1967, and that beginning in 1975 they had been found from Pool 52 to the Falls of the Ohio (i.e., in the lower reach). According to Trautman (1981), stocking took place in 1968 with the release of fry into various reservoirs and other waters in the Ohio River drainage, including the Little Muskingum River (enters Belleville Pool), but with discouraging results. Smith (1979) reported that striped bass were first recorded in Illinois' portion of the Ohio River in 1974 and presumed that this fish was the result of stocking in impoundments in western Kentucky. Clay (1975) documented that as early as 1957 striped bass were stocked in impoundments within the drainages of the Cumberland (enters Pool 52), Green (enters J. T. Myers Pool), Kentucky (enters McAlpine Pool), and Big Sandy (enters Greenup Pool) Rivers. Clay (1975) also stated that successful spawning probably was not occurring in Kentucky, but that stocking could maintain the fishery.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that striped bass were generally commonly sampled in the lower (i.e., ORKm 1,053 to 1,578) and middle (i.e., ORKm 527 to 1,052) reaches and occasionally sampled in the upper reach (i.e., ORKm 0 to 526; Appendix B). The species was not sampled in Pike Island Pool or in the uppermost three pools (i.e., Montgomery, Dashields, and Emsworth Pools; Appendix B). Analysis of ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) did not reveal any significant trends in the abundance of striped bass in the Ohio River.

Swimming abilities and behaviors (e.g., pelagic or benthopelagic, and migratory) suggest that white, yellow, and striped bass are probably capable and motivated to move upstream through open dams on the Ohio River. White bass, yellow bass, and white perch are known to occupy tailwaters, particularly in spring (Carter 1955 in Clay 1975; Finke 1966 in Becker 1983; Cochran and Hesse 1994). White bass are known to move upstream through navigation dams on the Upper Mississippi River during spring (Finke 1966 in Becker 1983). White perch are probably similarly motivated as the other moronids to move upstream base on their anadromous life history, but may be more limited in ability because of their smaller size and estimated lower swimming speed (Table 8). Likewise, white and yellow bass may be somewhat more restricted than striped bass. Based on their relatively early spring migration periods, moronids should encounter open dams in the lower reach of the Ohio River relatively often with decreasing frequency going upstream (Appendix B).

With the potential exception of white perch, passage restrictions imposed by dams do not seem to be affecting the distribution or abundance of moronids. White, yellow, and striped bass seem to be expanding their distributions, and potentially increasing in abundance since completion of the mainstem dams. These trends probably are the result of improved conditions for these species in terms of reduced turbidities and pollutants (Clay 1975; Pearson and Pearson 1989). As well, ongoing stocking programs for white and striped bass may be contributing to their apparent success. The success of white perch is probably not dependent on fish-passage opportunities given their apparent success in lentic systems elsewhere (Lee et al. 1980; USGS 2003). If other environmental factors are not limiting, white perch may eventually spread throughout the system. However, given their apparent limited distribution (i.e., generally two pools in the lower portion of the upper reach) and that they were introduced into the Ohio River as early as 1993, white perch may be limited by other factors.

Walleye and sauger *(Stizostedion* species*)* are benthopelagic indicating that they can be found near the bottom or suspended in the water column. Walleye and sauger have been classified as macrohabitat generalists (T. Koel, National Park Service, Yellowstone National Park, Wyoming, unpublished data); however, sauger may be fluvial dependent (Clay 1975; Lee et al. 1980; Trautman 1981). Nelson (1968 in Lee et al. 1980) noted that sauger reproduction and survival of young may be dependent on large river habitats. Both species are piscivores that can be found in rivers or lakes; however, walleye are less tolerant of turbidity and silt as compared to sauger (Clay 1975; Lee et al. 1980; Trautman 1981). Walleye and sauger in the Upper Mississippi River prefer flowing-water habitats including main and side channels and tailwaters of dams (Becker 1983). Both species are known to spawn in rivers and lakes (Clay 1975; Becker 1983), but walleye may be more generalists when selecting spawning sites than are sauger, as walleye also use backwater areas and flooded wetlands to spawn (Clay 1975; Smith 1979; Becker 1983). As well, both species generally spawn over gravel or rock bottoms, and eggs initially adhere to the substrate but become buoyant and drift upon hardening (i.e., nonguarder, litho-pelagophils; Simon 1999). Male sauger reached sexual maturity at age 2, whereas females mature at age 3 or 4 (Becker 1983). Male walleye mature at age 2 to 5, whereas females mature at age 4 to 8.

In spring, both species make migrations up rivers and tributaries to spawn, which reportedly occurs at water temperatures of about 4 to 11°C for sauger and 6 to 11°C for walleye (Scott and Crossman 1973). Collette et al. (1977 in Becker 1983) noted that sauger were the most migratory of the percids and moved up to 380 km during one tagging study. Walleye and sauger moved up to 63 km and 57 km, respectively, away from tagging sites in the Mississippi

River, but in general movement out of the navigation pool they were tagged in was not significant (Hubley 1963 in Becker 1983). Hubley (1963 in Becker 1983) also indicated that dams did not prohibit walleye and sauger movements between navigation pools. In the Tennessee River, radio-tagged sauger concentrated in the tailwater area of the Pickwick Dam in fall and winter (Pegg et al. 1997) and then after the presumed spawning period migrated downstream up to 200 km into Kentucky Lake. During that study, four radio-tagged sauger moved upstream through the locks of Pickwick Dam (Pegg et al. 1997). Clay (1975) noted that walleye and sauger are potadromous and that one tagged sauger reportedly moved upstream 385 km in the Tennessee River. Walleye also move considerable distances into rivers to spawn. For example, in Lake Winnebago, Wisconsin, walleye moved up to 123 km into the Fox River during the spawning season (Becker 1983).

Two studies (Jones et al. 1974; Tunink 1975) found that the prolonged swimming speed of walleye was 0.80 m/s (Table 8). The observed prolonged swimming speed of sauger was 0.60 m/s (Tunink 1975). The estimated burst swimming speeds of adult-sized walleye and sauger were 2.20 and 2.14 m/s, respectively, based on a study of walleye (Peake et al. 2000). The maximum swimming speeds (U_{max}) as determined by the methods of Winter and Van Densen (2001; Equation 1) were 2.67 to 4.30 m/s for walleye and 2.36 to 4.14 m/s for sauger (Table 8).

The Ohio River Basin defines the southern and eastern (at that latitude) extent of the native range for walleye and sauger (Lee et al. 1980). Pearson and Pearson (1989) found that walleye and sauger were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). Pearson and Krumholz (1984) reported that sauger were common throughout the Ohio River and indicated that they were more abundant after 1970, particularly in the middle reach. They also noted that sauger were taken only occasionally in the upper 322 km before 1970, but had since increased in abundance in that reach. Conversely, they believed that walleye populations were declining. However, in an update of the work done by Pearson and Krumholtz (1984), Pearson and Pearson (1989) indicated that populations of walleye and sauger had increased in the last 20 years.

The distribution of walleye and sauger before 1850 is unclear because early accounts considered these fishes as a single species (Trautman 1981). Henshaw (1888 in Trautman 1981) indicated that walleye and sauger were common in the Ohio River in 1887. Trautman (1981) stated that the larger and less turbid streams in Ohio contained abundant walleye before 1900, but that after that time a decrease was apparent. Kirtland (1850 in Trautman 1981) noted a decrease in the abundance of walleye in the Mahoning River (enters Beaver River that enters Montgomery Pool) following the construction of a dam on that river. As well, Klippart (1874 in Trautman 1981) noted a decline in the abundance of walleye and sauger from once abundant to rare on the Scioto River (enters Meldahl Pool) following the construction of the State Dam a few miles downstream from Chillicothe. Trautman (1981) noted that after 1940 walleye rarely occurred in the Scioto River; however, recently fishing for walleye had been fair possibly because of stocking programs in upstream reservoirs. On the Ohio River, accounts indicated that walleye were less abundant after dams were constructed (about 1911) as compared to before (Trautman 1981). Smith (1979) reported that walleye and sauger are sporadic in Illinois, but that sauger were probably more common than reports indicated. Clay (1975) noted that walleye were present in all major drainages in Kentucky; however, early reports may be erroneous given that these reports did not always make distinctions between the two species.

Hubbs and Lager (1947 in Trautman 1981) indicated that sauger were present in the Ohio River drainage including the Tennessee River System before settlement by the Europeans. Trautman (1981) stated that from 1925 to 1950 sauger were fairly numerous from the Indiana state line (Markland Pool) to Washington County (Belleville and Willow Island Pools in the upper reach of Ohio River) and in the Scioto River (enters Meldahl Pool) upstream to Pickaway County. Trautman (1981) noted that sauger were considerably less abundant in the Muskingum River (enters Belleville Pool) as compared to the Scioto River between 1925 and 1950. Trautman (1981) also noted that the abundance of inland sauger was never high and remained relatively constant between 1950 and 1980; however, they were broadly distributed in the Ohio River in Ohio during this period. Clay (1975) stated that sauger were found in all rivers of Kentucky and noted their preference for rivers and impoundments, but not small streams.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that walleye were generally collected occasionally to commonly in the lower reach (i.e., ORKm1,053 to 1,578), occasionally in the middle reach (i.e., ORKm 527 to 1,052), and commonly in the upper reach (i.e., ORKm 0 to 526; Appendix B). Sauger were commonly collected in all three reaches of the Ohio River (Appendix B). Analysis of the ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) indicated that walleye were increasing in all three sections of the Ohio River (upper—ORKm 0 to 327; middle—ORKm 327 to 1,134; and lower—ORKm 1,142 to 1,578; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]) and that sauger were increasing in the upper and middle sections, but not in the lower section.

Life history and swimming performance information for walleye and sauger suggest they are probably capable and motivated to move upstream through open mainstem dams (Table 8). Both species are known to move upstream through navigation dams on the Upper Mississippi or Ohio Rivers (Hubley 1968 in Becker 1983; Holland et al. 1984; C. O'Bara, West Virginia Department of Natural Resources, Parkersburg, West Virginia, personal communications). Walleye and sauger are benthopelagic suggesting that they may be able to take advantage of the lowest water velocities in the upper portion of the gate openings to move upstream through dams. Their early spring spawning period suggests that they could take advantage of the open river period at lower and middle reach dams (Appendix B). As well, sauger occupy tailwater areas during other seasons (Pegg et al. 1997) and thus may pass upstream through open dams at times other than spring.

The abundance and distribution information for walleye and sauger suggest that they are not dependent on movement through dams to be successful in the Ohio River. Rather local (within pool) or upstream populations are apparently responsible for their broad distribution and abundant status. Despite an apparent initial declined in abundance following dam construction in the Ohio River and associated tributaries, walleye and sauger appear to be increasing in abundance and distribution recently, particularly in the upper and middle reaches (Pearson and Pearson 1989; Lowman 2000). Pearson and Pearson (1989) suggest this expansion in abundance and distribution is related to improvements in water quality. Others have noted that stocking programs may play a role in recent increases in abundance in tributaries (Trautman 1981); this may also be a factor in the Ohio River mainstem. Whether the initial decline was related to factors other than lack of upstream fish passage (e.g., turbidity or pollution) is uncertain given the qualitative nature of the historic information and the concurrent nature of these stressors. Likewise, present abundance may still be lower than pre-dam abundance but information on historical abundance and controlling factors are uncertain. More system-specific research is

needed on the factors that influence the population dynamics of *Stizostedion* species to help ascertain if the lack of upstream passage at mainstem dams affects their production potential in the Ohio River and its major tributaries.

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Table 1. A list of the common and scientific names of the 44 target fish species used in the assessment of fish passage opportunities at Ohio River mainstem dams.

Common Name	Scientific Name
Lake sturgeon	*Acipenser fulvescens*
Shovelnose sturgeon	*Scaphirhynchus platorynchus*
Paddlefish	*Polyodon spathula*
Longnose gar	*Lepisosteus osseus*
Shortnose gar	*L. platostomus*
Goldeye	*Hiodon alosoides*
Mooneye	*H. tergisus*
American eel	*Anguilla rostrata*
Alabama shad	*Alosa alabamae*
Skipjack herring	*A. chrysochloris*
Alewife	*A. pseudoharengus*
Goldfish	*Carassius auratus*
Grass carp	*Ctenopharyngodon idella*
Common carp	*Cyprinus carpio*
Silver carp	*Hypophthalmichthys molitrix*
Bighead carp	*H. nobilis*
River carpsucker	*Carpiodes carpio*
Quillback	*C. cyprinus*
Highfin carpsucker	*C. velifer*
White sucker	*Catostomus commersoni*
Blue sucker	*Cycleptus elongates*
Smallmouth buffalo	*Ictiobus bubalus*
Bigmouth buffalo	*I. cyprinellus*
Black buffalo	*I. niger*
Spotted sucker	*Minytrema melanops*
Silver redhorse	*Moxostoma anisurum*
River redhorse	*M. carinatum*
Black redhorse	*M. duquesnei*
Golden redhorse	*M. erythrurum*
Shorthead redhorse	*M. macrolepidotum*
White catfish	*Ameiurus catus*
Blue catfish	*Ictalurus furcatus*
Channel catfish	*I. punctatus*
Northern pike	*Esox lucius*
Muskellunge	*E. masquinongy*
White perch	*Morone americana*
White bass	*M. chrysops*
Yellow bass	*M. mississippiensis*
Striped bass	*M. saxatilis*
Smallmouth bass	*Micropterus dolomieu*
Largemouth bass	*M. salmoides*
Sauger	*Stizostedion canadense*
Walleye	*S. vitreum*
Freshwater drum	*Aplodinotus grunniens*

Table 2. Channel and floodplain width, stream gradient, and mean annual discharge at or between various locations along the Ohio River mainstem. *Data from Pearson (1992). **Gradient estimated from Figure 1 between ORKm 0 and 496, ORKm 496 and 1,274, and ORKm 1,274 and 1,578. Ohio River Kilometer (ORKm) is measured from the source of the Ohio River at the confluence of the Allegany and Monongahela Rivers.

Point (ORKm)	Channel* width (m)	Floodplain* width (m)	Channel substrate elevation (m)	Gradient** (m/km)	Discharge* (m^3/s)
Source (0)	366	1,300	689	-	906
Middle (496)	460	-	480	0.13	2,210
Middle (1,274)	550	-	325	0.06	3,796
Mouth (1,578)	1,097	11,000	250	0.08	7,307

Table 3a. Characteristics of the Ohio River mainstem dams and navigation pools in the Louisville District.

Dam	Dam 53	Dam 52	Smithland	J. T. Myers	Newburgh	Cannelton	McAlpine	Markland
Type	movable wicket dam, navigable pass	movable wicket dam, navigable pass	gated-dam, navigable fixed-weir	gated-dam, navigable fixed-weir	gated-dam, navigable fixed-weir	gated-dam, fixed-weir	gated-dam	gated-dam
River kilometer	1,549.1	1,511.0	1,478.1	1,361.5	1,249.0	1,160.0	976.5	855.3
Pool length (km)	36.5	33.0	116.7	112.5	89.2	183.5	121.2	153.4
Number of major tributaries[a]	0	2	1	1	0	1	1	2
Normal pool elevation (m)	88.4	92.0	98.8	104.2	109.1	116.7	128.0	138.7
Normal lift across dam (m)	4.1	3.7	6.7	6.7	4.9	7.6	11.3	10.7
Year open	1929	1928	1980	1975	1975	1972	1961	1963
Total dam span (m)[b]	1,230	1,023	994	1,159	835	522	850[c]	608
Total sill length (m)[d]	---	---	---	---	---	---	---	---
Fixed weir spillway width (m)	1085	914	479	682	396	59	---	---
Gated spillway width (m)	---	---	424	386	348	371	324	425
Number of gates	---	---	11	10	9	12	9	12
Type of gates	---	---	tainter	tainter	tainter	tainter	tainter	tainter
Hydropower (Y or N)	N	N	N	N	N	N	Y	Y
Major modifications	1974: addition of temporary main lock	1969: addition of temporary main lock	---	---	---	---	---	---

[a]Tributaries with annual mean discharges $\geq$28.3 m^3/s.
[b]Total span of structure from land wall to abutment…includes locks, dam, and hydropower.
[c]Only includes sections perpendicular to channel; excludes fixed weir and gated section parallel to channel.
[d]Combined length of sill and stilling basin for gated sections.

Table 3b. Characteristics of the Ohio River mainstem dams and navigation pools in the Huntington District.

Dam	Meldahl	Greenup	R. C. Byrd	Racine	Belleville	Willow Island
Type	gated dam, fixed-weir	gated-dam, fixed-weir	gated-dam	gated-dam	gated-dam, fixed-weir	gated-dam, fixed-weir
River kilometer	702.0	548.8	449.3	382.2	328.1	260.2
Pool length (km)	153.2	99.5	71.8	54.1	67.9	56.8
Number of major tributaries[a]	1	2	1	---	2	---
Normal pool elevation (m)	147.8	157.0	164.0	170.7	177.4	183.5
Normal lift across dam (m)	9.1	9.1	7.0	6.7	6.7	6.1
Year open	1964	1962	1937	1967	1965	1972
Total dam span (m)[b]	626	482	434	408	465	435
Total sill length (m)[c]	39	38	51	40	44	38
Fixed weir spillway width (m)	113	75	---	---	58	34
Gated spillway width (m)	422	318	345	310	310	310
Number of gates	12	9	8	8	8	8
Type of gates	tainter	tainter	roller	tainter	tainter	tainter
Hydropower (Y or N)	N	Y	N	Y	N	N
Major modifications		1982: addition of hydropower		1983: addition of hydropower		
Additional comments	fixed weir with 95 m open crest	fixed weir with 68 m open crest			fixed weir with 40 m open crest	fixed weir with 26 m open crest

[a]Tributaries with annual mean discharges $\geq$28.3 m^3/s.
[b]Total span of structure from land wall to abutment…includes locks, dam, and hydropower.
[c]Combined length of sill and stilling basin for gated sections.

Table 3c. Characteristics of the Ohio River mainstem dams and navigation pools in the Pittsburgh District.

Dam	Hannibal	Pike Island	New Cumberland	Montgomery	Dashields	Emsworth
Type	gated-dam, fixed weir	gated-dam, fixed-weir	gated-dam	gated-dam, fixed-weir	fixed-weir	gated-dam, fixed-weir
River kilometer	203.4	135.5	87.5	51.0	21.4	10.0
Pool length (km)	67.9	48.0	36.5	29.6	11.4	38.8
Number of major tributaries[a]	0	0	0	1	0	2[b]
Normal pool elevation (m)	189.9	196.3	202.5	207.9	210.9	216.4
Normal lift (m)	6.1	6.4	6.2	5.3	3.0	5.5
Year open	1972	1963	1959	1936	1929	1921
Total dam span (m)[c]	518	487	490	486	549	361
Total sill length (m)[d]	41	35	31	36	---	31
Fixed weir spillway width (m)	24	60	---	67	483	11
Gated spillway width (m)	311	338	401	354	---	513[e]
Number of gates	8	9	11	10	---	14[e]
Type of gates	tainter	tainter	tainter	Sidney	---	Sidney
Hydropower (Y or N)	Y	N	N	N	N	N
Major modifications	1988: addition of hydropower shortened fixed weir from 34 m to 24 m					1938: converted to gated structure, raising pool an additional 2.1 m

[a]Tributaries with annual mean discharges $\geq$28.3 m^3/s.
[b]Allegheny and Monongahela rivers.
[c]Total span of structure from land wall to abutment…includes locks, dam, and hydropower.
[d]Combined length of sill and stilling basin for gated sections.
[e]284 m, 8-gated main channel dam, plus 229 m, 6-gated back channel dam.

Table 4. Tributaries of the Ohio River with mean annual discharge rates at the gaging station nearest the Ohio River =28.3 m^3/s. Raw data was from the U.S. Geological Survey's real-time water data Web site, http://waterdata.usgs.gov/.

Tributary	Enters Ohio River at river km	Enters Ohio River at navigation pool	Gaging station location			Mean of annual mean stream flow in m^3/s at station	Minimum of annual mean stream flow in m^3/s at station	Maximum of annual mean stream flow in m^3/s at station
			Latitude	Longitude	Nearest city			
Allegheny River (PA)	0.0	Emsworth	40`36'55"	79`43'07"	Natrona, PA	556	346	815
Monongahela River (PA)	0.0	Emsworth	40`23'28"	79`51'30"	Braddock, PA	355	234	597
Beaver River (PA)	40.6	Montgomery	40`53'19"	80`20'14"	Wampum, PA	72	27	127
Muskingum River (OH)	275.5	Belleville	39`38'42"	81`51'00"	McConnelsville, OH	217	78	360
Little Kanawha River (WV)	295.4	Belleville	39`03'32"	81`23'23"	Palestine, WV	61	28	102
Kanawha River (WV)	425.1	Byrd	38`22'17"	81`42'08"	Charleston, WV	429	232	680
Guyandotte River (WV)	488.3	Greenup	37`50'32"	81`58'34"	Logan, WV	33	14	57
Big Sandy River (WV-KY)	507.4	Greenup	38`10'16"	82`38'05"	Louisa, KY	128	42	225
Scioto River (OH)	570.4	Meldahl	39`12'44"	82`51'50"	Higby, OH	134	38	249
Licking River (KY)	752.3	Markland	38`42'31"	84`18'38"	Catawba, KY	116	36	224
Great Miami River (OH)	785.8	Markland	39`23'28"	84`34'20"	Hamilton, OH	94	27	178
Kentucky River (KY)	873.3	McAlpine	38`26'20"	84`57'48"	Lockport, KY	238	81	394
Salt River (KY)	1007.8	Cannelton	37`59'06"	85`43'03"	Shepherdsville, KY	45	13	96
Green River (KY)	1254.7	Myers	37`32'02"	87`15'50"	Calhoun, KY	316	97	660
Wabash River (IN-IL)	1356.8	Smithland	38`24'07"	87`45'10"	Mt. Carmel, IL	797	205	1,705
Cumberland River (KY-TN)	1472.6	Pool 52	36`29'26"	87`50'20"	Dover, TN	693	309	1,123
Tennessee River (KY-TN)	1495.2	Pool 52	35`13'29"	88`15'26"	Savannah, TN	1,559	716	2,259

Table 5. Information pertaining to the raw temperature data extrapolated to estimate average weekly water temperature in each navigation pool (Table 11). Raw data obtained from Environmental Protection Agency's Storet Database at http://www.epa.gov/storet/. ORKm is Ohio River Kilometer measured as distance downstream from Pittsburgh.

Location	First year	Last year	ORKm	Number of observations
South Heights, Pennsylvania	1963	1986	24.5	20,693
Wheeling, West Virginia	1951	1975	139.7	7,920
Evansville, Indiana	1968	1986	1,273.5	14,868
Joppa, Illinois	1975	1986	1,532.3	8,817

Table 6. Kinematic variables used to calculate maximum swimming speeds (U_{max}; Table 8) of target species (after Winter and Van Densen 2001). Median migration temperatures derived from information obtained from proximal sources, for example, Trautman (1981; see Methods); *Rostrum excluded from paddlefish total length.

Species	Base maximum tailbeat frequency - $F_{max\text{-}base}$ (Hz)	Maximum tailbeat frequency at 15°C - $F_{max\text{-}15^oC}$ (Hz)	Maximum tailbeat frequency at median migration temperature - $F_{max\text{-}t}$ (Hz)	Stride length (body lengths)	Median total length of adults (cm)	Median migration temperature °C
Lake sturgeon	15	4.0	3.5	0.7	101	13
Shovelnose sturgeon	15	7.3	7.3	0.7	59	15
Paddlefish	15	5.1	3.9	0.7	84*	11
Longnose gar	20	7.2	9.5	0.4	81.4	19
Shortnose gar	20	9.4	12.4	0.4	62.5	19
Goldeye	25	17.5	11.5	0.7	34	9
Mooneye	25	18.8	12.4	0.7	29.5	9
American eel elver	15	15.0	30.0	0.5	7.5	25
American eel	15	13.2	19.8	0.5	36.8	25
Alabama shad	25	18.0	20.7	0.7	32.5	17
Skipjack herring	25	17.3	15	0.7	35.7	13
Alewife	25	20.3	16.8	0.7	22.6	12
Goldfish	15	13.1	11.4	0.7	17	13
Grass carp	15	4.05	4.3	0.7	100	16
Common Carp	15	6.2	8.1	0.7	72	19
Silver carp	15	5.7	8.5	0.7	77	21
Bighead carp	15	6.3	9.4	0.7	69	21
River carpsucker	15	10.8	16.2	0.7	31	21
Quillback	15	7.9	9.8	0.7	52	18
Highfin carpsucker	15	11.4	13.1	0.7	26.5	17
White sucker	25	18.0	16.7	0.7	33	14
Blue sucker	25	11.3	11.2	0.7	66.5	15
Smallmouth buffalo	15	7.3	9.0	0.7	58	18
Bigmouth buffalo	15	10.05	9.4	0.7	35.5	14
Black buffalo	15	7.9	9.1	0.7	52	17
Spotted sucker	25	17.7	16.5	0.7	32	14
Silver redhorse	25	18.0	13.7	0.7	32.5	11
River redhorse	25	14.5	22.0	0.7	48	21
Black redhorse	25	19.3	19.2	0.7	27.5	15
Golden redhorse	25	19.0	17.7	0.7	28.8	14
Shorthead redhorse	25	16.0	16.0	0.7	40.8	15
White catfish	20	16.6	20.4	0.7	21	18
Blue catfish	20	7.2	10.1	0.7	81	20
Channel catfish	20	14.0	22.7	0.7	33	22
Northern pike	25	13.3	7.6	0.4	57	7
Muskellunge	25	7.5	4.9	0.4	95	9
White perch	25	23.5	17.9	0.7	13.5	11
White bass	25	18.2	21.0	0.7	31.8	17
Yellow bass	25	19.7	21.1	0.7	25.7	16
Striped bass	25	15.5	11.6	0.7	43.1	11
Smallmouth bass	20	13.2	9.37	0.7	38	10
Largemouth bass	20	12.6	12.6	0.7	41	15
Sauger	25	18.0	10.3	0.7	33	7
Walleye	25	17.2	10.7	0.7	35.6	8
Freshwater drum	15	9.4	11.6	0.7	40.6	18

Table 7. Information pertaining to the water surface elevation data used to assess fish passage opportunities at the 20 mainstem dams on the Ohio River. Swellhead is the difference between headwater surface elevation and tailwater surface elevation at the time when gates are first lifted clear of the water.

Dam	Normal pool elevation (m)	Swellhead estimate used to determine open river (m)	Data years	Number of observations	
				Headwater gage	Tailwater gage
Emsworth	216.6	0.153	1995-2000	2,327	2,327
Dashields	211.1	0.153	1980-2000	7,800	7,800
Montgomery	208.0	0.153	1980-2000	7,795	7,795
New Cumberland	202.7	0.153	1980-2000	7,802	7,802
Pike Island	196.4	0.153	1980-2000	7,741	7,740
Hannibal	190.0	0.153	1980-2000	7,740	6,934
Willow Island	184.6	0.153	1975-2000	9,336	9,336
Belleville	177.5	0.153	1975-2000	9,562	9,562
Racine	170.8	0.305	1975-2000	8,468	9,259
R. C. Byrd	164.1	0.153	1975-2000	9,492	9,532
Greenup	157.1	0.305	1975-2000	9,475	9,475
Meldahl	147.9	0.153	1975-2000	9,329	9,557
Markland	138.8	0.153	1975-2000	9,497	9,497
McAlpine	128.1	0.915	1975-2000	9,497	9,497
Cannelton	116.8	0.153	1975-2000	9,418	9,418
Newburgh	109.2	0.153	1975-2000	9,418	9,418
J. T. Myers	104.3	0.153	1975-2000	9,497	9,497
Smithland	98.8	0.153	1981-2000	7,305	7,305
Dam 52	92.1	0.153	1975-2000	9,497	3,624
Dam 53	88.5	0.153	1981-2000	7,309	770

Table 8. Estimated swimming speeds for target fishes of the Ohio River. Prolonged speed (U_{crit10}) is the speed a fish can maintain for 10 min. Burst speed is the speed a fish can maintain for 30 s or less. Maximum swimming speeds ($U_{max\text{-}t}$ and U_{max15}) are kinematically determined speeds for adult-sized fish (TL = total length) at a median spawning migration temperature (Table 6) and at 15°C, respectively (Winter and Van Densen 2001; Equation 1). Shaded areas represent estimates derived from species-specific swimming speeds. Numbers in parenthesis are references cited. Subscripts (o) and (m) indicate method of deriving swimming speeds either directly observed or based on empirical models, respectively. See Table 1 and Appendix A for scientific names.

Species	Median adult TL (cm)	Prolonged speed U_{crit10} ($m\ s^{-1}$)	Burst speed ($m\ s^{-1}$)	Maximum speed $U_{max\text{-}t}$ ($m\ s^{-1}$)	Maximum speed $U_{max\text{-}15}$ ($m\ s^{-1}$)	Surrogate species[a]
Lake sturgeon	101	$0.83_{(m)}$ (12)	$1.55_{(m)}$ (11)	2.49	2.86	---
Shovelnose sturgeon	59	$0.65_{(o)}$ (1), $0.77_{(o)}$ (13)	1.00	3.00	3.00	B-lake sturgeon
Paddlefish	84[b]	$0.65_{(o)}$ (13)	1.40	2.29	3.00	B-lake sturgeon
Longnose gar	81.4	0.45	4.68, 2.50	3.09	2.34	P,B-northern pike
Shortnose gar	62.5	0.45	4.68, 2.50	3.10	2.35	P,B-northern pike
Goldeye	34	$0.8_{(o)}$ (13), $0.6_{(o)}$ (8)	$3.47\text{-}4.15_{(o)}$ (15)	2.77	4.20	B-American shad
Mooneye	29.5	0.8, 0.6	$3.47\text{-}4.15_{(o)}$ (15)	2.56	3.87	P-goldeye, B-American shad
American eel (elvers)	7.5		$<0.50_{(o)}$ (9)	1.12	0.56	B-European eel elvers
American eel	36.8		$1.14_{(o)}$ (5)	3.63	1.81	B-European eel
Alabama shad	32.5	0.8 (13)	$3.47\text{-}4.15_{(o)}$ (15)	4.74	4.12	P-goldeye, B-American shad
Skipjack herring	35.7	0.8 (13)	$3.47\text{-}4.15_{(o)}$ (15)	3.75	4.31	P-goldeye, B-American shad
Alewife	22.6	0.6 (8)	4.73 (16)	3.12	4.10	P-goldeye
Goldfish	17	0.83	$1.00_{(o)}$ (2)	1.35	1.55	P-common carp
Grass carp	100	0.83	1.75	3.08	2.88	P,B-common carp
Common carp	72	$0.83_{(m)}$ (14)	$1.17_{(m)}$ (14), $1.75_{(o)}$ (4)	4.03	3.05	---
Silver carp	77	0.83	1.75	4.57	3.05	P,B-common carp
Bighead carp	69	0.83	1.75	4.58	3.05	P,B-common carp
River carpsucker	31	0.83	1.75	3.49	2.32	P,B-common carp
Quillback	52	0.83	1.75	3.59	2.92	P,B-common carp
Highfin carpsucker	26.5	0.83	1.75	2.44	2.12	P,B-common carp
White sucker	33	$0.68_{(m)}$ (8)	$3.30_{(o)}$ (4)	3.87	4.16	B-western sucker
Blue sucker	66.5	$1.02_{(m)}$ (8)	$3.30_{(o)}$ (4)	5.22	5.22	P-longnose sucker, B-western sucker

Table 8 (continued).

Species	Median adult TL (cm)	Prolonged speed $Ucrit_{10}$ ($m\ s^{-1}$)	Burst speed ($m\ s^{-1}$)	Maximum Speed U_{max-t} ($m\ s^{-1}$)	Maximum speed U_{max-15} ($m\ s^{-1}$)	Surrogate species[a]
Smallmouth buffalo	58	0.83	1.75	3.69	3.00	P,B-common carp
Bigmouth buffalo	35.5	0.83	1.75	2.34	2.51	P,B-common carp
Black buffalo	52	0.83	1.75	3.36	2.92	P,B-common carp
Spotted sucker	32	0.66	$3.30_{(o)}$ (4)	3.68	3.96	P-white sucker, B-western sucker
Silver redhorse	32.5	0.54	$3.30_{(o)}$ (4)	3.12	4.10	P-white sucker, B-western sucker
River redhorse	48	$0.85_{(m)}$	$3.30_{(o)}$ (4)	7.38	4.86	P-longnose sucker, B-western sucker
Black redhorse	27.5	0.61	$3.30_{(o)}$ (4)	3.72	3.72	P-white sucker, B-western sucker
Golden redhorse	28.8	0.62	$3.30_{(o)}$ (4)	3.57	3.83	P-white sucker, B-western sucker
Shorthead redhorse	40.8	$0.78_{(m)}$ (8)	$3.30_{(o)}$ (4)	4.59	4.59	P-longnose sucker, B-western sucker
White catfish	21	0.62		3.15	2.09	P-channel catfish
Blue catfish	81	0.71		5.74	4.10	P-channel catfish
Channel catfish	33	$0.71_{(o)}$ (13)		5.28	3.26	---
Northern pike	57	$0.45_{(m)}$ (8)	$4.68_{(o)}$ (14), $2.50_{(o)}$ (4)	1.23	2.83	---
Muskellunge	95	0.6	4.68	1.88	2.85	P,B-northern pike
White perch	13.5	0.78		1.69	2.22	P-white bass
White bass	31.8	$0.78_{(o)}$ (13)	$3.47\text{-}4.15_{(o)}$ (15)	4.66	4.05	B-American shad
Yellow bass	25.7	0.78		3.81	3.56	P-white bass
Striped bass	43.1	$0.86_{(o)}$[c] (7)	$3.47\text{-}4.15_{(o)}$ (15)	3.52	4.69	B-American shad
Smallmouth bass	38	$0.88_{(m)}$ (6)	2.23	2.49	3.50	B-walleye
Largemouth bass	41	$0.60_{(m)}$[c] (3)	2.29	3.61	3.61	B-walleye
Sauger	33	$0.60_{(o)}$ (13)	2.14	2.36	4.14	B-walleye
Walleye	35.6	$0.80_{(m,o)}$ (8,13)	$2.20_{(m)}$ (10)	2.67	4.30	---
Freshwater drum	40.6	$0.75_{(o)}$ (13)		3.28	2.67	---

[a]P = prolonged, B = burst. [b]Rostrum excluded. [c]U_{crit30}.

References: (1) Adams et al. 1997; (2) Bainbridge 1960; (3) Beamish 1970; (4) Blaxter 1969; (5) Blaxter and Dicksen 1958; (6) Bunt et al. 1999; (7) Freadman 1979; (8) Jones et al. 1974; (9) McCleave 1980; (10) Peake et al. 2000; (11) Peake et al. 1997; (12) Peake et al. 1995; (13) Tunink 1975; (14) Videler 1993; (15) Weaver 1965; (16) Wardle and He 1988.

Table 9. Percent of years that Ohio River mainstem dams were at open river (i.e., tailwater elevation greater than normal pool elevation minus swellhead) for at least one day during a particular calendar week in 20 to 26 years. Data years are consecutive, with the last year of data being 2000. Frequency of open river at Emsworth Dam is based on 6 years of actual data and 16 years of estimated data (see Methods). Dark shading ≥50% of years; medium shading <50% and ≥30%; light shading <30% and ≥10%; no shading <10%. Swellhead is the difference between headwater surface elevation and tailwater surface elevation at the time when gates are first lifted clear of the water. D53 is Dam 53, D52 is Dam 52, Smi is Smithland Dam, Mye is J. T. Myers Dam, Neb is Newburgh Dam, Can is Cannelton Dam, Mca is McAlpine Dam, Mar is Markland Dam, Mel is Meldahl Dam, Gre is Greenup Dam, Byr is R. C. Byrd Dam, Rac is Racine Dam, Bel is Belleville Dam, Wil is Willow Island Dam, Han is Hannibal Dam, Pik is Pike Island Dam, Nec is New Cumberland Dam, Mon is Montgomery Dam, Das is Dashields Dam, and Ems is Emsworth Dam. Table on facing page.

Dam →	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Years of data → / ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 10. Mean, standard deviation (std), and range of the number of days that Ohio River mainstem dams were at open river (i.e., tailwater elevation greater than normal pool elevation minus swellhead) during weeks in which that dam reached open river for at least one day. Swellhead is the difference between headwater surface elevation and tailwater surface elevation at the time when gates are first lifted clear of the water.

Dam	Mean (days)	Std (days)	Range (days)	Number of open-river weeks	Years of data
Dam 53	6.8	0.9	1-7	964	20
Dam 52	6.2	1.6	1-7	743	26
Smithland	5.0	2.1	1-7	162	20
J. T. Myers	5.2	2.1	1-7	357	26
Newburgh	4.9	2.2	1-7	453	26
Cannelton	3.8	2.2	1-7	158	26
McAlpine	3.5	2.1	1-7	131	26
Markland	2.8	1.9	1-7	34	26
Meldahl	3.0	1.9	1-7	100	26
Greeenup	3.0	1.6	1-7	124	26
R. C. Byrd	2.8	1.6	1-7	143	26
Racine	2.3	1.3	1-6	71	26
Belleville	1.8	0.8	1-3	28	26
Willow Island	1.8	0.8	1-3	29	26
Hannibal	1.3	0.6	1-2	3	21
Pike Island	1.8	0.7	1-3	12	21
New Cumberland	1.4	0.5	1-2	9	21
Montgomery	1.1	0.3	1-2	9	21
Dashields	1.8	1.3	1-6	43	21
Emsworth	1.0	0	1	4	21

Table 11. Estimated water temperatures at Ohio River mainstem dam by calendar week. Shading darkens with increasing temperature. Data from four stations along the Ohio River (Environmental Protection Agency's Storet Database at http://www.epa.gov/storet/; Table 5) were used to derive these values. D53 is Dam 53, D52 is Dam 52, Smi is Smithland Dam, Mye is J. T. Myers Dam, Neb is Newburgh Dam, Can is Cannelton Dam, Mca is McAlpine Dam, Mar is Markland Dam, Mel is Meldahl Dam, Gre is Greenup Dam, Byr is R. C. Byrd Dam, Rac is Racine Dam, Bel is Belleville Dam, Wil is Willow Island Dam, Han is Hannibal Dam, Pik is Pike Island Dam, Nec is New Cumberland Dam, Mon is Montgomery Dam, Das is Dashields Dam, and Ems is Emsworth Dam.

Dam→ ↓Week of year	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
39 – Sep	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	22	22	21	21
40 – Oct	21	21	21	22	22	22	22	22	22	22	22	22	22	21	21	21	21	20	19	19
41 – Oct	19	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	19	18	18	18
42 – Oct	18	18	18	19	19	19	19	19	19	19	19	19	19	19	19	19	18	17	16	16
43 – Oct	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	16	16	15	15
44 – Oct/Nov	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	15	14	14	14
45 – Nov	15	15	15	15	14	14	14	14	14	14	14	14	14	14	14	14	13	13	12	12
46 – Nov	13	12	12	12	12	13	13	13	13	13	13	13	13	13	13	13	12	11	10	10
47 – Nov	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	10	9	9	9
48 – Nov/ Dec	9	9	9	10	10	10	9	9	9	9	9	9	9	9	9	9	8	8	7	7
49 – Dec	7	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	7	6	6	6
50 – Dec	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	5	5	5
51 – Dec	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	4	4	4
52 – Dec	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	4	3	3	3
1 – Jan	5	5	5	4	4	4	4	4	4	4	4	5	5	5	5	5	4	3	3	3
2 – Jan	4	4	4	4	3	3	3	4	4	4	4	4	4	4	4	4	3	3	2	2
3 – Jan	4	4	4	4	3	3	3	4	4	4	4	4	4	4	4	4	3	2	2	2
4 – Jan	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3
5 – Jan/Feb	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	2	2
6 – Feb	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	2	2
7 – Feb	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3
8 – Feb	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	4	4
9 – Feb/Mar	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	4	4
10 – Mar	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5
11 – Mar	8	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	6	6
12 – Mar	9	9	9	9	8	8	8	8	8	8	8	7	7	7	7	7	7	7	7	7
13 – Mar/Apr	10	10	9	9	9	9	9	8	8	8	8	8	8	8	8	8	8	8	8	8
14 – Apr	12	12	12	11	10	10	10	10	10	10	9	9	9	9	9	9	9	9	9	9
15 – Apr	13	13	13	12	12	12	11	11	11	11	11	11	10	10	10	10	10	10	10	10
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17 – Apr	16	16	16	15	15	15	15	15	14	14	14	14	14	14	14	14	14	14	14	14
18 – Apr/May	17	17	17	17	16	16	16	16	16	16	15	15	15	15	15	15	15	15	15	15
19 – May	18	18	18	18	18	18	17	17	17	17	17	17	17	17	17	17	17	16	16	16
20 – May	20	20	19	19	19	19	18	18	18	18	18	18	17	17	17	17	17	17	18	18
21 – May	21	21	21	20	20	20	20	20	20	19	19	19	19	19	19	19	19	19	19	19
22 – May/Jun	22	22	22	22	22	21	21	21	21	21	21	21	20	20	20	20	20	20	20	20
23 – Jun	23	23	23	23	23	23	22	22	22	22	22	22	22	22	22	22	22	22	22	22
24 – Jun	25	25	25	24	24	24	24	24	24	24	24	24	24	24	24	24	23	23	23	23
25 – Jun	26	26	26	25	25	25	25	25	25	25	25	25	25	25	25	24	24	24	24	24
26 – Jun/Jul	27	27	27	26	26	26	26	26	26	25	25	25	25	25	25	25	25	24	24	24
27 – Jul	27	27	27	27	27	27	27	26	26	26	26	26	26	26	26	26	26	25	25	25
28 – Jul	28	28	28	28	28	27	27	27	27	27	27	26	26	26	26	26	26	26	26	26
29 – Jul	29	29	29	28	28	28	28	28	27	27	27	27	27	27	27	27	27	27	26	26
30 – Jul	29	29	29	29	28	28	28	28	28	28	28	27	27	27	27	27	27	27	27	27
31 – Jul/Aug	29	29	29	28	28	28	28	28	28	28	28	28	28	28	28	27	27	27	27	27
32 – Aug	29	29	29	28	28	28	28	28	28	27	27	27	27	27	27	27	27	27	27	27
33 – Aug	29	28	28	28	28	28	28	28	27	27	27	27	27	27	27	27	26	26	26	26
34 – Aug	28	28	28	28	28	28	28	27	27	27	27	27	27	27	27	27	26	26	26	26
35 – Aug/Sep	28	28	28	28	28	28	27	27	27	27	27	27	27	27	27	27	26	26	26	26
36 – Sep	27	27	27	27	27	27	27	27	27	26	26	26	26	26	26	26	26	25	25	25
37 – Sep	26	26	26	26	26	26	26	26	26	25	25	25	25	25	25	25	25	24	24	24
38 – Sep	25	25	25	25	25	25	24	24	24	24	24	24	24	24	24	24	23	23	23	23

Table 12. General life history characteristics, occurrence by reach, and distribution of the 44 target species in the Ohio River. Occurrence– A is absent and P is present based on Pearson and Pearson (1989) for the lower (Ohio River Kilometer [ORKm] 1,053 to 1,578), middle (ORKm 527 to 1,052), and upper (ORKm 0 to 526) reaches of the Ohio River between 1970 and 1988; in parentheses, A is absent, U is uncommon, O is occasional, and C is common in standardized lock rotenone samples (ORSANCO 2001) and night electrofishing samples (OEPA 2002) collected between 1989 and 2001. General distribution group– E is extirpated, L is more common in lower reach than middle and upper reaches, LM is more common in lower and middle reaches than the upper reach, LMU common in all three reaches, MU more common in the middle and upper reaches than the lower reach, and U more common in the upper reach than in middle and lower reaches based on occurrence columns. General habitat after Koel (unpublished data); pelagic/benthic after Winemiller and Rose (1992); reproductive strategy after Simon (1999), Balon (1975), or Pearson and Krumholz (1984); pollution tolerance after Lyons et al. (2001), Simon and Emery (1995), or Pearson and Krumholz (1984); spawning temperature and migratory status generally based on proximal sources, for example, Trautman (1981; see Methods).

Common name	General habitat	Pelagic or benthic	Migatory	Spawning temperature °C	Reproductive strategy	Pollution tolerant or sensitive	Occurrence			General distribu-tion group
							Lower reach	Middle reach	Upper reach	
Lake sturgeon	Fluvial dependent	Benthic	Yes*	8.5-21	Nonguarder litho-pelagophil	Sensitive	A (A)	A (A)	A (A)	E
Shovelnose sturgeon	Fluvial specialist	Benthic	Yes	15.5-21.5	Nonguarder litho-pelagophil	Sensitive	P (A)	P (A)	A (A)	L
Paddlefish	Fluvial dependent	Pelagic	Yes *	10-16	Nonguarder litho-pelagophil	Sensitive	P (O)	P (O)	P (A-O)	LM
Longnose gar	Fluvial dependent	Pelagic	Yes	21	Nonguarder phyto-lithophil	Tolerant	P (A-C)	P (O-C)	P (A-C)	LMU
Shortnose gar	Macrohabitat generalist	Pelagic	--	19-24	Nonguarder phytophil	Tolerant	P (A-O)	P (A-O)	P (A)	L
Goldeye	Fluvial dependent	Pelagic	Yes	10-22	Nonguarder litho-pelagophil	Sensitive	P (O-C)	P (U-C)	P (A-U)	LM
Mooneye	Fluvial dependent	Pelagic	Yes	10-13	Nonguarder litho-pelagophil	Sensitive	P (A-C)	P (O-C)	P (A-C)	LMU
American eel	Macrohabitat generalist	Benthic	Yes *	---	Nonguarder pelagophil	--	P (A-C)	P (A-O)	P (A-U)	LM
Alabama shad	Fluvial dependent	Pelagic	Yes *	19-22	Nonguarder lithophil	--	A (A)	A (A)	A (A)	E
Skipjack herring	Fluvial dependent	Pelagic	Yes	Unknown	Nonguarder phyto-lithophil	Tolerant	P (C)	P (C)	P (O-C)	LMU
Alewife	Fluvial dependent	Pelagic	Yes *	13-16	Nonguarder phyto-lithophil	--	A (A)	P (A)	P (A-O)	U
Goldfish	Macrohabitat generalist	Benthopelagic	--	>15	Nonguarder phytophil	Tolerant	P (A)	P (A-U)	P (A-O)	MU
Grass carp	Fluvial dependent	Benthopelagic	--	18-19	Nonguarder pelagophil	--	P (A)	P (A)	A (A)	LM
Common carp	Macrohabitat generalist	Benthopelagic	Yes	17-27	Nonguarder phyto-lithophil	Tolerant	P (C)	P (O-C)	P (C)	LMU
Silver carp	Fluvial dependent	Pelagic	Yes	18-30	Nonguarder pelagophil	--	P (A)	P (A)	A (A)	LM
Bighead carp	Fluvial dependent	Benthopelagic	Yes	18-30	Nonguarder pelagophil	--	A (A-O)	A (A)	A (A)	L
River carpsucker	Macrohabitat generalist	Benthopelagic	Yes	23.9	Nonguarder litho-pelagophil	Tolerant	P (O-C)	P (C)	P (A-C)	LMU
Quillback	Macrohabitat generalist	Benthopelagic	Yes	13-28	Nonguarder litho-pelagophil	Tolerant	P (O-C)	P (O-C)	P (O-C)	LMU
Highfin carpsucker	Fluvial dependent	Benthopelagic	Yes	13-25	Nonguarder litho-pelagophil	Sensitive	P (A-O)	P (O-C)	P (A-O)	LM
White sucker	Macrohabitat generalist	Benthopelagic	Yes	4-20	Nonguarder litho-pelagophil	Tolerant	P (A)	P (A)	P (A-U)	U
Blue sucker	Fluvial specialist	Benthic	Yes	10-23	Nonguarder litho-pelagophil	Sensitive	P (A-O)	P (A-O)	P (A)	L

Table 12 (continued).

Common name	General habitat	Pelagic or benthic	Migatory	Spawning temperature °C	Reproductive strategy	Pollution tolerant or sensitive	Occurrence			General distribu-tion group
							Lower reach	Middle reach	Upper reach	
Smallmouth buffalo	Macrohabitat generalist	Benthopelagic	Yes	15.5-27	Nonguarder phyto-lithophil	Tolerant	P (C)	P (C)	P (A-C)	LMU
Bigmouth buffalo	Macrohabitat generalist	Benthopelagic	Yes	15.5-18.3	Nonguarder phytophil	Tolerant	P (O-C)	P (A-O)	P (A-U)	L
Black buffalo	Macrohabitat generalist	Benthopelagic	--	18-21	Nonguarder phytophil	Sensitive	P (A-C)	P (A-O)	P (A-C)	LMU
Spotted sucker	Macrohabitat generalist	Benthic	Yes	12.2-19.4	Nonguarder lithophil	Sensitive	P (A)	P (A-C)	P (A-C)	U
Silver redhorse	Macrohabitat generalist	Benthopelagic	Yes	13-13.3	Nonguarder lithophil	Sensitive	P (A)	P (A-C)	P (A-C)	MU
River redhorse	Fluvial specialist	Benthopelagic	Yes	22-25	Nonguarder lithophil	Sensitive	P (A)	P (A-O)	P (A-C)	MU
Black redhorse	Fluvial dependent	Benthopelagic	Yes	13-23	Nonguarder lithophil	Sensitive	A (A)	P (A-U)	P (A-C)	U
Golden redhorse	Fluvial dependent	Benthopelagic	Yes	10-15.5	Nonguarder lithophil	Sensitive	P (A)	P (A-C)	P (A-C)	MU
Shorthead redhorse	Fluvial dependent	Benthopelagic	Yes	11-22	Nonguarder lithophil	Sensitive	P (A-O)	P (A-C)	P (A-C)	MU
White catfish	Macrohabitat generalist	Benthic	--	20-22.2	Guarder spelophil	--	P (A-O)*	P (A-O)*	P (A)	LM
Blue catfish	Fluvial specialist	Benthic	Yes	21-24	Guarder spelophil	--	P (O-C)	P (A-C)	P (A)	L
Channel catfish	Macrohabitat generalist	Benthic	Yes	23.9-26.7	Guarder spelophil	Tolerant	P (C)	P (C)	P (C)	LMU
Northern pike	Macrohabitat generalist	Pelagic	Yes	4-11	Nonguarder phytophil	--	A (A)	P (A)	P (A)	MU
Muskellunge	Macrohabitat generalist	Pelagic	Yes	8.9-13.3	Nonguarder phytophil	Sensitive	A (A)	P (A)	P (A)	MU
White perch	Fluvial dependent	Pelagic	Yes *	11-16	Nonguarder phyto-lithophil	--	A (A)	A (A)	A (A-O)	U
White bass	Fluvial dependent	Pelagic	Yes	12.5-26.1	Nonguarder phyto-lithophil	Tolerant	P (C)	P (C)	P (O-C)	LMU
Yellow bass	Fluvial dependent	Benthopelagic	Yes	>15	Nonguarder phyto-lithophil	--	P (A-C)	P (A-U)	P (A)	L
Striped bass	Fluvial dependent	Benthopelagic	Yes *	>14.4	Nonguarder phyto-lithophil	--	P (O-C)	P (O-C)	P (A-O)	LM
Smallmouth bass	Macrohabitat generalist	Benthopelagic	Yes	>4-16.6	Guarder polyphil	Sensitive	P (A-O)	P (A-C)	P (O-C)	MU
Largemouth bass	Macrohabitat generalist	Benthopelagic	--	15.5-21.1	Guarder polyphil	--	P (O-C)	P (C)	P (A-C)	LMU
Sauger	Macrohabitat generalist	Benthopelagic	Yes	3.9-11	Nonguarder litho-pelagophil	--	P (C)	P (C)	P (C)	LMU
Walleye	Macrohabitat generalist	Benthopelagic	Yes	5.6-11.1	Nonguarder litho-pelagophil	Sensitive	P (O-C)	P (A-C)	P (O-C)	LMU
Freshwater drum	Macrohabitat generalist	Benthopelagic	Yes	19-22	Nonguarder pelagophil	Tolerant	P (C)	P (C)	P (C)	LMU

* Indicates highly migratory

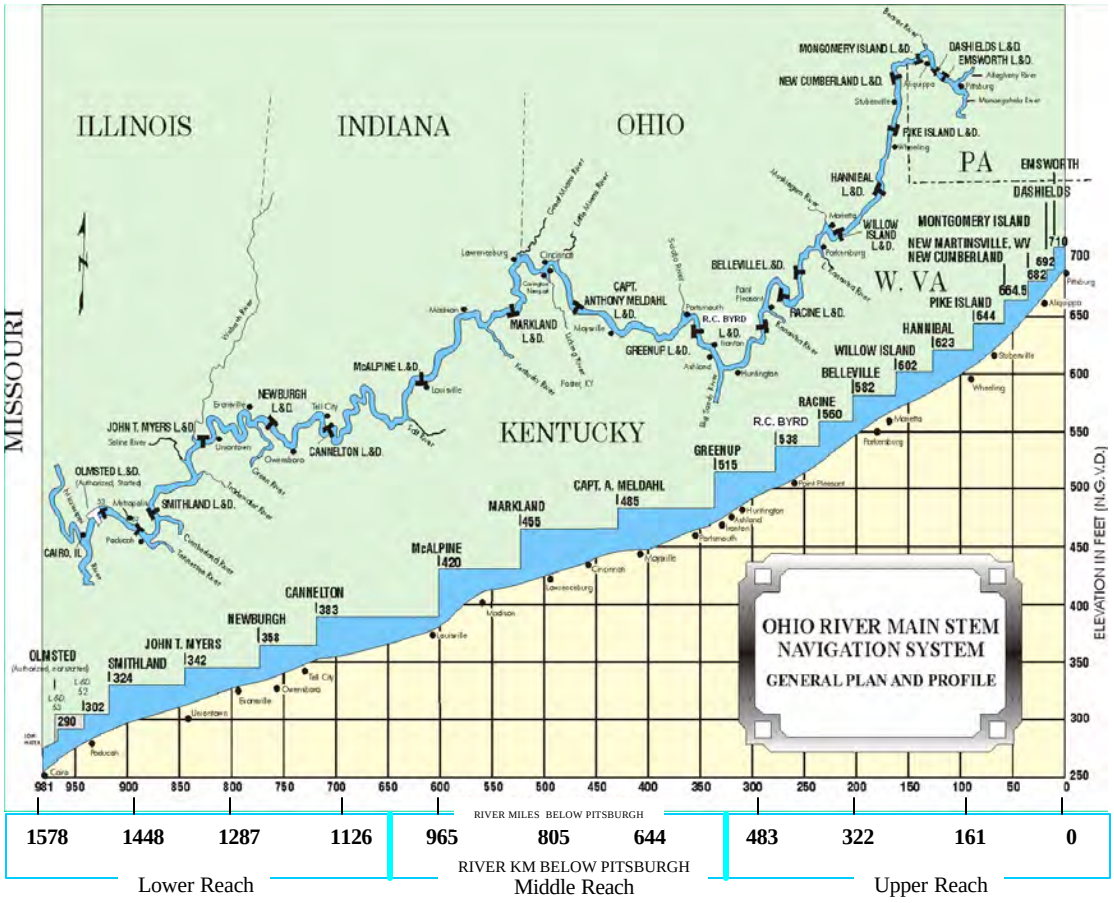


Figure 1. Map showing the locations of the 20 mainstem dams on the Ohio River between its source at the confluence of the Allegheny and Monongahela Rivers to its confluence with the Mississippi River near Cairo, Illinois (Figure modified from the U.S. Army Corp of Engineers' Web site at http://www.lrl.usace.army.mil/ormss/). Reaches are equivalent to those defined in Pearson and Pearson (1989).

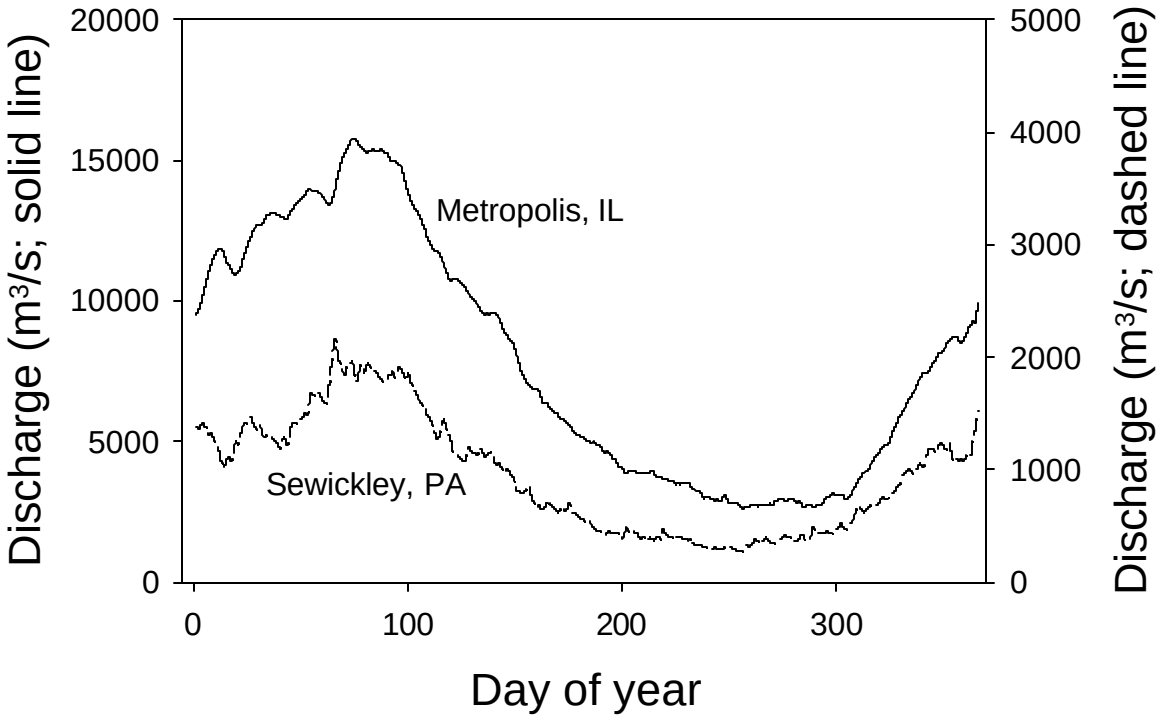


Figure 2. The mean annual discharge at Sewickley, Pennsylvania (*dashed line*; right y-axis), near the source of the Ohio River and at Metropolis, Illinois (*solid line*; left y-axis), near the mouth of the Ohio River. Derived from raw data from the U.S. Geological Survey's Web site http://water.usgs.gov/).

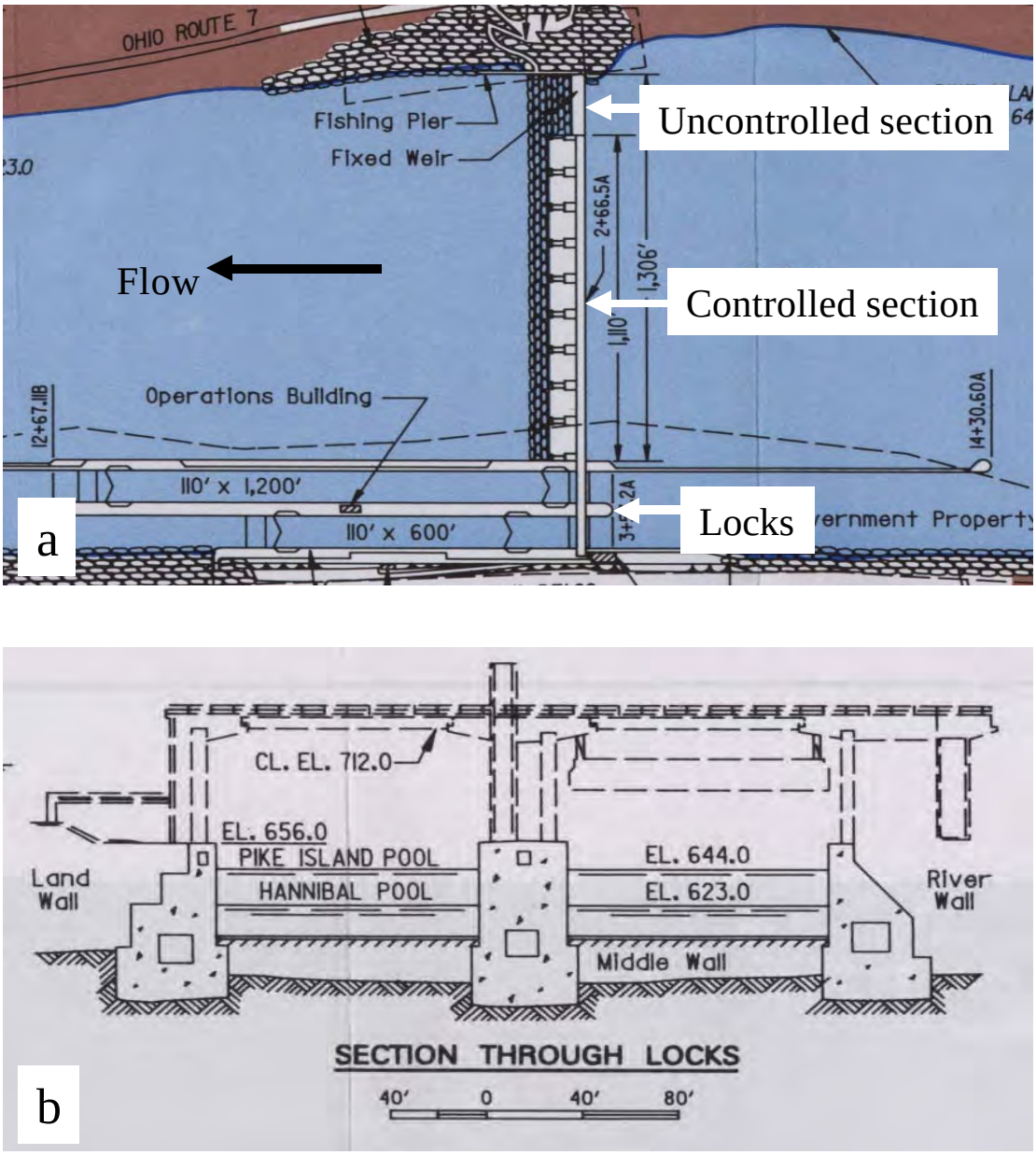
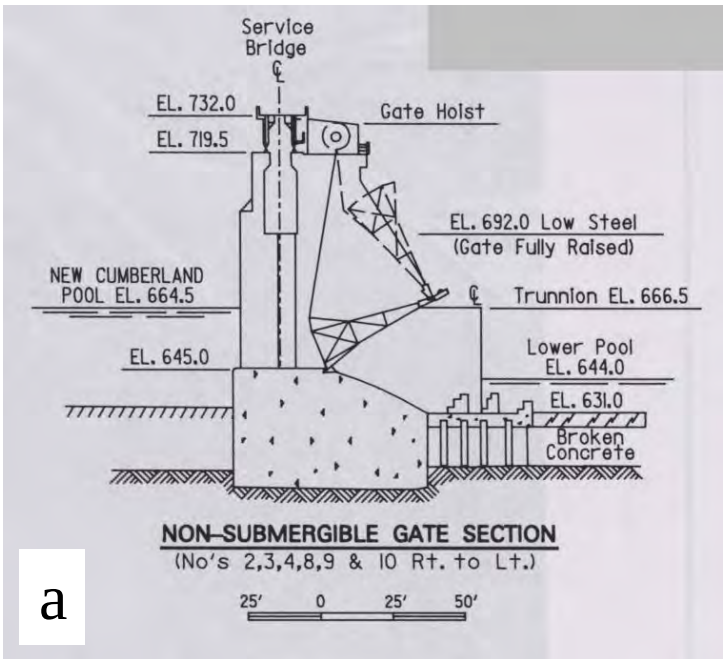


Figure 3. (*a*) Diagram of a typical mainstem dam showing the three primary sections including the uncontrolled section (fixed weir), controlled section (gated portion), and the locks. (*b*) Section view through the locks at Pike Island Dam. Diagrams are from project plans on District Web sites served by the U.S. Army Corps of Engineers.



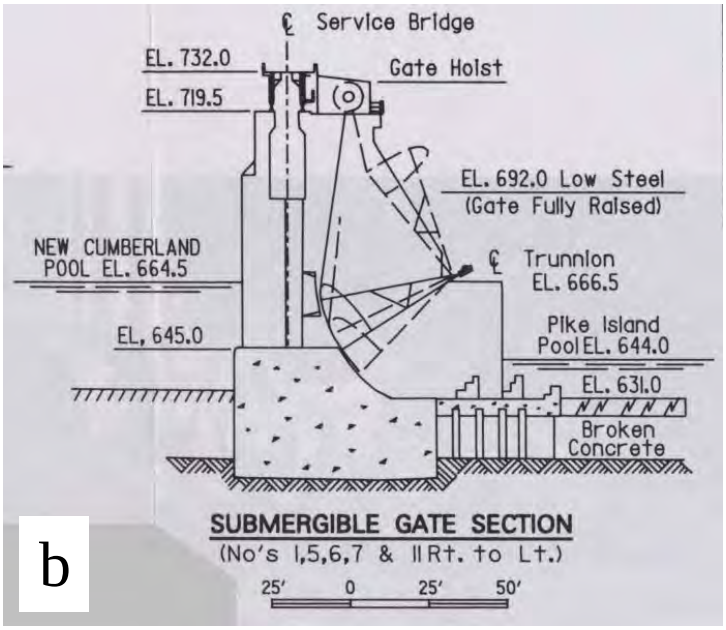
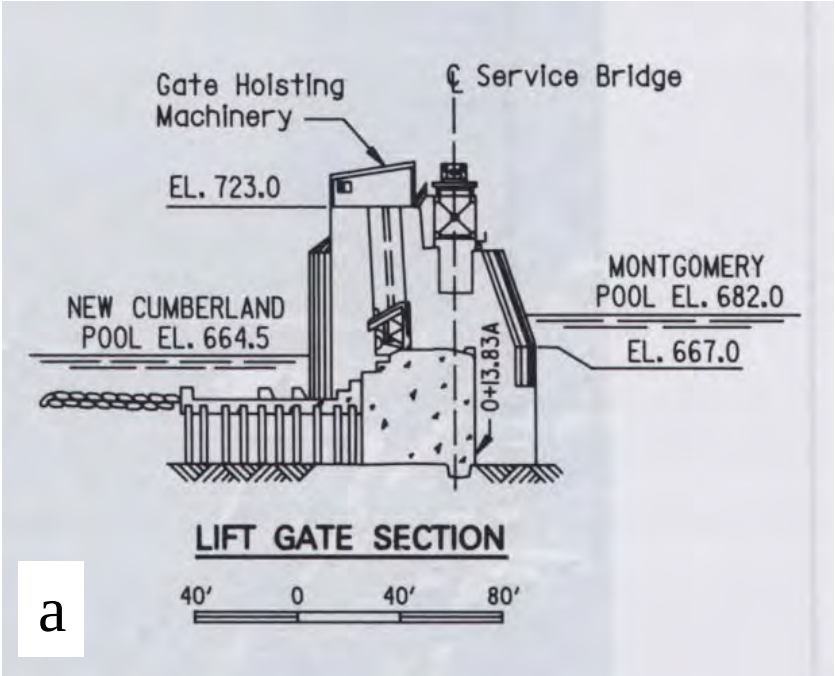


Figure 4. Diagrams of typical (*a*) non-submergible and (*b*) submergible tainter gates found on the controlled sections of mainstem dams on the Ohio River. Diagrams are from project plans on District Web sites served by the U.S. Army Corps of Engineers.



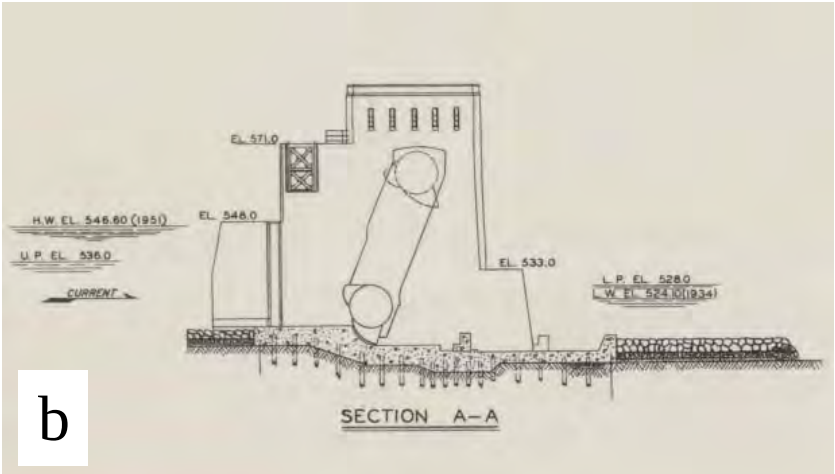


Figure 5. Diagrams of typical (*a*) Sydney-type lift gate and (*b*) roller gate found on the controlled sections of mainstem dams on the Ohio River. Diagrams are from project plans on District Web sites served by the U.S. Army Corps of Engineers.

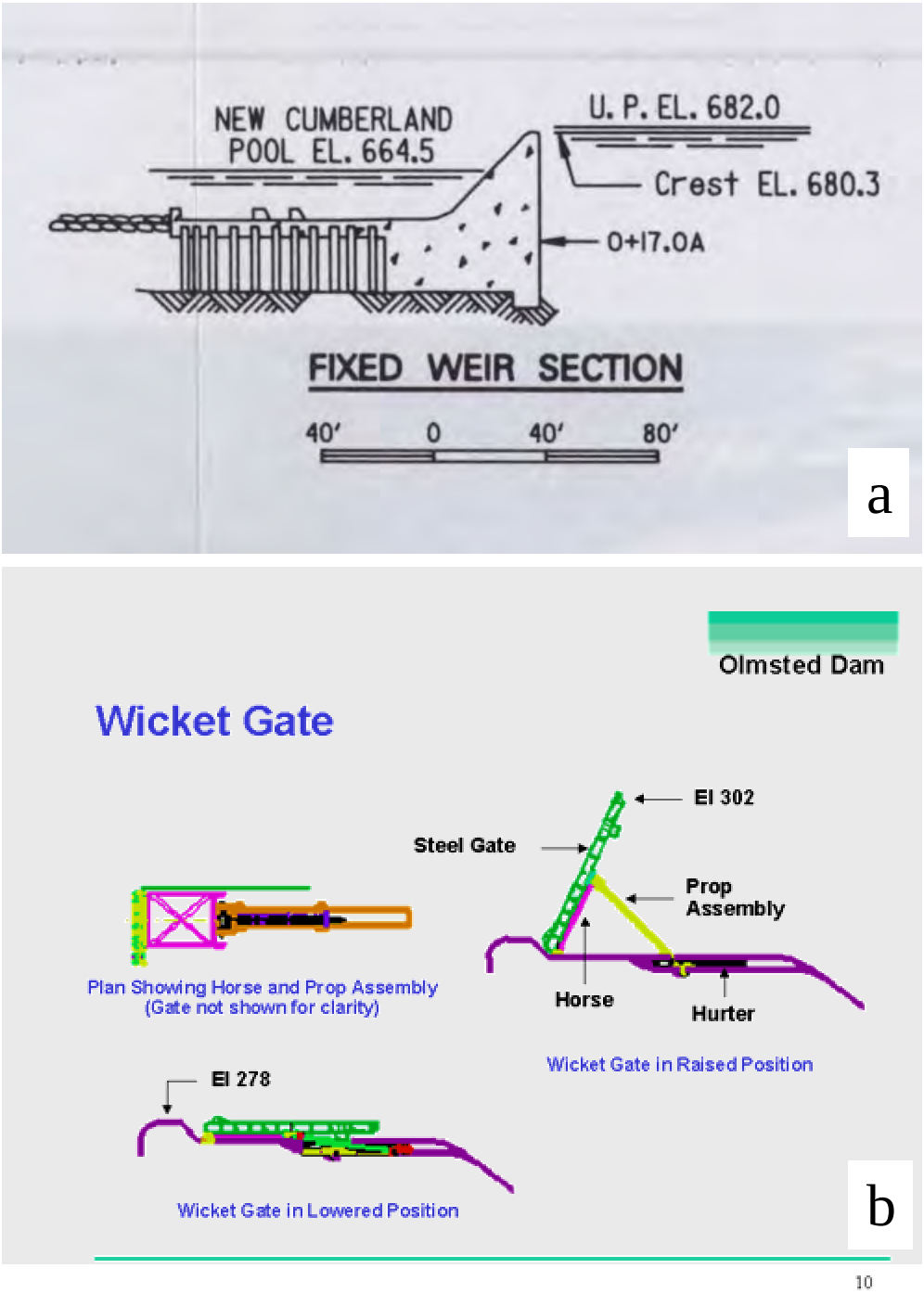


Figure 6. (*a*) Diagram of a typical fixed-weir found on the uncontrolled sections of mainstem dams on the Ohio River. (*b*) Illustration of a movable section of a wicket-type dam similar to those found at Dams 52 and 53 on the Ohio River. Diagrams are from project plans on District Web sites served by the U.S. Army Corps of Engineers.

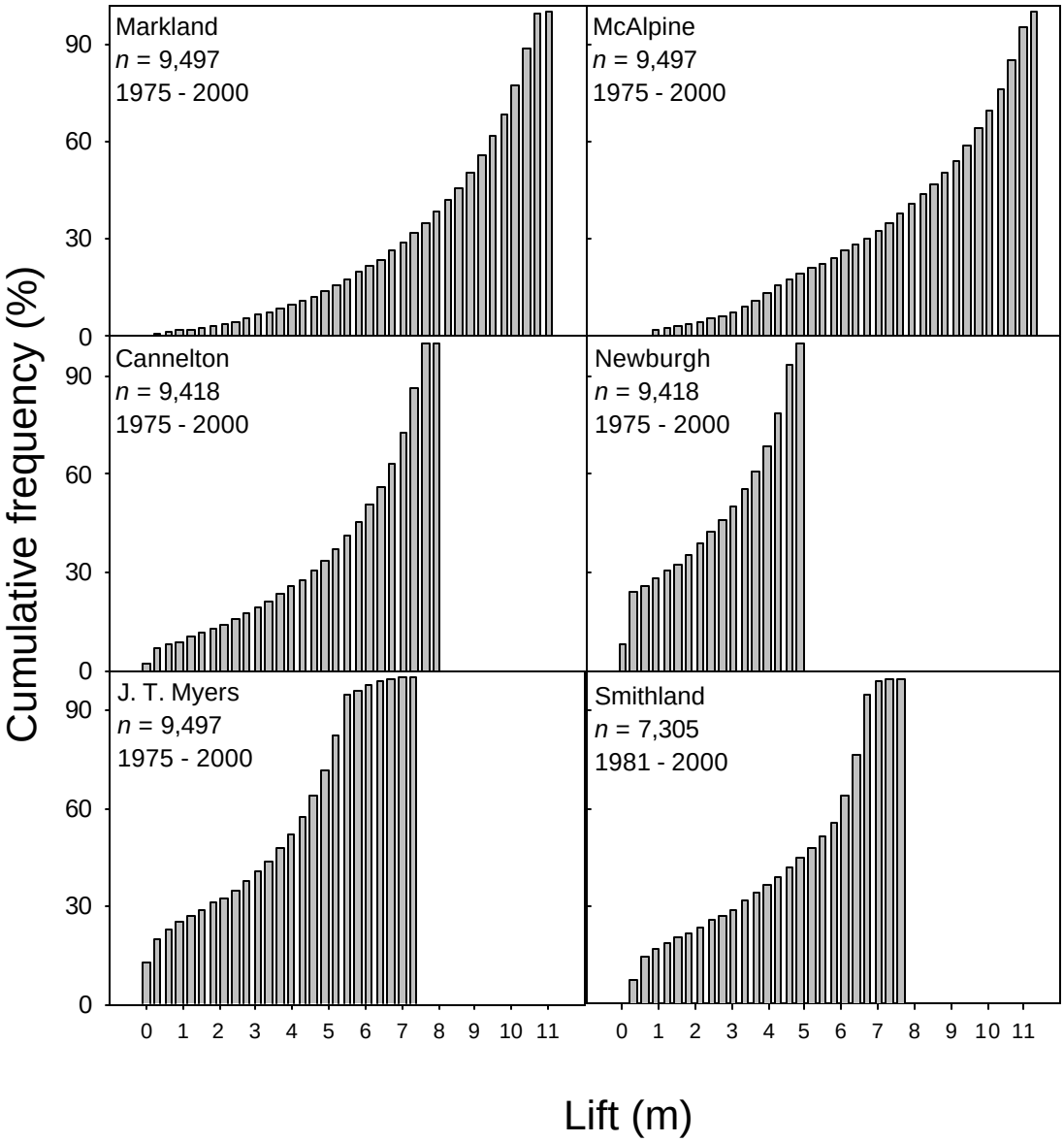


Figure 7a. Cumulative frequency of lift (headwater elevation minus tailwater elevation) at Ohio River mainstem dams in the Louisville District. *n* = number of daily observations.

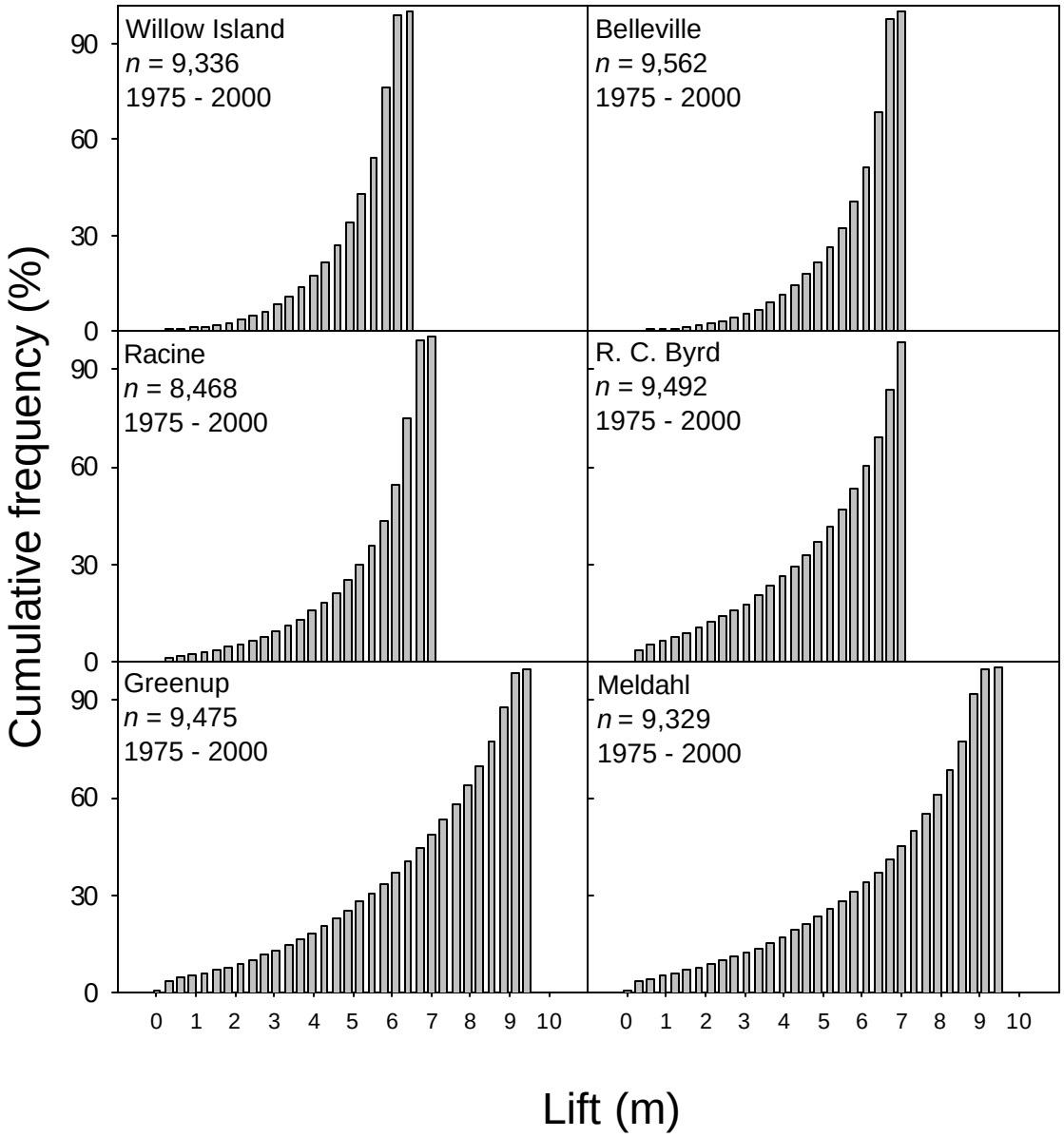


Figure 7b. Cumulative frequency of lift (headwater elevation minus tailwater elevation) at Ohio River mainstem dams in the Huntington District. *n* = number of daily observations.

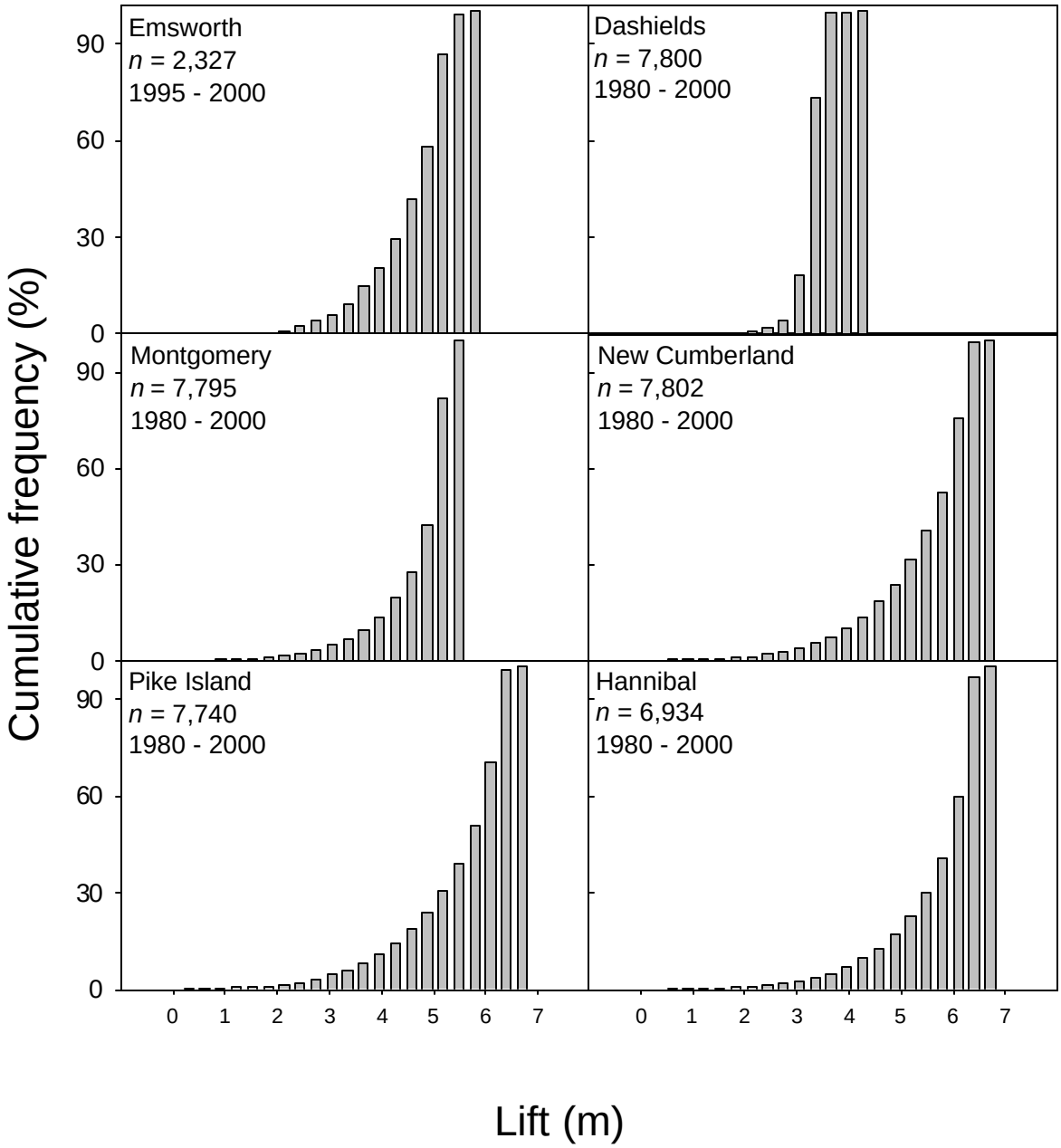


Figure 7c. Cumulative frequency of lift (headwater elevation minus tailwater elevation) at Ohio River mainstem dams in the Pittsburgh District. n = number of daily observations.

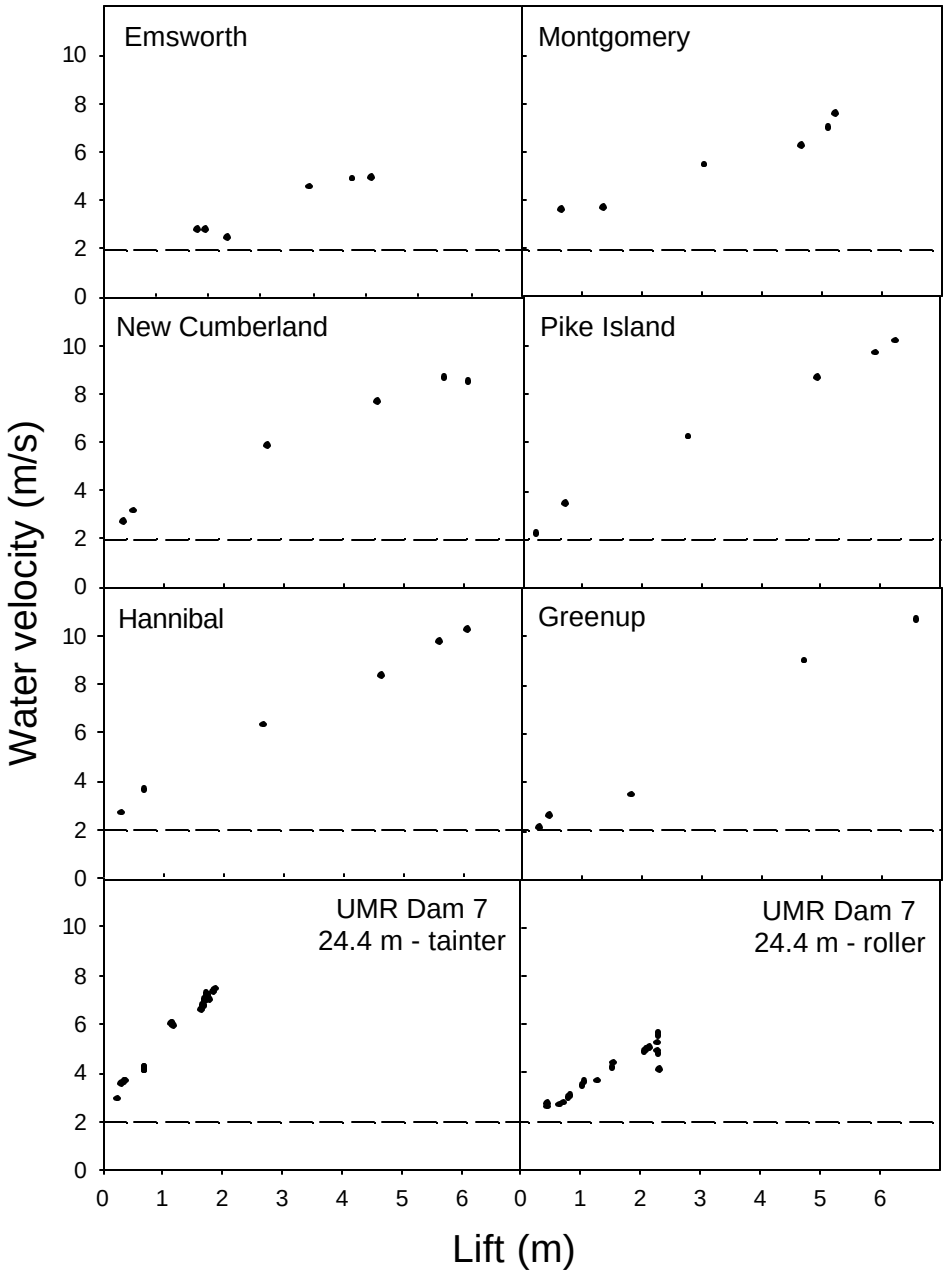


Figure 8. Estimated water velocities through the gate openings of mainstem dams on the Ohio River and at Lock and Dam 7 on the Upper Mississippi River (UMR) at various lifts. Dashed line is 2.0 m/s.

Appendix A: List of the common and scientific names of five surrogate species used to estimate swimming speeds of target species (Table 8).

Common name	Scientific name
European eel	*Anguilla anguilla*
American shad	*Alosa sapidissima*
Longnose sucker	*Catostomus catostomus*
Sacramento sucker	*C. occidentalis*
Rainbow trout	*Oncorhynchus mykiss*

Appendix B: Occurrence and distribution information and estimated spawning migration period *shaded* over the frequency of open river by navigation pool (Table 9) for the 44 target species from the Ohio River. See Table 1 for scientific names. D53 is Dam 53, D52 is Dam 52, Smi is Smithland Dam, Mye is J. T. Myers Dam, Neb is Newburgh Dam, Can is Cannelton Dam, Mca is McAlpine Dam, Mar is Markland Dam, Mel is Meldahl Dam, Gre is Greenup Dam, Byr is R. C. Byrd Dam, Rac is Racine Dam, Bel is Belleville Dam, Wil is Willow Island Dam, Han is Hannibal Dam, Pik is Pike Island Dam, Nec is New Cumberland Dam, Mon is Montgomery Dam, Das is Dashields Dam, and Ems is Emsworth Dam.

Lines 2 and 3 of each table. Distribution information is from Pearson and Pearson (1989). The two periods are original (1800 to 1969; O) and recent (since 1970; R). The three river reaches are upper (ORKm 0 to 526), middle (ORKm 527 to 1,052), and lower (ORKm 1,053 to 1,578). Reaches are separated by a vertical line. Shaded blocks with a "P" indicate that the species was present in that reach during that period. Unshaded blocks with an "A" indicate that the species was absent in that reach during that period.

Line 4 of each table. Recent occurrence information by navigation pool is based on our analysis of lock rotenone (ORSANCO 2001) and night electrofishing samples (OEPA 2002) between 1989 and 2001. "A" (absent) indicates that the species was absent in all samples; "U" (uncommon) indicates that the species occurred in less than 15% of samples; "O" (occasional) indicates that the species occurred in 15 to 50% of samples; "C" (common) indicates that the species occurred in greater than 50% of the samples; and --- indicates no information was available.

Lines 6 to 57 of each table. The percent of past years (i.e., 20 to 26 years) that a particular calendar week was at open river for each mainstem dam (Table 9). For a calendar week to be considered an open-river week in the frequency analysis that dam had to be open at least one day during that week. Migration period (*shaded*) for each species is estimated as the range of spawning temperatures reported in the literature (*dark shading*; Table 12) and 4 weeks before the lowest reported spawning temperature (*light shading*). Estimated water temperature by calendar week and navigation pool is shown in Table 11.

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	A						A			A										
Occurrence (89-01)	---	---	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Lake sturgeon

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P				P									
Distribution (R)	P						P				A									
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Shovelnose sturgeon

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	O	O	O	O	O	O	O	A	O	A	A	A	U	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Paddlefish

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P				P									
Distribution (R)	P						P				P									
Occurrence (89-01)	----	----	A	O	C	O	C	C	C	C	O	C	C	C	O	C	O	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Longnose gar

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P				P									
Distribution (R)	P						P				P									
Occurrence (89-01)	---	---	O	O	A	O	A	A	U	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Shortnose gar

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	O	O	O	C	O	O	U	A	A	A	A	A	U	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Goldeye

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	A	C	O	C	C	C	O	C	O	O	O	O	O	O	C	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Mooneye

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P				P									
Distribution (R)	P						P				P									
Occurrence (89-01)	----	----	C	A	O	O	A	O	U	U	A	U	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

American eel

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						P			A										
Distribution (R)	A						A			A										
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Alabama shad

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			P					P							P					
Distribution (R)			P					P							P					
Occurrence (89-01)	---	---	C	C	C	C	C	C	C	C	C	C	C	O	O	C	O	C	C	O
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Skipjack herring

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						A			A										
Distribution (R)	A						P			P										
Occurrence (89-01)	---	---	A	A	A	A	A	A	A	A	U	A	A	U	A	O	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Alewife

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	---	---	A	A	A	A	A	U	A	O	U	O	O	U	A	U	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Goldfish

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						A				A									
Distribution (R)	P						P				A									
Occurrence (89-01)	---	---	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Grass carp

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	C	C	O	C	C	C	C	C	C	C	C	C	C	C	C	C
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Common carp

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						A			A										
Distribution (R)	P						P			A										
Occurrence (89-01)	---	---	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Silver carp

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						A			A										
Distribution (R)	A						A			A										
Occurrence (89-01)	----	----	A	O	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Bighead carp

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			P					P							P					
Distribution (R)			P					P							P					
Occurrence (89-01)	----	----	O	C	C	C	C	C	C	C	C	C	C	C	O	C	O	O	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

River carpsucker

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	O	C	C	C	O	C	C	C	C	C	C	C	O	C	C	C	C	O
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Quillback

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	O	O	O	O	O	C	O	A	U	U	A	A	A	U	O	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Highfin carpsucker

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	A	U	A	A	A	U	U	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

White sucker

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	A	O	O	A	U	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Blue sucker

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	A	O
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Smallmouth buffalo

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	C	O	O	U	O	A	A	U	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Bigmouth buffalo

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	C	A	O	A	O	O	O	C	O	O	O	A	O	U	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Black buffalo

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	A	A	A	A	O	U	C	U	O	C	C	O	O	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Spotted sucker

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P				P									
Distribution (R)	P						P				P									
Occurrence (89-01)	----	----	A	A	A	A	A	C	C	O	O	C	C	O	A	O	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Silver redhorse

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			P					P							P					
Distribution (R)			P					P							P					
Occurrence (89-01)	----	----	A	A	A	A	O	O	O	O	O	U	C	A	U	O	O	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

River redhorse

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						P			P										
Distribution (R)	A						P			P										
Occurrence (89-01)	----	----	A	A	A	A	A	U	A	U	O	A	C	C	C	C	C	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Black redhorse

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Modern	----	----	A	A	A	A	O	C	C	C	C	O	C	C	C	C	C	O	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Golden redhorse

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P					P								
Distribution (R)	P						P					P								
Modern	----	----	A	O	O	O	A	C	C	C	C	C	C	O	O	C	C	C	A	C
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Shorthead redhorse

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						A			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	A	A	O	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

White catfish

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	O	C	A	U	U	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Blue catfish

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Channel catfish

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						P			A										
Distribution (R)	A						P			P										
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Northern pike

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						P			P										
Distribution (R)	A						P			P										
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Muskellunge

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						A			A										
Distribution (R)	A						A			A										
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	O	O	A	A	A	U	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

White perch

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P				P									
Distribution (R)	P						P				P									
Occurrence (89-01)	----	----	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	O
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

White bass

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						A			A										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	O	A	A	A	A	U	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Yellow bass

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						A			A										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	O	C	C	C	O	C	C	O	U	O	O	O	U	A	O	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Striped bass

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P				P									
Distribution (R)	P						P				P									
Occurrence (89-01)	----	----	A	O	A	A	O	C	C	C	C	O	C	C	C	C	C	O	C	O
Yrs of data→ ↓Week of year	20	20	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Smallmouth bass

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	O	O	C	C	C	C	C	C	C	C	C	C	O	C	O	O	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Largemouth bass

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			P					P							P					
Distribution (R)			P					P							P					
Occurrence (89-01)	----	----	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Sauger

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	O	O	C	C	A	O	O	C	C	C	O	O	C	C	C	C	C	O
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Walleye

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Freshwater drum

Winter Habitat Used by Fishes in Smithland Pool and Belleville Pool, Ohio River

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Final Combined Project Report

Prepared December 2003

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Executive Summary

Introduction

For many fishes that inhabit large rivers, winter poses a challenge to both age-0 and older life stages. Swimming ability is compromised at low temperatures in many species. Further, energetic condition often declines as food availability declines during winter. Hence, fishes occupying rivers may congregate in warm, low velocity shelters with abundant food to avoid poor growth and survival. If these sites are in proximity to vessel traffic in navigable systems such as the Ohio River, displacement may compromise fish success.

Approach

We conducted a literature review to assess the potential habitat use of several Ohio River fishes during winter. Using predictions generated by this review, we identified general sites in the Smithland Pool (Southern Illinois University Carbondale: SIUC) and Belleville Pool (West Virginia University: WVU) of the Ohio River that may provide winter habitat: artificial, island backwater, tributary, and main channel (about 30 sites per river pool, stratified equally across habitat types). Artificial sites were defined as scours associated with structures in the main channel (e.g., wing dams). Island backwaters were areas between channel borders and islands. Tributaries were sampled near the confluence with the Ohio River. Main channel sites were directly adjacent to or in the main channel. Catch per hour of fish was quantified using variable-depth alternating current (AC) electrofishing (identical units at both institutions) at depths ranging 3-14 m during the winters of 2002 and 2003. This gear was chosen because of its ease of standardization and ability to sample in a variety of river macrohabitats. Further,

fish were expected to aggregate in deep water areas with low flow velocities during cold temperatures. This gear effectively sampled fish in areas difficult to sample with other active gear types. Water quality characteristics that were quantified included dissolved oxygen concentration, secchi depth, temperature, and flow rate. In addition to the coordinated joint effort, each research group collected additional data in other habitats (e.g., island tips, embayments) and with other gears (e.g., gill nets).

Literature Review

The literature revealed that most species require low velocity refuges when temperatures < 4°C. Swimming ability is compromised at these low temperatures. However, overwintering in low velocity backwater habitats that may become hypoxic may also negatively affect winter survival. Species will likely differ in their ability to persist in areas in proximity to the main channel. Channel catfish, a common species in the Ohio River, should be able to tolerate relatively high flows at low temperatures. Conversely, survival of species such as largemouth bass should be compromised if they cannot successfully seek low velocity refuges away from the main channel. Use of habitat by fishes during winter should be affected by trade-offs between swimming ability in the main channel and surviving potentially low oxygen conditions in backwaters.

Site Description

Smithland (river miles: 162-204) and Belleville (river miles: 843-913) Pools of the Ohio River differ in size, elevation, and abiotic characteristics. Each pool is created by lock and dams that maintain a 2.7-m deep (9 foot) navigation channel at low

discharge. Smithland Pool, currently the southernmost impoundment of the Ohio River, is 115 km long with an area of 11,134 ha during normal pool. Belleville Pool, to the north of Smithland Pool and at a higher elevation, is 70-km long with a smaller surface area of 2,850 ha. Island and artificial habitats were much more limited in Belleville than in Smithland Pool. Smithland Pool did not contain the extensive embayment area that was present in Belleville Pool. Depths of sites sampled were somewhat shallower, on average, in Belleville Pool. Artificial sites in Smithland ranged 8-11 m (mean = 9 m). Only one artificial site was sampled by WVU in Belleville Pool. Island backwaters sites ranged 5-8 m (mean=6 m) in Smithland Pool and 2-6 m (mean=5 m) in Belleville Pool. Main channel sites were 6-9 m (mean= 8 m) and 3-9 m (mean=6 m) in Smithland and Belleville Pools, respectively. Tributary habitats ranged 3-8 m (mean = 5 m) in Smithland Pool and 2-9 m (mean = 6 m) in Belleville Pool. WVU included a separate "deep hole" category for distinct, main channel scour holes that ranged 7-14 m (mean = 9 m). These sites were similar in depth and characteristics of many of the main channel sites chosen in Smithland Pool by SIUC.

Winter conditions

Winter conditions differed between Smithland and Belleville Pools during winters 2002 and 2003. Discharge was quite high and variable during both sampling years in Smithland Pool, with river stage frequently increasing by 8-10 m within a few days (see Figure 2-2, Chapter 2). Consequently sampling was often compromised, and we were relegated to sampling during periods of relatively low flow in the pool. In Belleville Pool, discharge was less variable and relatively lower, with stage only increasing by a maximum of 2.5 m relative to base flow (Figure 3-3, Chapter 3). Flow rates quantified in

Belleville Pool during both winters were often higher (reaching or exceeding 1.0 m/s) in main channel sites than in Smithland Pool. This occurred because WVU could sample during periods of moderate discharge, whereas these moderate flow conditions never occurred in Smithland Pool. In both pools, depth-stratified profiles revealed that water chemistry (e.g., dissolved oxygen concentration, conductivity) and temperature did not vary appreciably with depth. During warmer months, dissolved oxygen concentrations in tributaries of Smithland Pool but not Belleville Pool declined below levels (< 4-5mg/L) preferred by fish and other organisms. Unlike Belleville Pool, dissolved oxygen concentrations in Smithland Pool tributaries were typically lower than at other sites associated with the main channel during all sampling sessions. Specific conductance, a factor that affects electrofishing efficiency, differed between pools, with conductivity often being higher in main channel sites of Smithland Pool.

Habitat-specific Conditions

We used multivariate analyses to assess macrohabitat-specific abiotic characteristics during winter including flow, dissolved oxygen, conductivity, and temperature. In Smithland Pool, habitats did separate out with respect to physical conditions, but often not in direct correspondence with our predetermined habitat delineations. Tributaries clustered with respect to low dissolved oxygen concentration, high water clarity (as estimated with secchi readings), and low flow. In Belleville Pool, sites typically did not show specific clustering with respect to the abiotic variables quantified, although tributaries did have consistently lower flow rates. During some winter periods, tributaries were colder than main channel sites in Belleville Pool.

Fish Habitat Use

Species richness (i.e., number of species sampled) differed between Smithland and Belleville Pools during the two sampling winters. In Smithland Pool, a total of 19 species was sampled each year. Species richness was much higher in Belleville Pool, with AC electrofishing generating a total of 28 species. During both years in Smithland Pool, freshwater drum and blue catfish dominated samples, often comprising > 90% of fishes. In Belleville Pool, freshwater drum were often abundant, but channel catfish was the dominant catfish species. These species typically comprised 80% of fishes sampled, with other species such as gizzard shad being important as well.

Winter habitat use by fishes differed between the pools. During both winters in Smithland Pool, catch per unit effort (CPUE; number of fish per hour) was higher in sites adjacent to the main channel (i.e., main channel and artificial) than in tributaries (Table 1). CPUE varied considerably among sites in Belleville Pool, with maximum average catch rates exceeding those in Smithland Pool (Table 1). Catch rates of fish were higher in tributaries in Belleville than in Smithland Pool, with catch rates of fish in Belleville Pool being higher in sites associated with the main channel in 2003 (Table 1).

Species richness in macrohabitats of Smithland Pool varied with abiotic factors during both winters. Both tributary and island backwater sites had high species richness at cold temperatures. Further, species richness in tributaries increased with a slight rise in flow rates. When dissolved oxygen concentrations declined below 5 mg/L in Smithland tributaries (which occurred at warm, late-spring temperatures), fish species richness declined. Small, young freshwater drum were associated with tributary sites during winter in Smithland Pool, suggesting that these areas may provide some refuge for early life stages. In Belleville Pool, high catch rates and richness in tributaries during winter

were likely due to the low flow rates in these macrohabitats. However, when temperatures in these areas declined below 4°C, fish were more abundant in main channel areas, suggesting that fish leave cold water areas to inhabit relatively warmer but higher flow areas in the river. In Belleville Pool, shallow areas with large woody debris were also sampled with DC surface electrofishing, revealing the presence of other fish species not sampled with the variable depth AC gear.

Variable-depth electrofishing was compared with other gear types such as sonar and gill nets. Gill netting conducted by WVU in Belleville Pool revealed low catch rates with species composition similar to that generated by electrofishing. Low catch rates with active gill netting are not unexpected given the cold temperatures and low activity of fishes. Both groups conducted some comparisons between sonar and variable depth electrofishing and found no strong relationships between abundance as estimated by the two gears. A study conducted during winter 2002 in Pool 25, upper Mississippi River by SIUC in collaboration with the Missouri Department of Conservation and the US Army Corps of Engineers, St. Louis District, compared variable depth AC electrofishing with purse seining and trawling behind chevron dikes. AC electrofishing generated similar sizes and species as the other gears, further confirming that this technique provides a relatively clear picture of fish assemblages at depths > 3 m.

Conclusions and Implications

During both winters and in both pools of the Ohio River, fish assemblages and abundance differed among the macrohabitats we identified at the outset. In Smithland Pool, habitats adjacent to the main channel appeared to be important for fish during the winter. Particularly, island backwaters and submerged boulders at the channel border

were areas that contained large aggregations of fish during cold, winter conditions. Deep scours created by artificial structures (e.g., submerged wing dikes) also provided refuge for fish at cold temperatures. Tributary macrohabitats in Smithland Pool only appeared to provide important winter habitat when temperatures were low and when these areas were connected to the main channel. Tributaries in Smithland Pool are often disconnected from the main channel by a shelf of sediment and debris that may inhibit the passage of fish from the main channel. In Belleville Pool, tributaries and an embayment area appeared to play a critical role for wintering fishes. However, these macrohabitats may cool more than the main channel during some winter periods (e.g., as might be expected during a period of snow melt), necessitating the movement of fish into warmer main channel areas. Surface electrofishing of shallow areas adjacent to the main channel revealed that different fish assemblages may be using these areas during winter.

When fish use main channel habitats during winter, they may be subjected to changes in flow as barges move into their proximity. Fish with impaired swimming ability at cold temperatures (e.g., freshwater drum; see Table 1-1, Chapter 1) may be displaced by changes in flow direction and velocity. Preliminary data quantified with an acoustic doppler profiler behind wing dikes of the middle Mississippi River support this supposition. This instrument quantifies both flow velocity and direction at 0.5-m intervals from the surface to the bottom. In our study, we profiled flow at fixed points behind wing dams before, during, and after barges passed (Spier, Braeutigam, and Garvey unpublished data). Although our results are admittedly tentative, we found that flow was relatively low with coherent directionality as barges approached (Figure 1). After barge passage, displacement of water caused flow velocity to increase and an incoherent (i.e., multidirectional) flow pattern to occur (Figure 1). Flow rates continued

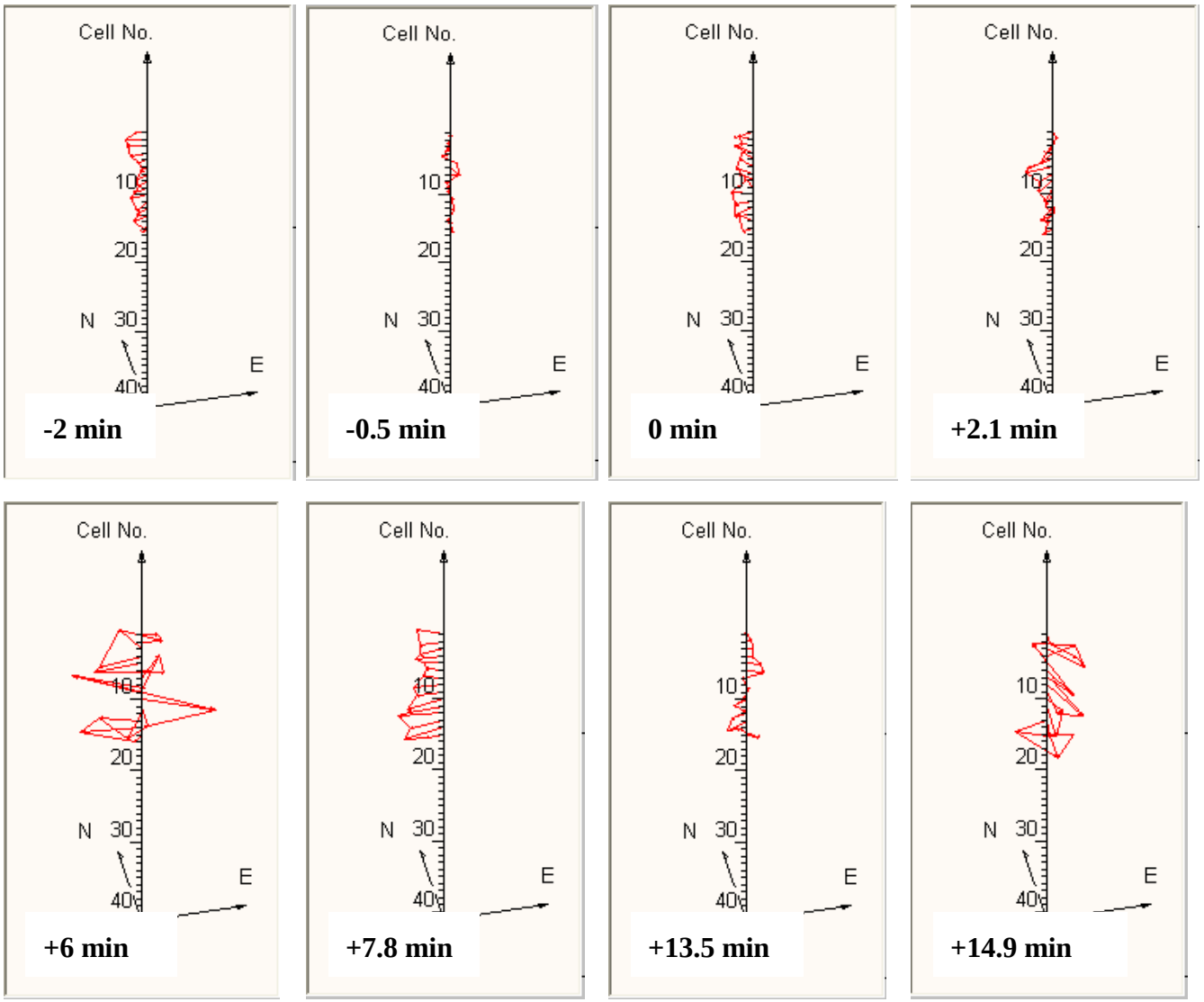
to be affected by barges 15 minutes following passage of the bow (Figure 1). Thus, fish seeking typically low velocity deep water habitats behind river structures may be displaced if low temperatures reduce swimming ability. Again, we will continue to view these results with caution until more data are collected, but the pattern is compelling and is congruent with other studies.

This unique opportunity to conduct parallel research projects in two impounded Ohio River reaches during the same winters has provided insight into the potential effects of anticipated increased navigation on fish assemblages. Tributary habitats are clearly important to wintering fish, and reduced connectivity in Smithland Pool likely compromises the success of many species. Improved connectivity, perhaps through dredging at confluences, may improve winter success of fishes in this pool. Higher species richness and greater tributary use by fishes in Belleville Pool suggest that connectivity may not be problematic in this impounded reach. Many fishes such as commercially important channel and blue catfish use sites adjacent to the main channel in Smithland Pool. Similarly, channel catfish use the main channel in Belleville Pool. Artificial sites such as wing dikes in Smithland Pool create scours that are used by river fishes, although some concern about displacement by barges does persist, requiring further exploration. Island backwater areas appear to be particularly important for fishes during winter. These areas provide flow breaks and are relatively sheltered from barge activity. River habitat management that enhances/maintains accessibility to these areas should be beneficial to wintering fish in the Ohio River.

Table 1. Mean number of fish per hour (CPUE) sampled with variable-depth electrofishing during winters 2002 and 2003 at common macrohabitats sampled in both Smithland Pool and Belleville Pool, Ohio River. * depicts site not sampled. In 2003, only one artificial (wing dam) site was sampled in Belleville Pool.

		Mean number of fish per hour			
Pool	Year	Artificial	Island Backwater	Main Channel	Tributaries
Smithland	2002	85	21	113	41
	2003	41	51	62	7
Belleville	2002	*	5	4	115
	2003	203	10	27	70

Figure 1. Flow velocity and vector profile behind a wing dam in the Mississippi River during December 2003. Each cell is 0.5-m in depth. The site was about 7.5-m deep. Times on the graph depict when the bow of a barge was approaching (negative), at (zero), and past (positive) the wing dam site. Direction of vectors represents the direction of flow (the thalweg was west of the profiler). Magnitude of flow is estimated by the length of the vectors.



General Introduction

Winter is a critical period in which high mortality occurs in fishes (Oliver et al. 1979; Cunjak 1996; Garvey et al. 1998). Many temperate fishes undergo a torpor-like state when exposed to prolonged cold temperatures and short days (Crawshaw 1984) and, as such, may be highly susceptible to vessel-passage induced displacement from velocity shelters. Because the Ohio River extends through mid-temperate latitudes, inter-annual variability in winter temperature may translate to highly variable responses of fish populations to acute abiotic perturbations (see Garvey et al. 1998) such as changes in flow velocity and flow direction with navigation. Laboratory (Sheehan et al. 1990; 2000a) and field studies (Sheehan et al. 1990b; Logsdon 1993; Johnson et al. 1998) showed that a number of Mississippi River fishes overwinter in stratified backwater areas, when they have access to them, or in low velocity areas in channels. Relatively small (0.08 to 0.16 $m \cdot s^{-1}$) velocity changes, such as those that can be induced by vessels, can displace small bluegill and channel catfish from low velocity habitats when water temperatures are low (1 to 4 ^{o}C) (Sheehan et al. 2000b). If fish are displaced into flowing channels at such temperatures, mortality will probably increase (Bodensteiner and Lewis 1994; Sheehan et al. 2000a).

Fish are an important economic and ecological component of the Ohio River ecosystem. Understanding how abiotic characteristics (e.g., latitude, channel morphometry, depth) regulate winter habitat use of critical fish species is the primary objective of this research. Habitat characteristics affecting winter survival of fish may well vary locally among adjacent pools as well as geographically between the upper and lower reaches of the Ohio River. We have completed an intensive literature review

(Chapter 1), quantifying winter habitat associations in fishes commonly found in the Ohio River. We also have completed a 2-year, winter survey of a lower (Smithland; SIUC, Chapter 2) and upper (Belleville; WVU, Chapter 3) pool of the Ohio River.

The literature review and field reconnaissance generated *a priori* expectations about habitat use of fish during winter (see Chapter 1). In Chapters 2 and 3, we present results from an intensive winter field effort conducted during winters 2002 and 2003 to fill in the gaps about winter habitat associations of common Ohio River fishes and their potential responses to winter navigation.

Chapter 1 – Literature Review

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Winter often is a critical period influencing the condition and survival of fishes in marine (Sogard 1997; Schultz and Conover 1997; Schultz et al. 1998; Hurst et al. 2000) and freshwater (Hubbs and Carlander 1935; Aggus and Elliott 1975; Gutreuter and Anderson 1985; Cunjak 1988; Garvey et al. 1998) temperate-zone systems. Winter mortality is typically highest for young-of-year (YOY) fish, with survival probability increasing with increasing body size (e.g., Toneys and Coble 1979; Ludsin and DeVries 1997; Garvey et al. 1998; Foy and Paul 1999). Thus, the extent of first-year growth, fall body size, and winter severity may regulate year-class strength in some species and systems. For age-0 fish as well as older life stages, rivers can be particularly challenging environments in which to reside during winter because a host of abiotic characteristics limit survival and growth (Sheehan et al. 1990; Bodensteiner and Lewis 1992; Cunjak 1996; Jakober et al. 1998). As such, fish must choose the most benign habitat available during winter to increase their probability of surviving. In the mainstem Ohio River, the quantity and availability of winter refuge may well determine the relative survival and abundance of resident fish populations. The ability of these habitats to provide refuge from vessel-induced displacement is essential, given the anticipated increases in barge traffic in the Ohio River. To determine what habitat-specific factors influence winter growth and survival of fish in the mainstem Ohio River, we reviewed > 300 articles pertaining to the winter physiology and ecology of fish, focusing on fishes commonly occurring throughout this system. Articles were obtained using standard abstracting services such as Biological Abstracts, Science Citation Index, and Aquatic Sciences and

Fisheries Abstracts, Dissertation Abstracts, and the U.S. Fish and Wildlife Reference System. Major reviews such as Carlander's Handbook of Freshwater Fishery Biology, Volumes 1-3 provided a source for early research articles (Carlander 1968, 1977, 1996).

Mechanisms influencing the Overwinter Condition and Survival of Riverine Fish

Overview

Several mechanisms may work either exclusively or in concert to affect the growth and survival of cool- and warm-water riverine fishes during winter. Failure to tolerate cold temperatures, flowing water, low food availability, or low dissolved oxygen concentrations can negatively affect fish throughout the Ohio River. The relative importance of these factors may vary as a function of reach-specific factors including (but not limited to) latitude, winter severity, within-pool location, and river morphometry.

Two major overwintering habitat types - main channel and backwater - can be categorized within the Ohio River, although much variation exists within each (e.g., Sheehan et al 1990; Logsdon 1993). Main channel reaches are oxygen-saturated with temperatures that likely differ among latitudes. Mainstems of northern river reaches (e.g., upper Mississippi River) are typically < 1°C during winter (Sheehan et al. 1990; Johnson et al. 1998). In contrast, main channel water temperatures in southern reaches may be warmer and more variable. For example, temperatures below the Smithland Pool of the lower Ohio River only declined below 2°C for about 1.5 weeks during one of three winters (Shawnee Fossil Fuel Electric Power Utility). Among years, water temperatures varied between 4 and 9°C in early January at this site (also see Chapter 2 for 2002). Hence, fish residing at different latitudes within the main channel may be confronted by fundamentally different temperature-dependent challenges during winter that vary among

years. Flow velocity within the main channel during winter is typically greater than that tolerated by many fish species at cold temperatures (see **Species Requirements**). However, fish may use various structures within the channel such as wing dams that provide relatively deep, low-velocity flow breaks (Heese and Newcomb 1982; Logsdon 1993), although these areas may be susceptible to vessel-induced displacement by barges (Todd et al. 1989). Low-flow sites connected to the main channel (e.g., backwaters) may provide refuge for fish during winter (Greenback 1956; Sheehan et al. 1990; Knights et al. 1995; Raibley et al. 1997). Temperatures stratify in these sites, providing elevated thermal habitat near the bottom (Sheehan et al. 1990; Johnson et al. 1998). However, dissolved oxygen can decline in these areas (Sheehan et al. 1990). In the following sections, we review how temperature, flow, energetic condition, and dissolved oxygen affect Ohio River fishes during winter. We then review winter habitat requirements of several species commonly found in this system.

Cold tolerance

Environmental temperatures dramatically affect physiological processes in fishes (Love 1980). Much research has been devoted to determining upper lethal thermal limits of fish (Hart 1952; Cvancara et al. 1977; Spotila et al. 1979). Lower lethal limits have received much less attention, although the lower thermal tolerances of many species likely exceed temperatures that occur in temperate rivers during winter (see **Species Requirements**). Researchers also have sought to determine the final thermal preferenda of temperate species (Reuter and Herdendorf 1974; Cherry et al. 1975; Kelsch and Neill 1990); preferred temperatures are typically absent during winter (Sheehan et al. 1990). Interestingly, if preferred temperatures become available to temperate species acclimated

to winter temperatures, they may seek them, even if the temperature difference is great (e.g., $\geq 10^{o}$C; Kelsch and Neill 1990). During winter, species may track even slight temperature differences, seeking the warmest temperatures available (see Chapter 2). Residing at cold temperatures is clearly not advantageous for most species in the Ohio River.

Cold temperatures may compromise the growth and survival of fish for several reasons. Typical winter temperatures are well below the maximum metabolic scope (Fry 1947) of Ohio River fishes. As such, consumption and activity rates are limited, greatly reducing growth potential. Rapid declines in temperature can cause cold shock, a condition in which fish lose equilibrium (Cichra et al. 1982) and may become susceptible to predators (Coutant et al 1974). In rivers, fish undergoing cold shock may be displaced into the open channel, with little opportunity to regain position in low velocity habitats (Lewis and Bodensteiner 1994; Sheehan et al. 2000). Although river temperatures may supercool to -0.1 C (Devik 1944), fish will not freeze because their internal salinity depresses their freezing point between -0.5 and -0.65 C (DeVries 1971). Physiological problems associated with declining temperature rather than freezing are apparently responsible for cold shock and associated mortality.

Cold tolerance may depend on body size (Edsall and Colby 1970), leading to the patterns of size-dependent winter survival documented for many fish species. Although all Ohio River fish species are considered pokilothermic, core body temperatures typically exceed those of the environment, with large fish generating as much as 0.5^{o}C more heat than small fish (Stevens and Fry 1970; 1976). When environmental temperatures decline abruptly, internal body temperature of small fish declines to a new, lower stable state much more rapidly (within 10 minutes) than that of large fish (2.5

hours for 4 kg fish; Spigarelli et al. 1974). Although the evidence is somewhat tenuous, the morphology of species may affect temperature tolerance, whereby laterally compressed species such as gizzard shad and white bass are less tolerant to temperature shock than heavy bodied species such as ictalurids and common carp (Reuter and Herdendorf 1976). Hence, small, laterally compressed fish species may be more susceptible and respond more rapidly to the negative physiological effects of extremely low temperatures in the Ohio River.

Because temperature strongly affects growth and survival, distribution of fishes in aquatic ecosystems is often associated with temperatures near or at their thermal preferenda (Crowder et al. 1981). In winter, we predict that the availability of "warm" ($\geq 4^{o}$C) water will be a primary factor affecting habitat choice in the Ohio River, regardless of river reach and latitude. Backwaters in the Upper Mississippi River provide such elevated thermal refuges. Indeed telemetry studies (e.g., Pitlo 1987; Knights et al. 1995; Raibley et al. 1997) and active and passive sampling efforts (Sheehan et al. 1990) during winter have demonstrated robust use of these habitats by riverine fish. Other structures such as cobble may elevate microhabitat temperatures sufficiently to facilitate survival (Smith and Griffith 1994). Warm effluent from thermal power generation may also harbor high densities of fish within localized points in the Ohio River (see Adams et al. 1982), although these areas can cause mortality due to cold shock if thermal effluent subsides. The Ohio River extends across about 3.5^{o} N latitude, with the northern reach of the river receiving water from the northern Allegheny River and the relatively mountainous Monongahela River. Hence, water flowing into the northern Ohio River should be substantially colder than that in the south, which often is $>4^{o}$C. We may surmise that seasonal and regional differences in winter temperature along the river

influence the duration and intensity of thermal refuge use, with relatively shorter stays occurring in the southern reach.

Swimming

A common response of many cold-, cool-, and warm-water fishes is to seek low velocity habitat during winter months. Although cool- or cold-water fishes may swim generally well at cool temperatures, swimming to maintain position can cause them to deplete limited energy reserves during winter (Cunjak 1987). Cederholm et al. (1987) found that increasing the quantity of large woody debris in streams created flow breaks, improving survival of coho salmon during winter. Young salmon seek low-flow, off-channel lentic habitats during winter (Bryant 1988), apparently to avoid the energetic costs of maintaining position. Warm-water fish attempting to maintain position at winter water temperatures and flows within their swimming tolerance also may incur energetic costs that may cause depletion of energy reserves and mortality.

Swimming ability of warm-water fishes can be impaired during winter (Sheehan et al. 1990). Species such as smallmouth and largemouth bass acclimated to winter photoperiods and temperatures do have improved swimming performance (Larimore and Duever 1968; Kolok 1991), but these adaptations are insufficient if flow rates exceed a critical point or temperatures decline below a critical minimum. Sheehan et al. (1990) and Logsdon (1993) determined experimentally that swimming ability of several fish species was compromised at temperatures < 4°C, although the degree of responses differed among species. Swimming ability of YOY walleye, a cool-water species, did not decline with declining temperature (see **Species Requirements**). Conversely, the swimming ability of warm-water YOY channel catfish, largemouth bass, and bluegill

declined with declining temperature. Within the limited range of lengths used, size did not affect swimming ability in any of the species tested at $0^{o}C$ (Sheehan et al. 1990). At higher temperatures, swimming ability increased with increasing size in several of the species (Sheehan et al. 1990). Failure to maintain position due to impaired swimming ability at low temperatures may cause fish to become displaced into the main channel (Bodensteiner and Lewis 1994; Sheehan et al. 2000), with the same potentially lethal consequences as cold shock. Improved swimming ability with increasing size may well mean that variable growth and first-year size affects patterns of survival of warmwater fishes in the Ohio River.

Habitat selection of Ohio River fishes during winter should depend on the relative effect of flow and temperature. If flow is low in the main channel (< 1 cm/s), these fish may not require low-velocity refuges (Johnson et al. 1998). At higher flow velocities, responses likely depend on species-specific tolerances to low temperatures. If temperatures vary along a gradient within the river, we may expect to see different fish responses (e.g., duration of refuge use) depending on river location. Under relatively mild winter temperatures ($\geq 4^{o}C$) that occur during some years in the lower Ohio River, many species may remain active but incur energetic costs of maintaining position, similar to cold-water fish at higher latitudes. These warm-water fish may seek low-flow velocity habitat not to reduce the negative effects of cold, but to reduce energetic costs. Clearly, these mechanisms need to be explored for fish assemblages in mid-latitude rivers such as the Ohio River.

Energy depletion

At temperate latitudes, ecosystem production declines during winter as

temperatures and day length decline. As such, food availability for most fishes declines, requiring that energy reserves be used to offset metabolic costs (Thompson et al. 1991; Miranda and Hubbard 1994a; Ludsin and DeVries 1997; Wright et al. 1999; Fullerton et al. 2000). Within populations of warm-water species, some individuals undergo an inactive, torpor-like state during winter (Sullivan 1984; Crawshaw 1984), minimizing metabolic costs but also eliminating energy intake. Other individuals within species may forage intermittently during winter at "intermediate" temperatures (e.g., 5-6°C for some species; Sullivan 1984; Garvey et al. 1998; see Chapter 2). In an overwinter pool experiment in which YOY largemouth bass were presented with invertebrate prey, some fish fed with variable success (i.e., some grew and others lost weight), whereas others did not feed or foraged rarely during the entire winter (Miccuci et al. in press). On average, non-feeding individuals lost less wet mass than those that foraged unsuccessfully (i.e., lost mass) in this experiment. If these variable responses to food availability during winter are typical within species, they may affect patterns of relative condition and survival in riverine systems at "intermediate" (> 4°C) temperatures.

The negative relationship between length and survival of YOY fishes during winter at temperate latitudes has often been attributed to size-specific differences in energy reserve depletion (Oliver et al. 1979; Miranda and Hubbard 1994a; Ludsin and DeVries 1997). Small fish typically have higher mass-specific metabolic rates and lower energy reserves than large counterparts, increasing their probability of depleting energy stores and dying when food is scarce during winter. This has been shown for a variety of species typically found in the Ohio River (see **Species Requirements**). However, patterns of size-selective mortality can vary among populations within a species (Garvey et al. 1998), suggesting that system-specific factors such as food availability (Fullerton et

al. 2000), temperature (Toneys and Coble 1980; Sheehan et al. 1990), and perhaps size-selective predation (Green 1982; Miranda and Hubbard 1994b; Miranda and Pugh 1997; Garvey et al. 1998) are important.

The cause of mortality at cold temperatures may be due to osmoregulatory dysfunction (Oliver 1977; Toneys and Coble 1980; Bodensteiner and Lewis 1992) and high associated energetic costs (Toneys and Coble 1980). Because of potential size-dependent differences in cold tolerance and energy depletion, small fish may suffer greater mortality than large counterparts as a function of this mechanism. Bodensteiner and Lewis (1992) found that freshwater drum residing in 4°C backwater habitats of the upper Mississippi River had higher plasma osomolalities than those in 0-1°C channel habitats, supporting the hypothesis that cold temperatures challenge water balance in the field. However, size-dependent energy depletion of largemouth bass, green sunfish, yellow perch, and brook trout at winter temperatures did not differ under freshwater and relatively isosmotic conditions (Toneys and Coble 1980). Although cold temperatures incur negative osmoregulatory effects on both small and large fish, they apparently do not affect patterns of energy depletion in these species.

How winter affects growth and survival of fish may also depend on the interactions among winter temperature, duration, body size, and food availability. In northern rivers (perhaps including the northern reach of the Ohio River), winter is long and cold. Conversely, winter duration is considerably shorter in southern systems. Fullerton et al. (2000) simulated northern (45°N) and middle (40°N) latitude winter conditions in experiments to determine how YOY largemouth bass respond to winter temperatures, photoperiods, and food availability. Largemouth bass that were fed fish prey during winter lost and maintained weight in the northern and middle-latitude

winters, respectively. Mass-balance bioenergetics models for largemouth bass predicted much greater loss of weight than occurred in either winter, suggesting that the fish reduced metabolic costs more than experimentally derived metabolic relationships predicted (Wright et al. 1999). Starved largemouth bass lost similar weight between the long, northern, simulated winter and the short, middle-latitude one (Fullerton et al. 2000). Apparently, the energetic costs of winter fasting do not increase with increasing latitude, because declining temperature-dependent metabolic costs offset the increased duration of starvation. We predict that winter food availability may differentially affect the condition and growth of largemouth bass and perhaps other fish with similar physiological/life history adaptations in northern and southern reaches of the Ohio River.

Oxygen

Declining oxygen during winter has long been recognized as an important factor structuring fish assemblages in north temperate lakes (Petrosky and Magnuson 1973; Klinger et al. 1982; Tonn and Pazkowski 1986). Species-specific tolerances for low oxygen and access to oxygen refuge (e.g., streams), determine the intensity of winterkill within these systems. Although oxygen is typically abundant in the main channel of rivers, oxygen availability in backwater refuges may decline when ice forms (Gent et al. 1995; Knights et al. 1995) or oxygen-poor groundwater inundates (Sheehan et al. 1990). Because 4°C water at the bottom of these systems may overlap with oxygen-poor conditions near the profundal zone due to high biological oxygen demand, fish may be restricted to cooler water higher in the water column. If the total water-column oxygen concentration declines below the tolerances of resident fish, telemetry movement studies have shown that they will leave these backwater habitats until oxygen concentrations

return to tolerable quantities (e.g., Gent et al. 1995).

By understanding the thermal- and oxygen-tolerance limits of riverine fish, we may improve backwater habitat during winter. Dissolved oxygen concentrations can be increased in backwaters by introducing water from the main channel through culverts (Johnson et al. 1998). This approach worked generally well in the Finger Lakes, a system of six backwaters of the upper Mississippi River, although stratification created by the influx of cold mainstem water limited the quantity of thermal habitat (Johnson et al. 1998). In the Ohio River, the availability and quality of backwater habitat also may be critical for overwintering fishes. Careful consideration of temporal variation in oxygen and temperature within these habitats will be necessary to determine their contribution to fish assemblages in this system. From this, we will be able to determine if management of oxygen within these habitats is necessary to improve overwintering success.

Synthesis

The Ohio River is a complex system with channel characteristics, tributaries, embayments, backwaters, and winter conditions etc. that vary among pools. How winter conditions affect fish assemblages depends to a great degree on the behavioral and physiological responses of individual species and the availability of critical refuge habitat within each segment. This habitat, typically defined as $\geq 4^{o}$C, low flow, and high oxygen, may vary in utility, depending on winter conditions along a latitudinal gradient within the river. Fish in northern reaches of the Ohio River may seek these refuge habitats primarily to avoid channel temperatures $< 4^{o}$C that compromise swimming ability and osmoregulatory function. Counterparts in lower reaches typically do not experience such low temperatures. However, given low food availability and energetic costs of

maintaining position during winter, fish may still seek low velocity habitats to avoid energy depletion. The critical importance of winter habitat in a northern and southern pool of the Ohio River was assessed during winter 2001-2002 with a coordinated field effort between West Virginia University and Southern Illinois University. Because several of these habitats are vulnerable to water displacement by barges, navigation in the Ohio River during winter may be a critical determinant of fish assemblage structure.

Species Requirements

Overview

In this section, we review how several commonly occurring Ohio River species respond to winter conditions (see Table 1-1). These responses plus published surveys of winter habitat use provide insight into potential habitat use/requirements in the Ohio River. For some species (e.g., largemouth bass), a fair amount of information is available about physiological and behavioral responses to winter conditions. Scant information exists for others. This information will be used to generate generic- or species-specific predictions for winter habitat use of fish in both the northern and southern reaches of the Ohio River.

Largemouth bass (Micropterus salmoides)

Largemouth bass from northern populations (*M. salmoides salmoides*) acclimated to winter temperatures can tolerate 0°C (Garvey et al. 1998; Sheehan et al. 2000). Sheehan et al. (1990) quantified higher mortality of YOY largemouth bass at 0°C (40%) than at 4°C. However, in outdoor pool experiments in Ohio under a winter photocycle and temperatures, mortality was often 0%, even though temperatures occasionally

reached 0°C (Garvey et al. 1998). Both the duration of exposure and the rate of cooling may affect tolerance to temperatures < 4°C. The Florida subspecies of largemouth bass (*M. salmoides floridanus*) cannot tolerate temperatures < 4°C (Isely et al. 1987; Garvey et al. 1998), and likely cannot persist at the latitudes that the Ohio River spans.

Largemouth bass swimming ability declines with declining temperature. Individuals were placed in a variable-velocity swimming tunnel in which flow velocity was increased by 10 cm/s every 10 minutes (Sheehan et al. 1990). Mean swimming duration declined from 8.81 minutes to 0.63 minutes at 4 ^{o}C and 0°C, respectively. Mean swimming duration did not differ between 11 ^{o}C and 4°C, suggesting that the ability for largemouth bass to maintain position in main channel habitat is primarily compromised at temperatures < 4°C. Thus, we should only expect this species to require low velocity shelters when temperatures decline below this threshold. Swimming performance increased with body size at temperatures $\geq$ 4°C (Sheehan et al. 1990).

Some individual largemouth bass will forage actively during winter when temperatures are $\geq$ 6°C (Micucci et al. 2003). Below this temperature, feeding appears to occur very rarely (Fullerton et al. 2000). At latitudes encompassing the Ohio River, largemouth bass will forage and grow when food is highly abundant during winter (Garvey et al. 1998). However, it is more likely that food will be scarce and energy reserves will be used to offset winter fasting (Ludsin and DeVries 1997). Although some studies have demonstrated that small largemouth bass exhaust energy reserves more rapidly than large counterparts (Miranda and Hubbard 1994a), others have not (Garvey et al. 1998). We predict that largemouth bass will forage rarely during winter in the Ohio River. Rather, they will seek low velocity habitats in which energy costs are minimized.

At warm temperatures (> 20°C), largemouth bass are unable to tolerate oxygen

concentrations below 1.5 ppm (Moss and Scott 1961) and will avoid these areas (Whitmore et al. 1960). Minimum oxygen concentrations at winter temperatures are lower (0.5-1 ppm). However, this species is quite susceptible to winterkill in lakes, suggesting that prolonged exposure to these or lower oxygen concentrations will eliminate them. Therefore, we predict that largemouth bass will occur at high densities in areas of high oxygen concentrations during winter.

Both surveys and telemetry demonstrate that largemouth bass seek backwater habitats in the upper Mississippi River, likely to exploit warm temperatures (Raibley et al 1997; Sheehan et al. 1990). Largemouth bass and smallmouth bass may school under winter conditions (Townsend 1916). If oxygen concentrations decline in backwater habitats during winter, radio-telemetry has demonstrated that they will depart and not return until concentrations rise (Gent et al. 1995). Thus, the avoidance of low oxygen likely is a major factor influencing movement of largemouth basin the Ohio River during winter.

Channel catfish (Ictalurus punctatus)

Channel catfish acclimated to winter conditions can tolerate temperatures reaching 0°C (Sheehan et al. 1990). When acclimated to warmer temperatures, and placed in cold (4°C) water, this species will experience cold shock (Smith and Griffith 1994). Swimming ability declined with declining temperature (Sheehan et al. 1990), although to a lesser extent than for other species (see above for largemouth bass). Mean swimming time declined from 11.5 minutes to 3.0 minutes when temperatures declined from 4°C to 0°C (Sheehan et al. 1990). Apparently, channel catfish are better adapted than several other warm-water species at maintaining position at moderate flows in

riverine habitats. We might expect this species to have moderately flexible habitat use in the Ohio River.

Channel catfish can tolerate oxygen concentrations of $\geq$ 1 ppm at warm (>20°C) temperatures (Moss and Scott 1961). Minimum lethal oxygen limits likely decline at cold temperatures, although this species is subject to winterkill when oxygen is depleted. Growth continued during winter in the Mississippi River (McInerny and Held 1995), suggesting that foraging and growth may continue during winter.

Channel catfish will congregate in low flow areas such as backwater habitats (Sheehan et al. 1990) and deep-water scour holes (Heese and Newcomb 1982; Newcomb 1989; Logsdon 1993) during winter. They also will use main channel flow breaks such as cobble or debris (Hawkinson 1980, Lubinski 1985). Their tolerance of cold temperatures and moderate flow should allow them to use the main channel Ohio River during winter. We predict that this species has a more cosmopolitan distribution in the Ohio River during winter by not being restricted solely to backwater habitats and continuing to forage. However, individuals in main channel flow breaks or scour holes may be more susceptible to vessel-induced displacement (Todd et al. 1989).

Black crappie (Pomoxis nigromaculatus)

Black crappie tolerate 0°C when acclimated to winter conditions (Sheehan et al. 1990). This species swims poorly at all winter temperatures, with mean swimming durations of 1.4 and 1.3 minutes at 4°C and 0°C (Sheehan et al. 1990). As such, it appears that black crappie is not well adapted for maintaining position in current during winter and must seek low flow areas. In support of this, Knight et al. (1995) found that radio-tagged black crappie in backwaters of the upper Mississippi River always sought

water velocities < 1 cm/s. Also, this species always remained in areas of > 2 ppm oxygen, even if this required relocating to lower water temperatures (Knight et al. 1995). Fluctuating oxygen concentrations (1.8 -4.1 ppm) during experimental winter conditions prevented spawning of black crappie relative to those at higher fluctuating oxygen concentrations (Carlson and Herman 1979). Apparently, high oxygen concentrations and low flow are higher priority characteristics for winter habitat than temperatures $\geq 4^{o}$C. Both black and white crappie cease feeding at temperatures < 10°C (Mathur 1972; McInerny and Held 1995); white crappie schools during winter (Hancock 1954). Although information is less complete than that for other species, we predict that black and white crappie are restricted to low-flow, high-oxygen habitats in the Ohio River during winter across a wide range of temperatures.

Walleye (Stizostedion vitreum)

Walleye acclimated to winter conditions suffered 25% mortality at 0°C in cold tolerance experiments (Sheehan et al. 1990). Mortality was negligible at 4°C. Walleye in outdoor pool experiments during winter in Ohio experienced occasional 0°C temperatures and exhibited no mortality (Kershner 1998). Apparently, this species can tolerate the extreme cold temperatures that occur in river sections. Walleye swimming performance was strong at all winter temperatures in a swimming tunnel experiment (Sheehan et al. 1990). Mean swimming durations were 13.9 and 12.4 minutes at 4°C and 0°C, respectively. Hence, this species is well adapted to maintaining position in flowing water during winter.

Walleye appear to have high oxygen requirement relative to other co-occurring riverine species. At warm temperatures (>20°C), walleye begin to experience stress at 2

ppm oxygen and mortality at 1.6 ppm (Moss and Scott 1961). Under winter conditions, walleye seek oxygen-rich water (Ager 1976; Sheehan et al. 1990; Coon 1998). Walleye forage actively during winter (Ager 1976; Kershner 1998). In one telemetry study in the Cedar River, Iowa, walleye were usually active in deep backwater areas at temperatures > 2.8^{o}C (Paramagian 1989). Available forage in the fall may improve winter condition and facilitate spring spawning success of walleye (Madenjian et al. 1996).

Small YOY walleye suffered higher mortality than large individuals in some systems (Joy 1975), but not in others (Copeland and Carline 1998). Although cannibalism has been suggested to contribute to these patterns of mortality (Forney 1976), Joy (1975) found no evidence of this mechanism in diets of adult walleye during winter. Hence, size-dependent energy depletion was implicated (Joy 1975). However, Copeland and Carline (1998) found no linkage between lipid depletion and overwinter mortality in laboratory experiments and Pennsylvania lakes. YOY saugeye experienced no size-selective overwinter mortality in Ohio reservoirs (Donovan et al. 1998).

Walleye and perhaps sauger should tolerate relatively high flow rates and temperatures in the Ohio River. However, we predict that *Stizostedion* spp. will avoid habitats with moderate to low oxygen concentrations. At the temperatures common to the southern extent of the Ohio River, walleye and sauger may well remain active for most of the winter.

Bluegill (Lepomis macrochirus)

Bluegill are intolerant of the cold temperatures that may occur in the main channel of rivers during winter (Sheehan et al. 1990). In cold tolerance experiments, bluegill survival was high at 4°C but declined to 44% at 0°C (Sheehan et al. 1990).

Bluegill swimming performance declined significantly with declining temperature, from 5.6- to 0.3-minute mean duration at 4°C and 0°C (Sheehan et al. 1990). Lower lethal oxygen concentrations for bluegill acclimated to winter conditions vary from 0.5-3.6 ppm (Cooper and Washburn 1949; Petrosky and Magnuson 1974). This species is relatively susceptible to winterkill in north temperate lakes (Pertrosky and Magnuson 1974; Tonn et al. 1980).

Although foraging activity of this species has been documented under the ice (Moffett and Hunt 1943), telemetry studies in eastern Tennessee demonstrated that activity is low for this species during winter (Gatz and Adams 1984). If foraging does occur, it is apparently insufficient for growth because several field studies have demonstrated that energy reserves are depleted in a size-dependent fashion in bluegill populations (Bulow et al. 1991; Booth and Keast 1986; Cargnelli and Gross 1997). Further, growth increments on otoliths decline dramatically as temperatures decline in fall (Garvey et al. in press). In YOY bluegill, mortality apparently does increase with declining body size during winter in some systems (Cargnelli and Gross 1996; Garvey et al. in press) but not others (Toneys and Coble 1979). Bluegill occupying shallow water during winter may be highly susceptible to wading shorebird predation (Glahn et al. 1998).

Bluegill must seek backwater habitat with 4°C, low flows, and moderately high oxygen during winter in the Ohio River (see Knights et al. 1995). Apparently, if these habitat requirements are not met, high mortality will occur, as it did in the upper Mississippi River (Bodensteiner and Lewis 1994).

White bass (Morone chrysops) and congeners

Very little information is available about the physiological requirements of white bass during winter. A congener, white perch, that is currently not present in the Ohio River, cannot tolerate temperatures $\leq 2.5^{o}$C, with greater mortality occurring in small YOY individuals (Johnson and Evans 1990, 1991). Survival is high for white perch at 4°C, when food is available (Johnson and Evans 1990, 1991). Striped bass, another congener, persists at cold temperatures typically found in river main channels during winter (Hurst et al. 2000; also see Harrell et al. 1988). Although white bass are found as far north as Lake Erie (Barans and Tubb 1973), they appear to have strong thermal preferences, actively seeking warm-water effluent from power plants during winter (Schneider et al. 1977) or areas of greatest temperature under natural winter conditions (Barans and Tubb 1973). During winter, white bass tend to move to deeper, offshore areas in lakes (Beck and Willis 2000) and occupy backwater habitats in the Mississippi River (Sheehan et al. 1990). Growth ceased in white bass when temperatures declined below 18°C in Navigation Pool 9 of the Mississippi River (McInerny and Held 1995). Taken in concert, this limited information suggests that white bass should become relatively inactive and seek warm-water refuges during winter in the Ohio River.

Freshwater Drum (Aplodinotus grunniens)

Freshwater drum is widely distributed throughout North America and reaches high abundances in river ecosystems (Scott and Crossman 1973; Braaten and Guy 1999). Thus, we may expect that this species tolerates a host of winter conditions to persist so widely. In a laboratory experiment, freshwater drum held at 1°C and 5°C experienced higher mortality than those at 10°C (Bodensteiner and Lewis 1992). When temperatures

declined to 0°C, these fish lost equilibrium. Freshwater drum at cold temperatures were less able to maintain osmotic balance than those at relatively warmer ones (Bodensteiner and Lewis 1992). In the Mississippi River, freshwater drum occupy deep water scour holes (Heese and Newcomb 1982; Logsdon 1993) or backwaters, apparently to exploit temperatures $\geq$ 4°C, low velocity, and high oxygen concentrations. If these conditions are not met in the Ohio River, high mortality may occur as was observed in the Mississippi River (Bodensteiner and Lewis 1994). Freshwater drum apparently cease foraging and growth at < 10°C (McInerny and Held 1995).

Green sunfish (Lepomis cyanellus)

Green sunfish are a common member of river fish assemblages. However, Sheehan et al. (1990) found that this species suffered high mortality at $\leq$ 4°C. Presumably, this species must search for > 4°C water and remain inactive to persist during winter. Although field information is limited, winter survival of YOY green sunfish appears to be unrelated to size (Toneys and Coble 1979) or osmoregulatory dysfunction (Toneys and Coble 1980). This species is found in backwaters of the Mississippi River (Sheehan et al. 1990) and is likely restricted to these habitats during winter in the Ohio River as well.

Other Ohio River species

Gizzard shad *Dorosoma cepedianum* are common and abundant in Ohio River fish assemblages. This species typically is found in river backwaters (Sheehan et al. 1990; Bodensteiner and Lewis 1994) and scour holes associated with main channel flow breaks (Logsdon 1993) during winter. This species is quite susceptible to cold shock,

with high mortality occurring in many populations during winter months (Miller 1960; Walburg 1964). This species stores energy as fat in fall (Pierce et al. 1980), with a subsequent decline in stores through winter. The abundance of gizzard shad in fall and during winter can affect survival (Adams et al. 1982) and reproductive success (Madenjian et al. 1996) of sportfish during winter. In our view, gizzard shad should be an important component of Ohio River food webs, with survival in backwater habitats potentially affecting the success of piscivores.

Large cyprinid species such as river carpsucker (*Carpiodes carpio*) and common carp (*Cyprinus carpio*) overwinter in deep scour holes (Heese and Newcomb 1982) and backwaters (Sheehan et al. 1990) of rivers. The minimum lethal temperature of common carp is 0.7^{o}C (Bardach and Berstein 1954), suggesting that this species has broad tolerance to winter temperatures in rivers. Common carp can remain relatively active during winter, when attempting to avoid ice or high flow velocities (Brown et al. 2000). We predict that common carp will occupy a variety of winter habitats both in the main channel and backwaters of the Ohio River.

Although information about overwintering shovelnose sturgeon (*Scaphirhynchus platorynchus)* is scarce, shortnose sturgeon (*Acipenser brevirostrum*) remain in areas of reduced flow in the main channel during winter (Moser and Ross 1995), presumably to reduce energetic costs of maintaining position (Kynard et al. 2000). Activity during winter varies for this species from relatively high in the Lower Cape Fear River, North Carolina (Moser and Ross 1995) to low in two Massachussetts rivers (Kynard et al. 2000). Paddlefish (*Polyodon spathula*) appear to use main channel habitats of the lower Alabama River during winter (Hoxmeier and DeVries 1997). Tagged paddlefish moved between lakes and tributaries in the Lower Cumberland and Tennessee Rivers, Kentucky

(Timmons and Hughbanks 2000). During winter in Alabama and Texas, diets of paddlefish included copepods, cladocerans, and mayfly nymphs (Hoxmeier and DeVries 1997; Moore and Cotner 1998). This information suggests that sturgeon and paddlefish should remain relatively active and use main channel habitat in the Ohio River during winter.

Species such as blacknose dace may move into crevices beneath rubble (Cunjak and Power 1986). Other cyprinid species may become hyporheic, burrowing into gravel at depths of 0.5 m (Emery et al. 1978). Bullheads can burrow into the substrate within backwaters presumably to take advantage of elevated thermal conditions (Loeb 1964; Bouvet et al. 1985). Overwintering tactics of many often overlooked species in the Ohio River (i.e., those with little commercial or recreational value) may be quite unique.

Summary

Winter habitat requirements of Ohio River species will revolve around the relative impacts of temperature, oxygen concentration, flow velocity, and perhaps food availability. Fish assemblages will contain species with varying tolerances to these winter conditions, affecting their habitat fidelity, condition, and survival. Because many species found in the Ohio River likely home to the same overwintering locations each year, as they do in other riverine systems (e.g., Pitlo 1987), these areas are likely very important for survival during this critical period (Sheehan et al. 1990). Winter temperatures vary in severity and duration throughout the Ohio River. Hence, constraints on overwinter success and factors influencing habitat use may vary depending on river mile. In addition, the vulnerability of fish to vessel-induced displacement during winter will depend largely on the interaction among winter conditions, habitat availability, and

habitat use. Future work exploring fish-habitat associations during winter in the Ohio River will begin to lend insight into these important issues.

Table 1-1. Predicted habitat used by fish species commonly found in the Ohio River during winter.

		Performance at < 4°C			Winter Habitat Use	
Species	Survival	Swimming Ability	Low oxygen	Activity/ Foraging	Upper River	Lower River
Largemouth Bass*	Medium	Low	Low	Low	Backwater	Backwater/ Channel
Channel Catfish*	High	Medium	Medium	Medium	Backwater/ Channel	Backwater/ Channel
Crappie*	Medium	Low	Low	Low	Backwater	Backwater/ Channel
Walleye	High	High	Low	Medium	Backwater/ Channel	Backwater/ Channel
Bluegill*	Low	Low	Low	Low	Backwater	Backwater/ Channel
White Bass*	Low	Low	N/A[a]	Low	Backwater	Backwater/ Channel
Freshwater Drum*	Low	Low	Low	Low	Backwater	Backwater/ Channel
Gizzard Shad*	Low	Low	Low	Low	Backwater	Backwater/ Channel
Carp*	High	Medium	Medium	Medium	Backwater/ Channel	Backwater/ Channel
Sturgeon/Paddlefish*	High	High	N/A[a]	High	Open Channel/ Channel	Open Channel

[a]Not Available

*Species encountered during winter 2002-2003 sampling

Chapter 2 – Smithland Pool Field Sampling 2001-2003

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Introduction

Winter is a critical period in which high mortality occurs in fishes (Oliver et al. 1979; Cunjak 1996; Garvey et al. 1998). Many temperate fishes undergo a torpor-like state when exposed to prolonged cold temperatures and short days (Crawshaw 1984) and, as such, may be highly susceptible to vessel-passage induced displacement from velocity shelters. Because the Ohio River extends through mid-temperate latitudes, inter-annual variability in winter temperature may translate to highly variable responses of fish populations to acute abiotic perturbations (see Garvey et al. 1998) such as changes in flow velocity and flow direction with navigation. Laboratory (Sheehan et al. 1990; 2000a) and field studies (Sheehan et al. 1990b; Logsdon 1993; Johnson et al. 1998) showed that a number of Mississippi River fishes overwinter in stratified backwater areas, when they have access to them, or in low velocity areas in channels. Relatively small (0.08 to 0.16 $m \cdot s^{-1}$) velocity changes, such as those that can be induced by vessels, can displace small bluegill and channel catfish from low velocity habitats when water temperatures are low (1 to 4 ^{o}C) (Sheehan et al. 2000b). If fish are displaced into flowing channels at such temperatures, mortality will probably increase (Bodensteiner and Lewis 1994; Sheehan et al. 2000a).

In this chapter, we describe research conducted in Smithland Pool, Ohio River during winters 2002 and 2003 to determine the habitat use of fish and to assess the

relative vulnerability of species and habitats to potential displacement by barge traffic. Fish were sampling with variable-depth AC electrofishing. Their relative abundance was then analyzed as a function of water quality parameters quantified at each site and sampling date.

Study Site

Smithland Pool was created by the formation of Smithland Lock and Dam in 1981. It is 115 km long and 11,134 ha at normal pool. After Smithland Lock and Dam was completed, water levels rose 5 m. Twenty six tributaries enter the pool, with the Wabash and Saline Rivers being the largest. Smithland Pool is currently the last pool of the Ohio River, with open river extending the reminder of its length to the confluence with the Mississippi River.

Methods and Approach

Habitat Assessment

During November 2001 we selected thirty sampling sites in the Smithland Pool of the Ohio River. These sites were selected to represent the five main macrohabitat types found in this section of the river (artificial, backwater, island, main channel, and tributary). Due to the scarcity of backwater habitat in the Smithland Pool, we combined backwater and island sites into one habitat category to represent the areas upstream, downstream, and on the non-channel side of islands (now called “Island”; Table 2-1). Main channel sites were typically located at areas with submerged boulders and other submerged structures that provide potential velocity shelters (Table 2-2). The sites were divided equally between the upper and lower halves of the pool and were stratified

relative to habitat type abundance in these halves (Table 2-2, Figure 2-1). During both 2002 and 2003, the abiotic characteristics of each site (specific conductance, dissolved oxygen, flow, secchi depth, and temperature) were quantified during each sampling trip with a Hydrolab Quanta water quality meter. Dissolved oxygen-temperature profiles were taken at each site. Quantities presented herein are water column averages, because neither temperatures nor dissolved oxygen concentrations varied by more than about 1% from the surface to the bottom at all sites and dates (i.e., stratification was absent). Six hobo-temp temperature-data recorders were placed in the pool near the bottom during both years. We also obtained daily discharge data during the study period from a USGS gauging station at Metropolis, Illinois.

Objective 2: Winter Fish Sampling

During 2002 and 2003, we used variable-depth, three-phase AC electrofishing (Multiquip 5000- watt generator with Honda motor) to quantify the habitat-specific relative abundance, species composition, size structure, and age structure of fishes in Smithland Pool during mid winter through late spring. The AC electrofisher consisted of three weighted electrodes that were lowered to a desired depth (usually 5-9 m). Current output typically ranged between 7-10 amps.

Sampling session 1 of the first sampling year occurred during January 2002. Session 2 of year 1 was conducted during late February through early March 2002. The third sampling session of year 1 was completed in June 2002. During the second sampling year, we sampled a small number of sites during fall 2002, although conditions deteriorated rapidly, thereby preventing us from including these data in most analyses. The first full sampling session of year 2 (i.e., henceforth session 1, 2003) was completed

during February through March 2003. The second session of year 2 was conducted in April 2003. The third session occurred during June 2003. Unavoidable factors during 2002 (elevated water levels, high flow rates, and extremely low conductivity) hindered sampling four sites during session one and two sites during session two (see Figure 2-2). Spring flooding delayed the third sampling effort during year 1 (Figure 2-2, upper panel). Similarly, during 2003, adverse conditions prevented sampling of most artificial sites during session 1 and nearly all sites during session 2 (Figure 2-2, bottom panel).

Sampling of all sites consisted of thirty minutes of non-continuous pedal time when possible. We idled backwards down-river to keep the probes at desired depths (5-9 m) beneath the boat. When possible, we distributed sampling effort at each site across two or three transects stratified across different depths. Sites that covered only a small area or contained high densities of fish were sampled during a shorter time. Fish collected were either taken back to the laboratory or measured in the field to the nearest 1 mm and released. All freshwater drum (*Aplodinotus grunniens*), channel catfish (*Ictalurus punctatus*), white bass (*Morone chrysops*), and crappie (*Pomoxis* spp.) were frozen and processed in the laboratory as per the approved scope of work. We grouped black crappie (*Pomoxis nigromaculatus*) and white crappie (*Pomoxis annularis*) into a single generic category. Because our sampling during year 1 revealed that blue catfish were abundant in Smithland Pool, we also collected individuals of this species for analysis during year 2. In the laboratory, the four target species and blue catfish were weighed (to the nearest 1 g) and measured (to the nearest 1 mm). Otoliths (and pectoral spines for catfish) were then removed for age determination. Two readers independently read all structures. For age estimates that were not in 100% agreement, readers consulted until agreement was met. If the readers could not agree, the structure was dropped from

the analysis. We also removed stomachs of a size-stratified sample of freshwater drum from the two winter sampling sessions during year 1 to determine whether foraging occurred during winter.

Results

General Patterns Both Years

Our reconnaissance of habitat in Smithland Pool suggests that low velocity, deep-water areas that may provide shelter for fish during winter are quite limited, particularly given the lack of extensive backwater habitats. Discharge was typically high during winter through late spring of both years (Figure 2-2). During both winters, we were only able to sample during three relatively short periods of low discharge and low gage height (Figure 2-2). During the remainder of both winters, water levels were typically 3-6 m above that conducive to effective, safe sampling (Figure 2-2). Only one temperature recorder was successfully retrieved from the bottom of Smithland Pool during 2002 and no loggers were retrieved during 2003. The one logger that was found revealed that temperatures declined to 4°C during a brief period in early January 2002 and then remained 5-7°C through the second sampling session (Figure 2-3, upper panel). During mid-May through June 2002, temperatures rose, exceeding 25°C by the end of sampling session 3 (Figure 2-3, upper panel).

Because all of our loggers were lost in 2003, we obtained daily water temperatures from the Shawnee Fossil Power Plant below Smithland Dam (Figure 2-3, bottom panel). These temperatures are quantified at a fixed level that is near the surface at normal flow. The logger's daily temperatures were related to that of the power plant (R^2=0.88, slope= 1.08), suggesting that the temperatures obtained from this source during

2003 reflected those occurring in the pool. However, surface temperatures were more variable than those at the bottom during winter (particularly at surface temperatures 5-15°C; Figure 2-3, bottom panel) revealing that temperatures at the bottom of Smithland Pool appeared to be more stable during this time. Daily temperatures from the power intake suggest that temperatures were likely near zero in Smithland Pool during the first sampling session of 2003. Temperatures were 11-12 ^{o}C during the second session and averaged 20 ^{o}C during the third session.

Water Quality

<u>2002 Conditions</u>

During sampling session 1 of 2002, mean water column temperatures ranged from 2.58 to 4.62 °C across sites (Table 2-3). Mean dissolved oxygen for the first session of this year ranged from 4.92 to 7.52 mg/L (Table 2-3). Sites during the first session had low flow rates with many (N=14) having no measurable flow (Table 2-3). Conductivity for five of the seven tributary sites sampled was lower than artificial, island, or main channel sites with values as low as 0.213 mS/cm (Table 2-3). Aside from those tributary sites, remaining conductivity values ranged between 0.500 and 0.700 mS/cm (Table 2-3). Water temperatures in session 2 of 2002 were warmer, ranging between 5.39 °C and 9.75 °C (Table 2-4; Figure 2-3). This wide range of temperatures may be attributed to varying factors (such as a longer sampling period, increased flow rates, and weather events). Dissolved oxygen during session 2 of this year ranged from 4.64 to 7.12 mg/L (Table 2-4). Flow rates during session 2 of 2002 were higher than in session 1 at 13 sites (Table 2-4; also see Figure 2-2). Twenty-two sites in session 2 had lower conductivity than during session 1 (Table 2-4). By June 2002, water temperatures were higher and dissolved

oxygen concentrations were lower in all sites relative to the other sampling dates (Table 2-5). Dissolved oxygen concentrations in tributaries were lower than in the other sites. In fact, several of the tributary sites were inaccessible due to low flow and low water depth.

To summarize conditions during winter 2002, sites could be characterized by flow, temperature, dissolved oxygen, specific conductance, and secchi depth during the coldest sampling session in January, although they did not separate by our habitat type definitions. Through the entire season, temperatures increased in all sites (Table 2-6). Mean dissolved oxygen declined more in tributaries than in other sites by spring 2002 (Table 2-6). Water clarity declined as average flow rates increased in the sites associated with the main channel (but not the tributaries) during late winter through late spring (Table 2-6). These results suggest that the tributary sites became more physically distinct (i.e, lower flow and oxygen) than those associated with the main site during late winter through spring (Table 2-6).

2003 Conditions

During the 2003 sampling session 1, temperatures were typically low (< 3°C) at all sites (Table 2-7; Figure 2-3). Higher temperatures at tributary site are due to the relative late sampling (mid March) of these sites relative to the main channel ones (mid February), a consequence of the high discharge and frequently truncated sampling effort. Dissolved oxygen concentrations during session 1 of 2003 were high at all sites (Table 2-7). Flow rates were higher at island and main channel sites, resulting in lower water clarity than in the tributary sites (Table 2-7). Specific conductance during session 1 was lower in tributaries than in sites associated with the main channel (Table 2-7). Persistent,

high discharge during sampling session 2 of 2003 made sampling difficult, and only a subset of sites were sampled. Conditions were similar among all sites during session 2, although flow was much lower (or zero) in tributaries (Table 2-8). By June through early July 2003, flow was near zero in tributaries and dissolved oxygen concentrations were low (Table 2-9). In other sites, flow rates and dissolved oxygen concentration were higher, with lower water clarity (Table 2-9).

In summary, water quality and flow patterns during our 2003 sampling were similar to those during winter 2002. Chronically high discharge rendered sampling challenging. Temperatures increased during the season, with dissolved oxygen concentrations declining more in tributaries than at other sites associated with the main channel (Table 2-10). Tributary sites during 2003 again became more distinct as the year progressed, although they typically had lower flow, higher water clarity and lower dissolved oxygen concentrations (Table 2-10).

Winter Multivariate Analysis

Because this was the coldest period during winter, we further explored abiotic characteristics of sites during 2002 and 2003 with principle components analysis (PCA), including temperature, dissolved oxygen concentration, secchi depth, flow rate, and conductivity in the analysis. The first two principle components explained 70% of the variance in the data. Principle component 1 had strong positive associations (eigenvectors > 0.4) with secchi depth and negative associations with flow and dissolved oxygen (Figure 2-4). Principle component 2 was negatively associated with temperature and dissolved oxygen and positively associated with specific conductance (Figure 2-4). Sites clustered somewhat by our defined habitat types (i.e., artificial, island, main, and

tributary; Figure 2-4). Tributary sites typically sorted out on the right side of the ordination plot, which corresponded with low dissolved oxygen, high secchi depths, and low flow (Figure 2-4). The four tributary sites in the lower right-hand quadrant of the plot are those that were sampled relatively late during winter 2003, and thus had higher temperatures than other sites (Figure 2-4). Three other clusters of sites occurred that did not appear to be closely related to out habitat delineations, although most were associated with the main channel. Typically all these sites corresponded with high conductivity and low temperatures but were probably separated primarily by flow and dissolved oxygen concentration (Figure 2-4). The two main channel sites clustered in the upper left quadrant of the plot were characterized by high flow, high dissolved oxygen, and cold temperatures (Figure 2-4). Artificial sites that created deep scour holes appeared to be intermediate in characteristics between tributaries and the main channel (Figure 2-4). These results suggest that sites do differ in abiotic characteristics during winter. If we understand species-specific requirements during winter, then these sites might be categorized for management.

Winter Fish Assemblages- Annual Patterns

Fish 2002

Samples from session 1 in January 2002 were dominated by freshwater drum (N= 333) and blue catfish (*Ictalurus furcatus*) (N= 58), accounting for > 89% of fish captured (Tables 2-11 through 2-13). Only two other species, emerald shiner (*Notropis atherinoides*) (in the island habitat type) and crappie (in the tributary habitat type), accounted for > 5% of the catch for any given habitat type (Table 2-12). Overall catch per unit effort (CPUE) was highest in artificial habitat types (60.30 fish per hour) followed

by main channel (49.50 fish/hr), tributary (44.65 fish/hr), and island (38.57 fish/hr) (Table 2-13). Tributary sites contained the most species (N=11) whereas the main sites contained only freshwater drum (Table 2-13). Artificial and island sites adjacent to the main channel contained intermediate numbers of species including channel catfish, blue catfish, and gizzard shad (Table 2-13).

Patterns for sampling session 2 during February through March 2002 were similar to those for session 1 of that year. Freshwater drum (N= 514) and blue catfish (N= 334) (Tables 2-14 through 2-16) accounted for > 97% of all fish captured during this session (Table 2-15). Island and tributary habitats contained far fewer fish (23.14 fish/hr and 36.92 fish/hr respectively) than did artificial and main channel habitats (110.53 fish/hr and 176.67 fish/hr respectively) (Table 2-16). Catch rates at the artificial and main channel sites were much higher than those at the same sites during session 1. Three sites (one tributary site from session 1 and one artificial and one island site from session 2) were excluded from these results due to extremely high catch rates (primarily consisting of freshwater drum and blue catfish). The number of species found in tributaries declined to eight during session 2 (Table 2-16). Channel catfish, blue catfish, and gizzard shad were captured in addition to freshwater drum at main sites during this time (Table 2-16). Artificial and island sites again contained intermediate numbers of species (Table 2-16), with blue catfish dominating catches in artificial sites.

By June 2002, total catch rates had declined at all sites (1.50 – 5.00 fish/hr; Tables 2-17 through 2-19). Although still dominant in the catch, freshwater drum and blue catfish only comprised about 71% of species captured (Table 2-18). Most of this decline occurred because catch rates in artificial and main sites declined (Table 2-19). Twelve species were sampled with channel catfish and gizzard shad becoming more prevalent;

only two species occurred in tributaries. Freshwater drum were absent and gizzard shad were abundant in tributary sites during this time (Table 2-19).

In summary for 2002, freshwater drum and blue catfish were the most abundant species sampled (Table 2-20). The majority of fish were associated with scour areas near artificial habitats (Table 2-20). Main channel sites produced the second highest number of fish (Table 2-20). It is important to note that this interpretation does not incorporate relative effort at each site. We will explore these issues in depth in a future section below.

Fish 2003

During February through March of 2003, freshwater drum and blue catfish dominated samples, accounting for 92% of fish captured (Tables 2-21 through 2-23). Other species that were moderately abundant in samples included goldeye, channel catfish, and smallmouth buffalo (Table 2-22). Overall catch per unit effort (CPUE) was highest in main channel sites, largely due to the high densities of freshwater drum (Table 2-23). CPUE in artificial and island habitats were equivalent, whereas tributary catch rates were quite low (Table 2-23). Artificial sites contained the most species (N=11) and tributary contained the least (N=4).

During session 2 of 2003, total number of species sampled were much lower, (Tables 2-24 through 2-26), largely due to our truncated sampling. Again, blue catfish and freshwater drum were the most abundant, primarily in artificial habitats (Table 2-26). The number of species captured was much lower (N=4 artificial, N=3 island, N=4 main, N=2 tributary).

Total catch rates were still low in June 2003, although our effort was much

greater. Blue catfish were the dominant species captured, with freshwater drum being less abundant (Tables 2-27 through 2-29). These two species again accounted for the majority (89%) of species sampled. Overall CPUE was much lower than the session 1, 2003 sample, although catch rates were still highest in main channel and artificial sites (Table 2-29). Species richness was again much lower than during the first sampling session of 2003 with a maximum of six species sampled in the artificial and main sites and only two in tributaries.

As in 2002, freshwater drum and blue catfish were the most abundant species at our sites (Table 2-30). Again, artificial sites followed by main channel ones harbored the highest number of fish (Table 2-30). The composition of species differed somewhat from 2002, but the total number of species sampled was the same between years (N= 19 each year).

General Fish Assemblage Patterns

To explore the effect of date and habitat type on habitat use by the three most common species (freshwater drum, blue catfish, and channel catfish), we combined the fish CPUE data across the two years and conducted a two way ANOVA (main effects: date and habitat). For freshwater drum, both session ($F_{2,98}$=7.48, P=0.001) and habitat ($F_{3,98}$=7.67, P=0.0001) affected CPUE, which likely occurred because overall CPUE declined through the season and CPUE was consistently higher in main channel habitats (Figure 2-5, upper panel). For blue catfish, neither habitat nor date affected CPUE (Figure 2-5, middle panel). However, it is important to note that catch of blue catfish was consistently low in tributaries (Figure 2-5). Channel catfish CPUE was only affected by habitat ($F_{3,98}$=5.12, P=0.002), which likely occurred because abundances were

consistently higher in main and island sites (Figure 2-5, lower panel).

We conducted a species assemblage PCA for each year to further explore how habitats differed among sampling dates. Only the 2002 analysis produced interpretable patterns. And in this analysis, the first and second principle components only explained 45% of the variance in the data set, suggesting that differentiating species assemblages by our site designations only weakly captured the variation in the data. Significant loadings did not occur for any of the abundant species such as freshwater drum, blue catfish, and channel catfish, perhaps because they were present in all sites during some dates. Species expected to reside in tributary sites were indeed associated with tributaries during the January and February-March 2002 sampling sessions (Figure 2-6). In January, tributaries were characterized by relatively high catches of flier, crappie, redear sunfish, and spotted bass (right upper quadrant, Figure 2-6). By session 2 of 2002, bluegill, longear, and warmouth were more closely associated with tributaries (lower left quadrant, Figure 2-6). By June, the tributary sites were more similar to the cluster of main, island, and artificial sites (upper left, Figure 2-6). This analysis suggests that tributaries had different assemblages (more lentic type species) than main channel sites during winter. This distinction declined by June 2002, perhaps as dissolved oxygen concentrations declined in the deeper waters of tributaries and most species moved into shallower water. Recall, richness of these tributary sites declined by June (Table 2-19).

To further explore relationships among species abundances, sites, and abiotic characteristics during the winter 2002 and 2003 sampling sessions, we used another ordination technique, non-metric multidimensional scaling (NMS). Only the three most abundant species (freshwater drum, blue catfish, and channel catfish) were included in the analysis. As with the PCA, no structure was found in the 2003 data set, so we only

present the results for the 2002 analysis (PC ORD, using the Sorenson distance measure). Abiotic characteristics had little influence on the data structure during winter 2002. However, we did find insightful associations between species and habitats. Blue catfish clustered with artificial sites (Figure 2-7). As our ANOVA (see above) demonstrated, freshwater drum were more closely associated with main channel habitats, whereas channel catfish appeared to cluster with island sites (Figure 2-7).

Body size may influence the habitat used by fish. Across all of the sites, no apparent pattern of size-specific habitat use arose, with the exception of freshwater drum during both 2002 and 2003 (Figure 2-8). When freshwater drum were present in the tributaries, average sizes were smaller than those of counterparts in the main channel sites. These small freshwater drum were absent from tributaries by late spring. We generally confirmed this interpretation with a two way ANOVA including data from the first two sampling sessions each year. For 2002, neither session nor habitat appeared to effect size of freshwater drum. However, in 2003, both session ($F_{1,19}$=6.89, P=0.02) and habitat ($F_{3,19}$=48.28, P=0.0001) did affect mean size of freshwater drum, with sizes being much smaller in tributaries.

By combining data for both years, we explored how species richness changed with abiotic factors in each habitat type. Because our power was low, we used an alpha of 0.1 as our cutoff for significance in our linear regressions. Species richness declined with increasing temperature at both island and tributary sites and remained unchanged in the artificial and main channel habitats (Figure 2-9). At only the island sites was species richness positively related to dissolved oxygen concentration (Figure 2-10), with no other apparent relationships occurring. Flow only appeared to affect richness in tributary sites, with the highest richness occurring when tributaries had moderate flow (Figure 2-10).

Species-Specific Patterns

The five species targeted for in-depth analysis were freshwater drum, channel catfish, black/white crappie, and white bass. During 2003 we added blue catfish. During 2002, average lengths of channel catfish were greater than those of the more abundant blue catfish (Table 2-20). Freshwater drum averaged 212 mm (Table 2-20). Average size of the six white bass caught was 277 mm (Table 2-20). During 2003, average lengths of channel catfish were again greater than those of blue catfish (Table 2-30). Average size of freshwater drum during 2003 was similar to 2002 at 239 mm (Table 2-30). Age ranges differed among species (Figure 2-12). Ages of freshwater drum spanned 28 years (Figure 2-12). Individuals of the other three species were never older than 12 years (Figure 2-12). The von Bertalanffy length at age relationship was $L=708(1-\exp(-0.094(t+1.06))$ for freshwater drum. For channel and blue catfish, growth did not appear to decline during later years, suggesting that we did not capture the oldest individuals in the population. Supplemental sampling, perhaps using different gear types (e.g., gill nets, fyke nets), is needed to collect more channel catfish, crappie, and white bass to generate robust age and growth information.

During the two winter sampling sessions, lengths of freshwater drum ranged from 80 to 700 mm, with an average of 205 mm (Figure 2-13). By June 2002, total catch rates declined and small, young individuals < 200 mm were absent from our catch (Figure 2-13). The same pattern occurred during fall 2002 through late spring 2003 (Figure 2-14). Using analysis of covariance (ANCOVA) in which length was the covariate and sampling session was the main factor, we found that these regression lines differed among sampling sessions (ANCOVA: $P < 0.05$), with the intercept declining by June. For both years, we computed relative weight (W_r) for freshwater drum, finding that these values

ranged widely between 70 and 150% (Figures 2-15 and 2-16). Although fits were poor (R^2<0.07 for most sessions), regression revealed that W_r increased slightly with length (P<0.05, both regressions) during the first two sessions of 2002 (Figure 2-15) and during February and April of 2003 (Figure 2-16). By June of both years, condition was unrelated to length (Figure 2-15 and 2-16). Small freshwater drum had a lower proportion of empty stomachs than large counterparts during the two cold winter sessions (Figure 2-17). Of the 28 individuals that contained food, 53%, 11%, and 35% contained mayfly larvae, mollusk/gastropods, and crayfish, respectively.

Channel catfish sizes ranged from 150 – 650 mm total length during winter through late spring 2002 and 2003, with two apparent age classes dominating the distribution in 2002 and one in 2003 (Figures 2-18 and 2-19). Relative weight did not vary with length during 2002 (Figure 2-20). In 2003, relative weight only increased with length during the last sampling session, although this was the only session in which fish > 600 mm were sampled (Figure 2-21). Average condition was 102 in 2002, ranging from 80 to 130 (Figure 2-20). In 2003, average condition was 87 (Figure 2-21), lower than 2002.

In contrast to freshwater drum, blue catfish length frequency distributions did not change appreciably during the winter through spring in 2002 or 2003 (Figures 2-22 and 2-23). Because standard weight equations are not readily available for blue catfish, we conducted an ANCOVA on length-weight relationships to compare growth during each session of each year (Figures 2-24 and 2-25). During both 2002 (P=0.0001) and 2003 (P=0.0001), intercepts but not slopes differed among sessions, suggesting that average fish weights changed during the year. During both years, the intercepts declined through the year, suggesting that weight declined as the winter progressed, although the biological

relevance of this change is uncertain (Figure 2-24 and 2-25).

Discussion

Unlike the upper Mississippi River in which extensive backwater systems provide wintering habitat for fishes, our field reconnaissance of Smithland Pool revealed that this portion of the Ohio River does not contain these habitats. Rather, deep-water, low velocity, and high temperature sites in this system often required by fish during winter (see Chapter 1) may be associated with the island, artificial scours, and tributary sites. Unlike backwater habitats in other systems, our sites generally did not stratify because oxygen concentrations and temperatures were similar throughout the water column. Understanding how these sites provide shelter both from negative winter conditions as well as from potential displacement by navigation is paramount for predicting the impacts of increased navigation traffic or climate change.

Results generated during January through June 2002 and during a similar period in 2003 suggest that sites associated with the main channel (including the artificial and island areas) often differ subtly in their abiotic conditions during winter. Tributary sites fell out as distinct during winter, with low flow, high clarity, and low oxygen. Even given the subtle physical differences that emerged, most sites had relatively warm temperatures ($\geq 4^{o}$C), low flow rates, and moderate dissolved oxygen concentrations relative to northern rivers in which channel temperatures reach much lower temperatures and higher flow velocities during winter (Chapter 1). Still, subtle differences among sites in Smithland Pool did affect fish abundance. Species exhibited some site-specific habitat use. And, finally, we could only sample during rare periods of low discharge, although flow rates in the main channel were frequently much greater than those we quantified.

Thus, species habitat use we quantified may reflect much greater differences in flow among sites during times when we could not sample. To gain more resolution about how these sites contribute to fish habitat preference and influence susceptibility to navigation, more complete physical information through time is necessary to determine how physical characteristics vary on a daily basis.

We selected variable depth electrofishing to sample fishes in deep-water sites. In backwaters of the Mississippi River during winter, this technique was non-selective for a wide range of fish species (Sheehan et al. 1990). The total number of species sampled with this technique across sites in Smithland Pool was low relative to Sheehan et al. (1990), with freshwater drum and blue catfish occurring most frequently. To effectively determine if these two species were simply numerically dominant at these sites or if this technique is selective for them, we must compare the catch composition of variable-depth electrofishing with that generated by gill nets and trap nets at several sites A pilot study has been conducted behind chevron dikes in Pool 25 of the upper Mississippi River, where colleagues and I have compared variable depth electrofishing with Missouri trawls and purse seines during December 2002. We found species assemblages similar to those in Smithland Pool. All gears produced generally the same sizes and relative abundances of fish species.

Freshwater drum, channel catfish, and perhaps blue catfish should swim well at moderately low main channel temperatures (2-4°C; Chapter 1), potentially explaining their ubiquitous presence during the entire winter. For freshwater drum, small individuals were present in tributaries in which flow was lower. This apparent size-specific partitioning of habitat may be related to differences in tolerance to differences in flow and temperature between tributaries and the main channel (Chapter 1). It is

important to note that our measurements of flow were taken near the surface, although fish were near the bottom. Hence, our estimates of flow may not accurately reflect the flows experienced by the fish. Future work will involve using an acoustic doppler current profiler recently acquired by the Fisheries and Illinois Aquaculture Center at SIUC to explore how flow varies at these bottom sites. We also must determine how flow changes throughout the water column during and after vessels have passed in proximity to these potential overwintering sites (see Executive Summary, Figure 1 for some preliminary findings).

We would expect greater use of the artificial scour areas in the main channel if these sites were used for refuge. Blue catfish appeared to have some association with these sites, although other species were infrequent. Although we might expect main channel areas to be exposed to displacement from barges or high flow, freshwater drum use of these sites was high during both years and only declined by late June, suggesting that these sites are preferred during cold months, perhaps due to enhanced foraging opportunities. Channel catfish use of the main channel and island sites was consistently high during both years. Why these species showed different apparent preferences for these habitats can only draw speculation, but this pattern was consistent between years and likely is related to the species-specific interactions between flow, temperature, and perhaps food availability. Overall abundance of fish declined with increasing temperature. This may be expected if many species using deep-water habitat during winter dispersed to different depths as temperatures increased.

Quantifying the number of species encountered at a site (i.e., richness) is another approach for estimating use. Physical factors at sites did appear to affect general use by species, with tributary and island backwater sites showing the most change. Species

richness increased in both island backwater and tributary sites with declining temperatures, suggesting that these areas might provide a refuge for species as temperatures decline. Flow rates at both of these sites were consistently lower than those in the main channel, supporting this view. Interestingly, species richness increased in tributaries with a slight increase in flow in these areas. These flow rates were still much lower than those in the main channel. Thus, the increase in species use with increased tributary flow may be related to an increase in connectivity of these areas with the main channel. Although we would expect fish species use in tributaries to be strongly tied to the low dissolved oxygen concentrations that often occurred at these sites, this did not occur. Fish species richness was only consistently low in tributaries when dissolved oxygen concentrations were less than 5 mg/L.

Body condition (i.e., relative weight) of freshwater drum was positively related with size and did not change during the winter sessions of 2002 and 2003. However, condition did decline by late spring, perhaps because individuals had expended energy for spawning. Other species such as channel catfish, white bass, and crappie had high relative weights during the study period. Relative weight often corresponds well with fat content in fishes. If this holds true for these populations, then these fish were likely consuming sufficient food to offset energetic costs of overwintering. Foraging did occur in freshwater drum, although it was size dependent. Smaller individuals foraged more frequently than large counterparts, perhaps because these individuals (which had lower condition values) required more energy intake to offset higher mass-specific metabolic rates and lower fat reserves.

Size distributions did change during winter in consistent ways during the two sampling years. Small freshwater drum were predominant in distributions during the

winter but declined by the late spring/summer sampling. Distributions of blue catfish, the other species for which we have sufficiently abundant size data, changed little during the sampling sessions. Potentially, small freshwater drum are moving from deep water and tributary habitats to forage in other habitats as temperatures increase. A contrasting interpretation would be that small individuals suffered higher mortality by late spring. However, condition of all individuals was high and thus does not support size-dependent winter mortality. All sizes of blue catfish appear to remain at sites that we sampled during winter through late spring/early summer.

Summary

Relative to late spring, fishes were more abundant in relatively rare, tributary or deep-water scour areas adjacent to the main channel when temperatures were < 10°C (expectations are outlined in Chapter 1). Fish assemblages in tributaries did differ from the main channel sites during winter, primarily because species that typically occupy more lentic systems were only present in tributaries (particularly in 2002). High catch rates at deep-water artificial sites and in the main channel during winter suggest that these sites are quite important for some species, including the commercially important blue catfish. During cold months, fish using sites adjacent to or directly in the main channel with low velocity refuges may be subject to displacement by barge traffic. As such, we would expect that survival of species that use these areas will be compromised by navigation. Both winter through spring 2002 and 2003 were characterized by high flow and relatively mild temperatures. Future research must explore how site-specific flow rates, temperatures, and fish use of these areas change as a function of different winter conditions (e.g., a more severe, dry winter) and proximity to navigation traffic (see

Executive Summary).

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Table 2-1. Sites selected for sampling during winter through late spring 2002 in the Smithland Pool of the Ohio River.

Habitat Type	Description
Main Channel	Area extending from shore including the center of the channel.
Island/Backwater	Area between an island and the shore. May be closed at one end of the channel (i.e., creating a flow break).
Artificial Flow Break	Artificial structures such as wing dams and moorings that create relatively deep scour holes; includes lock and dam complexes
Tributaries	Streams that flow into the main channel.

Table 2-2. Sampling sites in the Smithland Pool of the Ohio River during winter through late spring 2002 and 2003.

Habitat Type	Site (#)	Location in Pool	Site Description	Mean Depth (m)	River Mile	Location N	Location W
Artificial	14	Upper	Scour adjacent to J. T. Meyers Lock and Dam	7.6	846	37.47373	87.59593
	15	Upper	Scour behind submerged wingdam on the non-channel side of Wabash Island	7.6	850	37.46600	88.00766
	43	Upper	Scour behind submerged wingdam	7.6	875	37.47103	88.10740
	54	Upper	Scour behind submerged wingdam	9.1	883	37.45419	88.19456
	2	Lower	Scour downstream from an abandoned boat ramp	7.6	902.7	37.36623	88.48194
	61	Lower	Scour behind submerged wingdam	7.6	904.5	37.33731	88.48140
	62	Lower	Scour behind submerged wingdam on the non-channel side of Pryor Island	9.1	905.5	37.32228	88.48333
	66	Lower	Scour behind submerged wingdam	10.7	906.3	37.31522	88.49349
	63	Lower	Scour behind submerged wingdam	10.7	907	37.30203	88.50331
	64	Lower	Scour behind submerged wingdam	9.1	907.3	37.29828	88.50535
	65	Lower	Scour behind submerged wingdam	10.7	907.5	37.29581	88.50651
Island	13	Upper	Non-channel side of the first island upstream of Shawneetown Bar	6.1	855	37.43134	88.05804
	20	Upper	Non-channel side of Cincinnati Island	6.1	860	37.39384	88.09156
	53	Upper	Non-channel side of Cave In Rock Island	6.1	880.5	37.46170	88.15633
	30	Upper	Between Hurricane Island and unnamed island immediately downstream	4.6	889.5	37.43806	88.30481
	25	Lower	Non-channel side of Rondeau Island	6.1	901	37.37595	88.46862
	23	Lower	Non-channel side of Pryor Island	6.1	905	37.31287	88.49214

	11	Lower	Non-channel side of the first Sisters Islands	7.6	909	37.27226	88.50574
Main	70	Upper	Numerous submerged boulders near main channel immediately	7.6	869	37.55687	88.10599
	42	Upper	Scour downstream of a sand bar	7.6	878	37.48793	88.07469
	40	Upper	Sheer rock wall exposed to main channel	9.1	880	37.46892	88.14976
	27	Lower	Numerous submerged boulders near main channel	6.1	894.3	37.40544	88.37815
Tributary	22	Upper	Saline River	7.6	867	37.57049	88.12529
	34	Upper	Big Creek	6.1	889.5	37.44280	88.31506
	29	Lower	Deer Creek	4.6	893	37.39818	88.35518
	28	Lower	Small unnamed tributary	3	893.7	37.39668	88.36796
	35	Lower	Threemile Creek	3.1	896	37.42156	88.39661
	37	Lower	Grand Pierre Creek	6.1	897.6	37.42150	88.42973
	1	Lower	Lusk Creek	6.1	902.5	37.37155	88.48615

Table 2-3. Water quality data for each site of the Smithland Pool of the Ohio River during session 1 (January 2002).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	3.87	6.98	53	0	0.526
	15	3.81	7.12	51	*	0.526
	43	*	*	*	*	*
	54	4.36	6.84	77	0.18	0.594
	2	4.32	7.15	79	0.1	0.545
	61	4.23	7.07	69	0.2	0.592
	62	3.98	7.08	65	0	0.574
	66	4.14	7.15	73	0.2	0.59
	63	3.8	7.28	67	0	0.574
	64	3.79	7.26	66	0	0.575
	65	3.79	7.22	67	0	0.575
Island	13	2.58	7.5	39	0.05	0.646
	20	4.29	7.41	46	0.2	0.532
	53	4.49	6.91	63	0	0.587
	30	*	*	*	*	*
	25	4.32	7.12	65	0.2	0.592
	28	3.51	6.4	98	0	0.376
	11	3.7	7.28	64	0	0.573
Main	70	4.62	7.49	60	0.18	0.611
	42	*	*	*	*	*
	40	4.35	7.01	80	0.2	0.629
	27	*	*	*	*	*
Tributary	22	4.53	7.52	63	0	0.651
	34	2.8	5.85	157	0	0.373
	29	3.6	5.7	104	0	0.363
	23	4.19	7.38	59	0.25	0.56
	35	3.48	5.32	83	0	0.378
	37	3.68	5.34	123	0	0.266
	1	3.8	4.92	131	0	0.213

* Not available due to site inaccessibility or equipment failure.

Table 2-4. Water quality data for each site of the Smithland Pool of the Ohio River during session 2 (February through March 2002).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	7.72	6.12	45	0.08	0.436
	15	7.59	6.05	46	*	0.435
	43	8.94	5.69	16	0.22	0.498
	54	5.78	6.99	50	0.2	0.492
	2	6.64	6.73	34	0.02	0.499
	61	7.73	6.11	19	0.3	0.488
	62	6.51	6.76	34	0.1	0.446
	66	7.54	6.1	19	0.6	0.5
	63	7.51	6.18	21	0.2	0.5
	64	6.84	6.68	38	0.02	0.458
	65	6.52	6.49	41	0.02	0.458
Island	13	8.81	5.41	14	0.14	0.476
	20	7.47	6.36	31	0.1	0.441
	53	6.12	7.11	41	0.05	0.482
	30	7.82	6.68	48	1.1	0.514
	25	7.64	6.38	18	0.1	0.48
	23	*	*	*	*	*
	11	6.62	6.83	28	0.2	0.45
Main	70	9.75	5.12	18	0.22	0.552
	42	8.85	5.62	16	0.02	0.498
	40	5.39	7.12	32	0.2	0.568
	27	7.51	7.06	35	0.6	0.516
Tributary	22	7.76	5.51	23	0.04	0.654
	34	7.97	5.45	31	0	0.344
	29	8.77	4.64	35	0	0.253
	28	8.62	5.96	33	0	0.31
	35	8.61	5.01	19	0	0.291
	37	7.24	6.23	34	0	0.233
	1	*	*	*	*	*

* Not available due to site inaccessibility or equipment failure.

Table 2-5. Water quality data for each site of the Smithland Pool of the Ohio River during session 3 (June 2002).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	23.91	6.71	32	*	0.366
	15	23.7	7.2	28	*	0.362
	43	27.52	*	21	0.03	0.524
	54	22.97	6.52	31	0.08	0.372
	2	24.06	6.15	45	0.02	0.414
	61	24.85	6.16	27	*	0.415
	62	23.86	6.11	42	0.12	0.407
	66	25.07	6.1	47	*	0.417
	63	26.9	4.4	56	0	0.456
	64	23.87	6.14	45	0.06	0.406
	65	23.78	6.34	45	0.38	0.406
Island	13	24.5	7.47	15	*	0.511
	20	29.3	7.85	47	0	0.443
	53	23.18	6.92	31	0.1	0.367
	30	27.46	*	28	0.04	0.484
	25	27.64	*	59	0	0.465
	23	25.03	6.21	41	*	0.417
	11	23.69	6.22	41	0.08	0.405
Main	70	27.91	*	57	*	0.519
	42	29.8	8.99	49	*	0.526
	40	24.2	5.14	15	0.2	0.47
	27	24.7	6.3	40	*	0.41
Tributary	22	*	*	*	*	1.375
	34	22.71	*	42	0	0.369
	29	23.55	1	41	0	0.311
	28	22.96	3.1	46	*	0.28
	35	*	*	*	*	*
	37	24.29	5.67	31	0	0.424
	1	*	*	*	*	0.26

* Not available due to site inaccessibility or equipment failure.

Table 2-6. Mean water quality values across sites during three sampling sessions in Smithland Pool of the Ohio River during winter through late spring 2002.

Sampling Session	Habitat Type	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
January	Artificial	4.01	7.12	66.70	0.08	0.57
	Island	3.82	7.10	62.50	0.08	0.55
	Main	4.02	6.18	101.50	0.10	0.45
	Tributary	3.86	6.31	93.86	0.06	0.45
February-March	Artificial	7.25	6.36	31.75	0.17	0.47
	Island	7.37	6.48	32.40	0.32	0.47
	Main	7.88	6.23	25.25	0.26	0.53
	Tributary	8.16	5.47	29.17	0.01	0.35
June	Artificial	24.84	6.18	39.83	0.10	0.42
	Island	25.63	7.12	32.40	0.07	0.44
	Main	26.65	6.81	40.25	0.20	0.48
	Tributary	23.71	4.00	40.20	0.00	0.36

Table 2-7. Water quality data for each site of the Smithland Pool of the Ohio River during session 1 (February 2003).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	2.73	13.36	28	0	0.409
	15	*	*	*	*	*
	43	2.69	13.13	29	0.02	0.562
	54	2.65	13	29	0.22	0.459
	2	*	*	*	*	*
	61	*	*	*	*	*
	62	*	*	*	*	*
	66	*	*	*	*	*
	63	*	*	*	*	*
	64	*	*	*	*	*
	65	*	*	*	*	*
Island	13	3.24	14.49	32	0	0.559
	20	2.69	13.18	27	0.2	0.453
	53	2.34	12.99	28	0.1	0.472
	30	2.81	13.39	34	0.08	0.468
	25	2.87	12.73	40	0.12	0.482
	11	3.3	12.4	43	0.1	0.471
Main	70	2.82	12.6	30	0.4	0.577
	42	2.95	13.04	24	*	0.559
	40	2.75	12.78	30	0.5	0.553
	27	2.79	12.75	40	0.2	0.459
Tributary	22	*	*	*	*	*
	34	8.18	9.14	53	0	0.327
	29	7.71	11.06	46	0	0.287
	23	*	*	*	*	*
	28	7.5	11.14	28	0	0.279
	35	*	*	*	*	*
	37	8.17	9.96	67	0	0.32
	1	*	*	*	*	*

* Not available due to site inaccessibility or equipment failure.

Table 2-8 Water quality data for each site of the Smithland Pool of the Ohio River during session 2 (April 2003).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	12.43	7.89	30	0	0.291
	15	*	*	*	*	*
	43	*	*	*	*	*
	54	*	*	*	*	*
	2	*	*	*	*	*
	61	*	*	*	*	*
	62	*	*	*	*	*
	66	*	*	*	*	*
	63	*	*	*	*	*
	64	*	*	*	*	*
	65	*	*	*	*	*
Island	13	13.67	8.53	28	0.1	0.347
	20	13.12	8.33	29	0.08	0.303
	53	*	*	*	*	*
	30	*	*	*	*	*
	25	*	*	*	*	*
	23	*	*	*	*	*
	11	*	*	*	*	*
Main	70	13.51	8.67	28	0.28	0.351
	42	*	*	*	*	*
	40	*	*	*	*	*
	27	*	*	*	*	*
Tributary	22	*	*	*	*	*
	34	11.1	7.13	76	0	0.282
	29	11.76	6.61	61	0	0.251
	28	12.58	6.12	64	0	0.32
	35	*	*	*	*	*
	37	12.08	7.67	55	0	0.267
	1	*	*	*	*	*

* Not available due to site inaccessibility or equipment failure.

Table 2-9. Water quality data for each site of the Smithland Pool of the Ohio River during session 3 (June 2003).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	18.52	8	28	0.8	0.303
	15	*	*	*	*	*
	43	18.43	7.5	29	0.2	0.432
	54	18.36	7.11	26	0.18	0.312
	2	28.09	7.48	38	0.2	0.336
	61	18.53	5.72	30	0.1	0.334
	62	18.74	5.56	29	0.08	0.334
	66	28.05	8.11	36	0.08	0.324
	63	19.02	5.57	29	0.08	0.336
	64	27.86	8.56	36	0.1	0.327
	65	27.81	7.89	36	0.1	0.33
Island	13	18.97	5.76	26	0.12	0.463
	20	18.86	5.88	25	0.02	0.318
	53	18.34	6.95	28	0.4	0.312
	30	18.44	7.03	24	0.1	0.351
	25	18.48	5.61	33	0.14	0.343
	23	27.8	7.5	36	0.1	0.325
	11	27.77	7.61	32	0.02	0.331
Main	70	18.97	5.9	26	0.1	0.426
	42	29.8	8.99	49	*	0.526
	40	18.49	7.5	28	0.16	0.431
	27	18.4	6.24	35	0.2	0.349
Tributary	22	*	*	*	*	*
	34	17.65	1.83	56	0	0.181
	29	18.6	1.9	96	0	0.155
	28	18.42	2.16	110	0	0.125
	35	*	*	*	*	*
	37	17.15	2.87	72	0	0.126
	1	*	*	*	*	0.26

* Not available due to site inaccessibility or equipment failure.

Table 2-10. Mean water quality values across sites during three sampling sessions in Smithland Pool of the Ohio River during winter through late spring 2003.

Sampling Session	Habitat Type	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
February	Artificial	2.69	13.16	28.67	0.08	0.48
	Island	2.88	13.20	34.00	0.10	0.48
	Main	2.83	12.79	31.00	0.37	0.54
	Tributary	7.89	10.33	48.50	0.00	0.30
March-April	Artificial	12.43	7.89	30.00	0.00	0.29
	Island	13.40	8.43	28.50	0.09	0.33
	Main	13.51	8.67	28.00	0.28	0.35
	Tributary	11.88	6.88	64.00	0.00	0.28
June	Artificial	22.34	7.15	31.70	0.19	0.28
	Island	21.24	6.62	29.14	0.13	0.34
	Main	18.56	6.64	29.50	0.17	0.35
	Tributary	17.96	2.19	83.50	0.00	0.41

Table 2-11. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 1 of 2001-2002 (January 2002).

	Habitat types				
Species	Artificial	Island	Main	Tributary *	Total *
Bigmouth Buffalo	0	1	0	1	2
Blue Catfish	50	8	0	0	58
Bluegill	1	0	0	2	3
Channel Catfish	0	4	0	2	6
Common Carp	0	1	0	1	2
Emerald Shiner	0	10	0	0	10
Flathead Catfish	0	1	0	0	1
Flier	0	0	0	1	1
Freshwater Drum	142	65	33	93	333
Gizzard Shad	5	0	0	2	7
Longear Sunfish	0	0	0	0	0
Black/White Crappie	1	0	0	6	7
Quillback	0	0	0	0	0
Redear Sunfish	0	0	0	1	1
Smallmouth Buffalo	1	0	0	0	1
Spotted Bass	0	0	0	1	1
Warmouth	0	0	0	0	0
White Bass	1	0	0	2	3
Total *	201	90	33	112	436

* Excludes one tributary site with high catch of freshwater drum and catfish.

Table 2-12. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 1 of 2001-2002 (January 2002).

	Habitat types				
Species	Artificial	Island	Main	Tributary *	Total *
Bigmouth Buffalo	0.0	1.1	0.0	0.9	0.5
Blue Catfish	24.9	8.9	0.0	0.0	13.3
Bluegill	0.5	0.0	0.0	1.8	0.7
Channel Catfish	0.0	4.4	0.0	1.8	1.4
Common Carp	0.0	1.1	0.0	0.9	0.5
Emerald Shiner	0.0	11.1	0.0	0.0	2.3
Flathead Catfish	0.0	1.1	0.0	0.0	0.2
Flier	0.0	0.0	0.0	0.9	0.2
Freshwater Drum	70.6	72.2	100.0	83.0	76.4
Gizzard Shad	2.5	0.0	0.0	1.8	1.6
Longear Sunfish	0.0	0.0	0.0	0.0	0.0
Black/White Crappie	0.5	0.0	0.0	5.4	1.6
Quillback	0.0	0.0	0.0	0.0	0.0
Redear Sunfish	0.0	0.0	0.0	0.9	0.2
Smallmouth Buffalo	0.5	0.0	0.0	0.0	0.2
Spotted Bass	0.0	0.0	0.0	0.9	0.2
Warmouth	0.0	0.0	0.0	0.0	0.0
White Bass	0.5	0.0	0.0	1.8	0.7

* Excludes one tributary site with high catch of freshwater drum and catfish (N > 500).

Table 2-13. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 1 of 2001-2002 (January 2002).

	Habitat types			
Species	Artificial	Island	Main	Tributary *
Bigmouth Buffalo	0.00	0.43	0.00	0.40
Blue Catfish	15.00	3.43	0.00	0.00
Bluegill	0.30	0.00	0.00	0.80
Channel Catfish	0.00	1.71	0.00	0.80
Common Carp	0.00	0.43	0.00	0.40
Emerald Shiner	0.00	4.29	0.00	0.00
Flathead Catfish	0.00	0.43	0.00	0.00
Flier	0.00	0.00	0.00	0.40
Freshwater Drum	42.60	27.86	49.50	37.08
Gizzard Shad	1.50	0.00	0.00	0.80
Longear Sunfish	0.00	0.00	0.00	0.00
Black/White Crappie	0.30	0.00	0.00	2.39
Quillback	0.00	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.40
Smallmouth Buffalo	0.30	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.40
Warmouth	0.00	0.00	0.00	0.00
White Bass	0.30	0.00	0.00	0.80
Total	60.30	38.57	49.50	44.65
Total Effort (hours)	3.33	2.33	0.67	2.51

* Excludes one tributary site with high catch of freshwater drum and catfish (N > 500).

Table 2-14. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 2 of 2001-2002 (February through March 2002).

	Habitat types				
Species	Artificial *	Island *	Main	Tributary	Total *
Bigmouth Buffalo	0	0	0	0	0
Blue Catfish	298	11	21	4	334
Bluegill	0	0	0	10	10
Channel Catfish	8	14	6	0	28
Common Carp	1	0	0	1	2
Emerald Shiner	0	0	0	0	0
Flathead Catfish	0	0	0	0	0
Flier	0	0	0	0	0
Freshwater Drum	205	28	237	44	514
Gizzard Shad	10	0	1	6	17
Longear Sunfish	0	0	0	4	4
Black/White Crappie	2	0	0	2	4
Quillback	1	0	0	0	1
Redear Sunfish	0	0	0	0	0
Smallmouth Buffalo	0	1	0	0	1
Spotted Bass	0	0	0	0	0
Warmouth	0	0	0	1	1
White Bass	0	0	0	0	0
Total *	525	54	265	72	916

*Excludes one artificial and one island site due to high catch of freshwater drum and catfish (N > 500).

Table 2-15. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 2 of 2001-2002 (February through March 2002).

	Habitat types				
Species	Artificial *	Island *	Main	Tributary	Total *
Bigmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Blue Catfish	56.76	20.37	7.92	5.56	36.46
Bluegill	0.00	0.00	0.00	13.89	1.09
Channel Catfish	1.52	25.93	2.26	0.00	3.06
Common Carp	0.19	0.00	0.00	1.39	0.22
Emerald Shiner	0.00	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	0.00	0.00	0.00
Flier	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	39.05	51.85	89.43	61.11	56.11
Gizzard Shad	1.90	0.00	0.38	8.33	1.86
Longear Sunfish	0.00	0.00	0.00	5.56	0.44
Black/White Crappie	0.38	0.00	0.00	2.78	0.44
Quillback	0.19	0.00	0.00	0.00	0.11
Redear Sunfish	0.00	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	1.85	0.00	0.00	0.11
Spotted Bass	0.00	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	1.39	0.11
White Bass	0.00	0.00	0.00	0.00	0.00

*Excludes one artificial and one island site due to high catch of freshwater drum and catfish (N > 500).

Table 2-16. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 2 of 2001-2002 (February through March 2002).

	Habitat types			
Species	Artificial *	Island *	Main	Tributary
Bigmouth Buffalo	0.00	0.00	0.00	0.00
Blue Catfish	62.74	4.71	14.00	2.05
Bluegill	0.00	0.00	0.00	5.13
Channel Catfish	1.68	6.00	4.00	0.00
Common Carp	0.21	0.00	0.00	0.51
Emerald Shiner	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	0.00	0.00
Flier	0.00	0.00	0.00	0.00
Freshwater Drum	43.16	12.00	158.00	22.56
Gizzard Shad	2.11	0.00	0.67	3.08
Longear Sunfish	0.00	0.00	0.00	2.05
Black/White Crappie	0.42	0.00	0.00	1.03
Quillback	0.21	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.43	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.51
White Bass	0.00	0.00	0.00	0.00
Total	110.53	23.14	176.67	36.92
EF Effort (hrs)	4.75	2.33	1.50	1.95

*Excludes one artificial and one island site due to high catch of freshwater drum and catfish (N > 500).

Table 2-17. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 3 of 2001-2002 (June 2002).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0	0	0	0	0
Blue Catfish	86	28	5	0	119
Bluegill	0	0	0	2	2
Channel Catfish	4	5	17	0	26
Common Carp	2	0	2	0	4
Emerald Shiner	0	0	0	0	0
Flathead Catfish	3	2	5	0	10
Flier	0	0	0	0	0
Freshwater Drum	22	14	32	0	68
Gizzard Shad	4	0	0	19	23
Longear Sunfish	1	0	0	0	1
Black/White Crappie	0	0	0	0	0
Quillback	1	0	0	0	1
Paddlefish	3	0	0	0	3
Redear Sunfish	0	0	0	0	0
Smallmouth Buffalo	0	0	2	0	2
Spotted Bass	0	0	0	0	0
Warmouth	0	0	0	0	0
White Bass	2	0	1	0	3
TOTAL	128	49	64	21	262

Table 2-18. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 3 of 2001-2002 (June 2002).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Blue Catfish	67.19	57.14	7.81	0.00	45.42
Bluegill	0.00	0.00	0.00	9.52	0.76
Channel Catfish	3.13	10.20	26.56	0.00	9.92
Common Carp	1.56	0.00	3.13	0.00	1.53
Emerald Shiner	0.00	0.00	0.00	0.00	0.00
Flathead Catfish	2.34	4.08	7.81	0.00	3.82
Flier	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	17.19	28.57	50.00	0.00	25.95
Gizzard Shad	3.13	0.00	0.00	90.48	8.78
Longear Sunfish	0.78	0.00	0.00	0.00	0.38
Black/White Crappie	0.00	0.00	0.00	0.00	0.00
Quillback	0.78	0.00	0.00	0.00	0.38
Paddlefish	2.34	0.00	0.00	0.00	1.15
Redear Sunfish	0.00	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	3.13	0.00	0.76
Spotted Bass	0.00	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00	0.00
White Bass	1.56	0.00	1.56	0.00	1.15

Table 2-19. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 3 of 2001-2002 (June 2002).

	Habitat types			
Species	Artificial	Island	Main	Tributary
Bigmouth Buffalo	0.00	0.00	0.00	0.00
Blue Catfish	17.20	10.50	2.50	0.00
Bluegill	0.00	0.00	0.00	1.60
Channel Catfish	0.80	1.88	8.50	0.00
Common Carp	0.40	0.00	1.00	0.00
Emerald Shiner	0.00	0.00	0.00	0.00
Flathead Catfish	0.60	0.75	2.50	0.00
Flier	0.00	0.00	0.00	0.00
Freshwater Drum	4.40	5.25	16.00	0.00
Gizzard Shad	0.80	0.00	0.00	15.20
Longear Sunfish	0.20	0.00	0.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00
Quillback	0.20	0.00	0.00	0.00
Paddlefish	0.60	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	1.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00
White Bass	0.40	0.00	0.50	0.00
Total	25.60	18.38	32.00	16.80
EF Effort (hrs)	5.00	2.70	2.00	1.50

Table 2-20. Total combined catch and mean total length (mm) as a function of habitat type in Smithland Pool of the Ohio River during winter through late spring 2002.

	Number in Habitat						
Species	Artificial *	Island *	Main	Tributary *	Total *	Mean TL	SD
Bigmouth Buffalo	0	1	0	1	2	**	**
Blue Catfish	434	47	26	4	511	232.56	126.15
Bluegill	1	0	0	14	15	112.38	43.48
Channel Catfish	12	23	23	2	60	370.72	134.50
Common Carp	3	1	2	2	8	662.00	112.00
Emerald Shiner	0	10	0	0	10	**	**
Flathead Catfish	3	3	5	0	11	474.10	257.10
Flier	0	0	0	1	1	**	**
Freshwater Drum	369	107	302	137	915	212.90	123.36
Gizzard Shad	19	0	1	27	47	226.98	32.43
Longear Sunfish	1	0	0	4	5	136.60	17.85
Black/White Crappie	3	0	0	8	11	216.27	57.79
Quillback	2	0	0	8	10	442.00	80.61
Paddlefish	3	0	0	0	3	711.67	314.26
Redear Sunfish	0	0	0	1	1	**	**
Smallmouth Buffalo	1	1	2	0	4	420.25	143.86
Spotted Bass	0	0	0	1	1	**	**
Warmouth	0	0	0	1	1	131.00	
White Bass	3	0	1	2	6	276.67	113.98
Total	854	193	362	213	1622		

*Excludes sites with high catches of freshwater drum and catfish (N > 500).

**Not available.

Table 2-21. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 1 of 2002-2003 (February 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0	0	0	0	0
Blue Catfish	61	168	107	3	339
Bighead Carp	0	0	0	0	0
Bluegill	0	0	0	0	0
Channel Catfish	1	9	9	1	20
Common Carp	1	0	0	0	1
Emerald Shiner	0	0	0	0	0
Flathead Catfish	0	0	0	0	0
Flier	0	0	0	0	0
Freshwater Drum	142	131	294	33	600
Gizzard Shad	0	3	0	0	3
Goldeye	0	0	0	19	19
Longear Sunfish	0	1	0	0	1
Mooneye	0	2	2	0	4
Paddlefish	0	0	0	0	0
Black/White Crappie	0	0	0	0	0
Quillback	3	1	0	0	4
Redear Sunfish	0	0	0	0	0
River Carpsucker	5	0	0	0	5
Sauger	1	0	0	0	1
Smallmouth Buffalo	11	0	0	0	22
Spotted Bass	0	0	0	0	0
Shortnose Gar	0	1	0	0	1
Striped Bass	2	1	1	0	4
Warmouth	0	0	0	0	0
White Bass	1	0	0	0	1
Total	228	317	413	56	1025

Table 2-22. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 1 of 2002-2003 (February 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Blue Catfish	26.80	53.00	25.90	5.40	33.07
Bighead Carp	0.00	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00	0.00
Channel Catfish	0.40	2.80	2.20	1.80	1.95
Common Carp	0.40	0.00	0.00	0.00	0.10
Emerald Shiner	0.00	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	0.00	0.00	0.00
Flier	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	62.30	41.30	71.20	58.90	58.54
Gizzard Shad	0.00	0.90	0.00	0.00	0.29
Goldeye	0.00	0.00	0.00	33.90	1.85
Longear Sunfish	0.00	0.30	0.00	0.00	0.10
Mooneye	0.00	0.60	0.50	0.00	0.39
Paddlefish	0.00	0.00	0.00	0.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00	0.00
Quillback	1.30	0.30	0.00	0.00	0.39
Redear Sunfish	0.00	0.00	0.00	0.00	0.00
River Carpsucker	2.20	0.00	0.00	0.00	0.49
Sauger	0.40	0.00	0.00	0.00	0.10
Smallmouth Buffalo	4.80	0.00	0.00	0.00	2.15
Spotted Bass	0.00	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	0.30	0.00	0.00	0.10
Striped Bass	0.90	0.30	0.20	0.00	0.39
Warmouth	0.00	0.00	0.00	0.00	0.00
White Bass	0.40	0.00	0.00	0.00	0.10

Table 2-23. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 1 of 2002-2003 (February 2003).

	Habitat types			
Species	Artificial	Island	Main	Tributary
Bigmouth Buffalo	0.00	0.00	0.00	0.00
Blue Catfish	53.74	126.00	89.20	7.20
Bighead Carp	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00
Channel Catfish	3.53	9.00	18.00	2.40
Common Carp	2.40	0.00	0.00	0.00
Emerald Shiner	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	0.00	0.00
Flier	0.00	0.00	0.00	0.00
Freshwater Drum	153.91	98.25	249.20	23.73
Gizzard Shad	0.00	9.00	0.00	0.00
Goldeye	0.00	0.00	0.00	12.98
Longear Sunfish	0.00	3.00	0.00	0.00
Mooneye	0.00	3.00	8.00	0.00
Paddlefish	0.00	0.00	0.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00
Quillback	10.59	3.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00
River Carpsucker	17.65	0.00	0.00	0.00
Sauger	3.53	0.00	0.00	0.00
Smallmouth Buffalo	38.82	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	3.00	0.00	0.00
Striped Bass	7.06	3.00	2.40	0.00
Warmouth	0.00	0.00	0.00	0.00
White Bass	3.53	0.00	0.00	0.00
Totals	59.17	52.83	116.67	13.03

Table 2-24. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 2 of 2002-2003 (April 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0	0	0	0	0
Blue Catfish	20	1	1	0	22
Bighead Carp	0	0	0	0	0
Bluegill	0	0	0	0	0
Channel Catfish	1	1	1	1	4
Common Carp	0	0	0	0	0
Emerald Shiner	0	0	0	0	0
Flathead Catfish	1	0	1	0	2
Flier	0	0	0	0	0
Freshwater Drum	12	1	3	2	18
Gizzard Shad	0	0	0	0	0
Goldeye	0	0	0	0	0
Longear Sunfish	0	0	0	0	0
Mooneye	0	0	0	0	0
Paddlefish	0	0	0	0	0
Black/White Crappie	0	0	0	0	0
Quillback	0	0	0	0	0
Redear Sunfish	0	0	0	0	0
River Carpsucker	0	0	0	0	0
Sauger	0	0	0	0	0
Smallmouth Buffalo	0	0	0	0	0
Spotted Bass	0	0	0	0	0
Shortnose Gar	0	0	0	0	0
Striped Bass	0	0	0	0	0
Warmouth	0	0	0	0	0
White Bass	0	0	0	0	0
Total	34	3	6	3	46

Table 2-25. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 2 of 2002-2003 (April 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Blue Catfish	58.80	33.30	16.70	0.00	47.83
Bighead Carp	0.00	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00	0.00
Channel Catfish	2.90	33.30	16.70	33.30	8.70
Common Carp	0.00	0.00	0.00	0.00	0.00
Emerald Shiner	0.00	0.00	0.00	0.00	0.00
Flathead Catfish	2.90	0.00	16.70	0.00	4.35
Flier	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	35.30	33.30	50.00	66.70	39.13
Gizzard Shad	0.00	0.00	0.00	0.00	0.00
Goldeye	0.00	0.00	0.00	0.00	0.00
Longear Sunfish	0.00	0.00	0.00	0.00	0.00
Mooneye	0.00	0.00	0.00	0.00	0.00
Paddlefish	0.00	0.00	0.00	0.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00	0.00
Quillback	0.00	0.00	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00	0.00
River Carpsucker	0.00	0.00	0.00	0.00	0.00
Sauger	0.00	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	0.00	0.00	0.00	0.00
Striped Bass	0.00	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00	0.00
White Bass	0.00	0.00	0.00	0.00	0.00

Table 2-26. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 2 of 2002-2003 (April 2003).

	Habitat types			
Species	Artificial	Island	Main	Tributary
Bigmouth Buffalo	0.00	0.00	0.00	0.00
Blue Catfish	40.00	2.40	3.00	0.00
Bighead Carp	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00
Channel Catfish	2.00	2.40	3.00	4.00
Common Carp	0.00	0.00	0.00	0.00
Emerald Shiner	0.00	0.00	0.00	0.00
Flathead Catfish	2.00	0.00	3.00	0.00
Flier	0.00	0.00	0.00	0.00
Freshwater Drum	24.00	2.40	9.00	3.67
Gizzard Shad	0.00	0.00	0.00	0.00
Goldeye	0.00	0.00	0.00	0.00
Longear Sunfish	0.00	0.00	0.00	0.00
Mooneye	0.00	0.00	0.00	0.00
Paddlefish	0.00	0.00	0.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00
Quillback	0.00	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00
River Carpsucker	0.00	0.00	0.00	0.00
Sauger	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	0.00	0.00	0.00
Striped Bass	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00
White Bass	0.00	0.00	0.00	0.00
Total	22.67	1.22	6.00	0.94

Table 2-27. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 3 of 2002-2003 (June 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0	0	0	0	0
Blue Catfish	82	8	21	5	116
Bighead Carp	0	0	0	0	0
Bluegill	0	0	0	0	0
Channel Catfish	4	1	2	0	7
Common Carp	0	0	3	0	3
Emerald Shiner	0	0	0	0	0
Flathead Catfish	0	0	3	0	3
Flier	0	0	0	0	0
Freshwater Drum	9	3	23	1	36
Gizzard Shad	0	0	0	0	0
Goldeye	1	0	0	0	1
Longear Sunfish	0	0	0	0	0
Mooneye	0	0	0	0	0
Paddlefish	1	0	1	0	2
Black/White Crappie	0	0	0	0	0
Quillback	0	0	0	0	0
Redear Sunfish	0	0	0	0	0
River Carpsucker	1	0	0	0	1
Sauger	0	0	0	0	0
Smallmouth Buffalo	0	0	0	0	0
Spotted Bass	0	0	0	0	0
Shortnose Gar	0	0	0	0	0
Striped Bass	0	0	0	0	0
Warmouth	0	0	0	0	0
White Bass	0	0	0	0	0
Total	98	12	53	6	169

Table 2-28. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 3 of 2002-2003 (June 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Blue Catfish	83.70	66.70	39.60	83.30	68.64
Bighead Carp	0.00	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00	0.00
Channel Catfish	4.10	8.30	3.80	0.00	4.14
Common Carp	0.00	0.00	5.70	0.00	1.78
Emerald Shiner	0.00	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	5.70	0.00	1.78
Flier	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	9.20	25.00	43.40	16.70	21.30
Gizzard Shad	0.00	0.00	0.00	0.00	0.00
Goldeye	1.00	0.00	0.00	0.00	0.59
Longear Sunfish	0.00	0.00	0.00	0.00	0.00
Mooneye	0.00	0.00	0.00	0.00	0.00
Paddlefish	1.00	0.00	1.90	0.00	1.18
Black/White Crappie	0.00	0.00	0.00	0.00	0.00
Quillback	0.00	0.00	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00	0.00
River Carpsucker	1.00	0.00	0.00	0.00	0.59
Sauger	0.00	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	0.00	0.00	0.00	0.00
Striped Bass	0.00	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00	0.00
White Bass	0.00	0.00	0.00	0.00	0.00

Table 2-29. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 3 of 2002-2003 (June 2003).

	Habitat types			
Species	Artificial	Island	Main	Tributary
Bigmouth Buffalo	0.00	0.00	0.00	0.00
Blue Catfish	30.00	7.80	21.60	15.00
Bighead Carp	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00
Channel Catfish	5.00	3.00	3.00	0.00
Common Carp	0.00	0.00	3.40	0.00
Emerald Shiner	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	5.20	0.00
Flier	0.00	0.00	0.00	0.00
Freshwater Drum	4.50	4.50	22.13	3.00
Gizzard Shad	0.00	0.00	0.00	0.00
Goldeye	3.00	0.00	0.00	0.00
Longear Sunfish	0.00	0.00	0.00	0.00
Mooneye	0.00	0.00	0.00	0.00
Paddlefish	3.00	0.00	2.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00
Quillback	0.00	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00
River Carpsucker	3.00	0.00	0.00	0.00
Sauger	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	0.00	0.00	0.00
Striped Bass	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00
White Bass	0.00	0.00	0.00	0.00
Total	11.70	1.69	14.76	1.20

Table 2-30. Total combined catch and mean total length (mm) as a function of habitat type in Smithland Pool of the Ohio River during winter through late spring 2003.

	Number in Habitat						
Species	Artificial	Island	Main	Tributary	Total	Mean TL	SD
Bigmouth Buffalo	0	0	0	0	0	.	.
Blue Catfish	493	196	208	8	905	224.29	115.54
Bighead Carp	0	1	0	0	1	880.00	.
Bluegill	0	0	0	0	0	.	.
Channel Catfish	6	18	20	2	46	334.24	115.69
Common Carp	1	0	5	0	6	649.17	37.93
Emerald Shiner	0	0	0	0	0	.	.
Flathead Catfish	1	0	4	0	5	582.00	191.84
Flier	0	0	0	0	0	.	.
Freshwater Drum	197	209	377	36	819	239.96	88.90
Gizzard Shad	3	3	1	19	26	171.38	78.56
Goldeye	0	3	0	0	3	202.33	73.82
Longear Sunfish	0	1	0	0	1	114.00	.
Mooneye	0	2	2	0	4	207.00	62.78
Paddlefish	1	0	1	0	2	630.00	155.56
Black/White Crappie	0	0	1	0	1	224.00	.
Quillback	3	1	0	0	4	215.75	69.08
Redear Sunfish	0	0	0	0	0	.	.
River Carpsucker	7	0	1	0	8	323.75	110.50
Sauger	1	0	0	0	1	246.00	.
Smallmouth Buffalo	11	0	1	0	12	486.83	57.31
Spotted Bass	0	0	0	0	0	.	.
Shortnose Gar	0	1	0	0	1	168.00	.
Striped Bass	0	0	1	0	0	194.00	.
Warmouth	0	0	0	0	4	198.50	32.26
White Bass	1	0	0	0	1	337.00	.

Figure 2-1. Sites within Smithland Pool of the Ohio River during winter through spring 2002 and 2003.

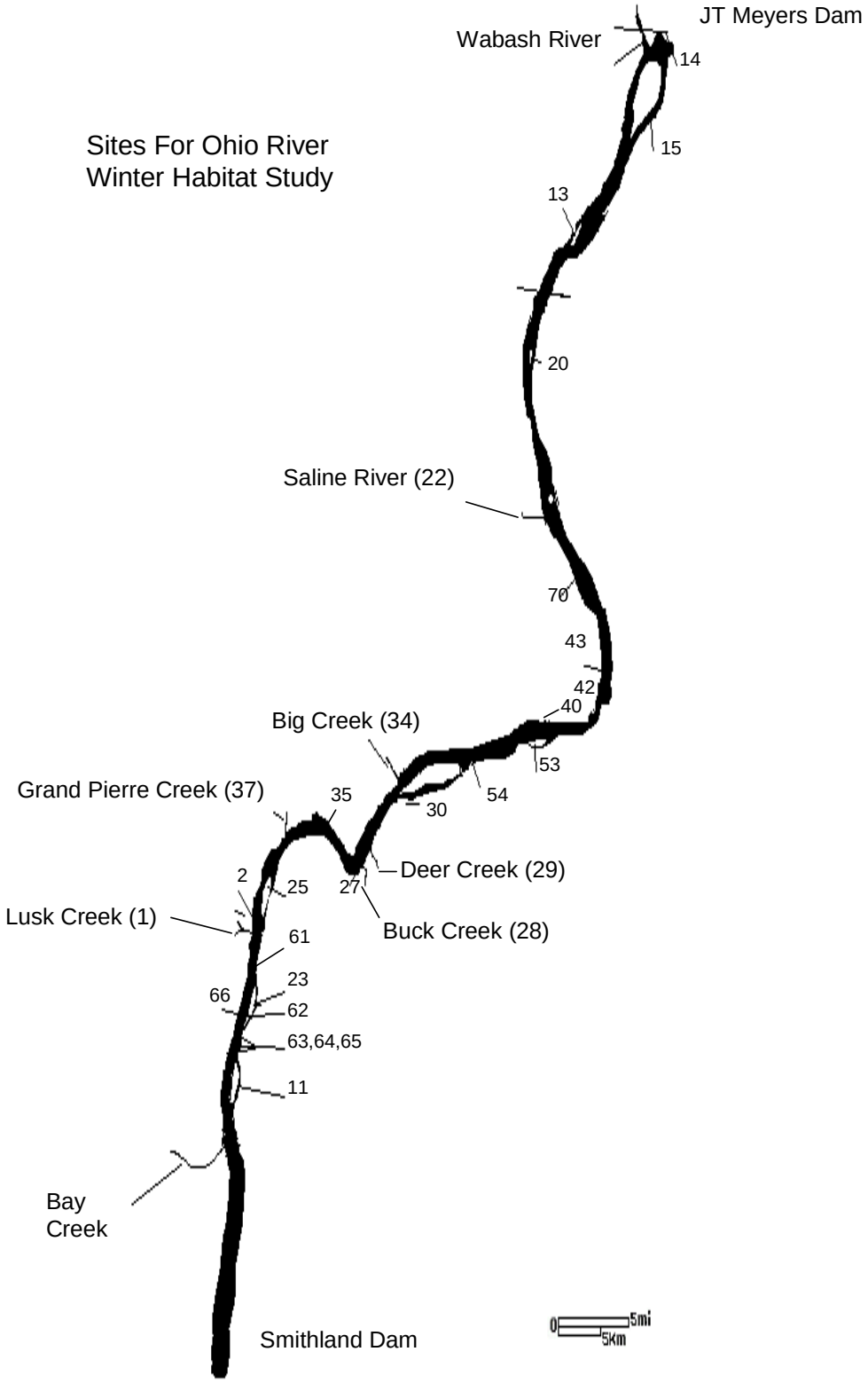


Figure 2-2. Daily discharge (ft^3/s; dashed line) and gage height (ft; solid line) during winter through spring 2002 and 2003 at a gauging station below Smithland Pool, Ohio River (USGS Metropolis, IL). Sampling could only occur during periods of low or normal flow.

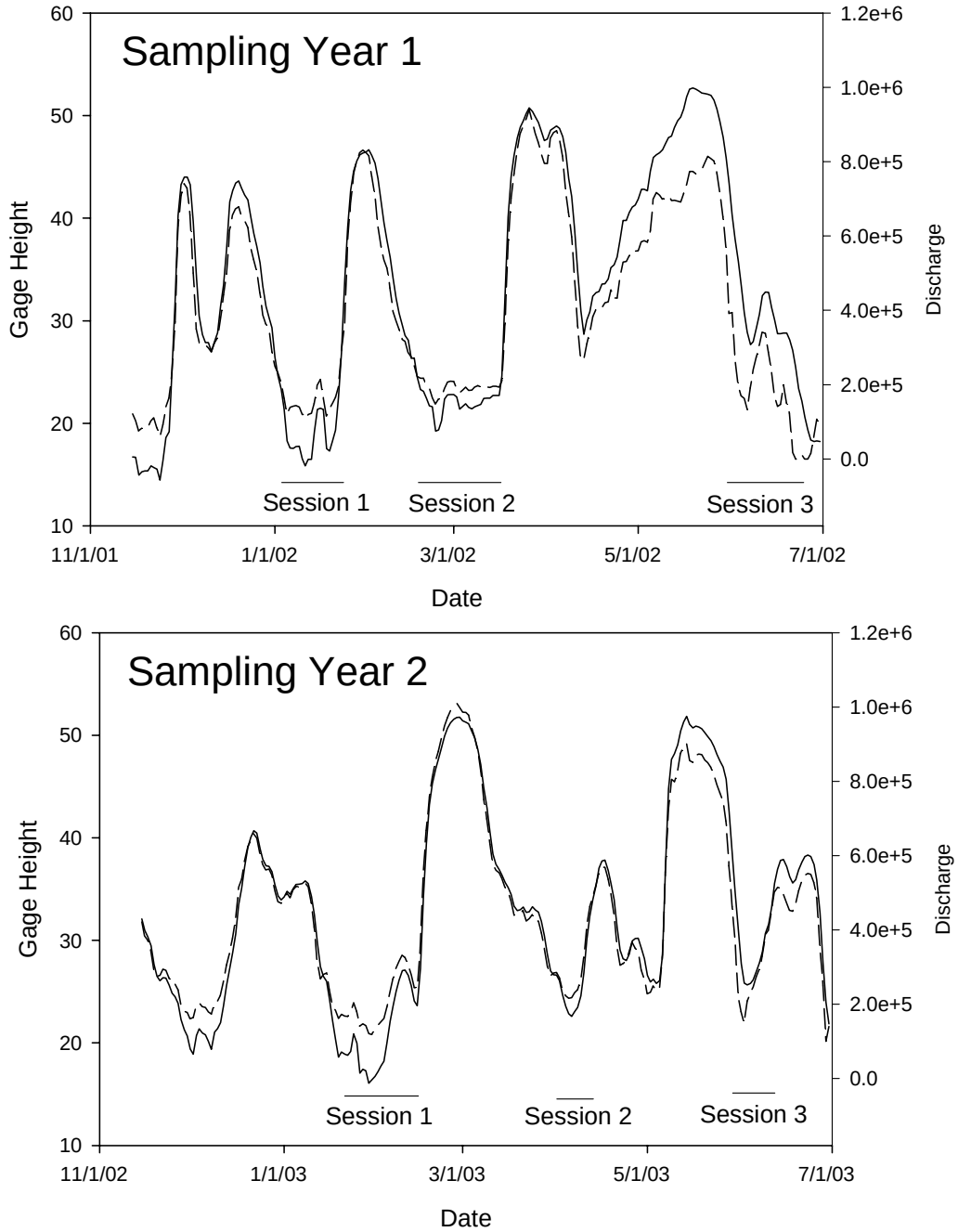


Figure 2-3. Water temperatures of the lower Ohio River during winter through spring 2002 and 2003. Bottom temperatures derive from the bottom of Smithland Pool. Bars above and below the trend line represent maximum and minimum daily temperatures. Surface temperatures derive from the Shawnee Fossil Power Plant below Smithland Dam. Lines on the bottom of each panel show sampling sessions.

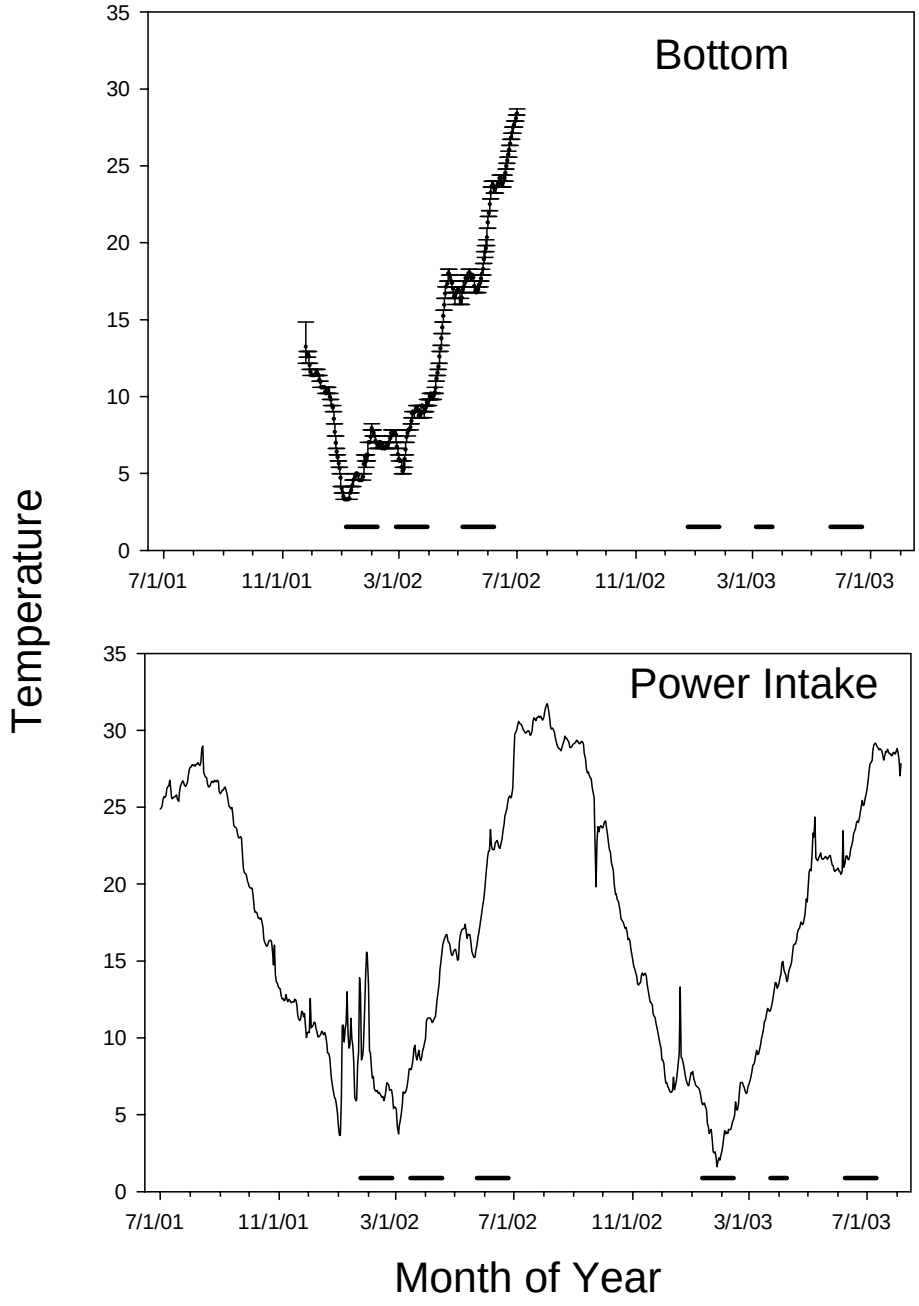


Figure 2-4. Results of a principle components analysis exploring how secchi depth, dissolved oxygen concentration, specific conductance, flow velocity, and temperature varied among sites in Smithland Pool, Ohio River during the winter 2002 and 2003 sampling sessions. The letter in each symbol represents artificial, island, tributary, or main. Note that low and > designations are relative only, often representing slight differences in quantities.

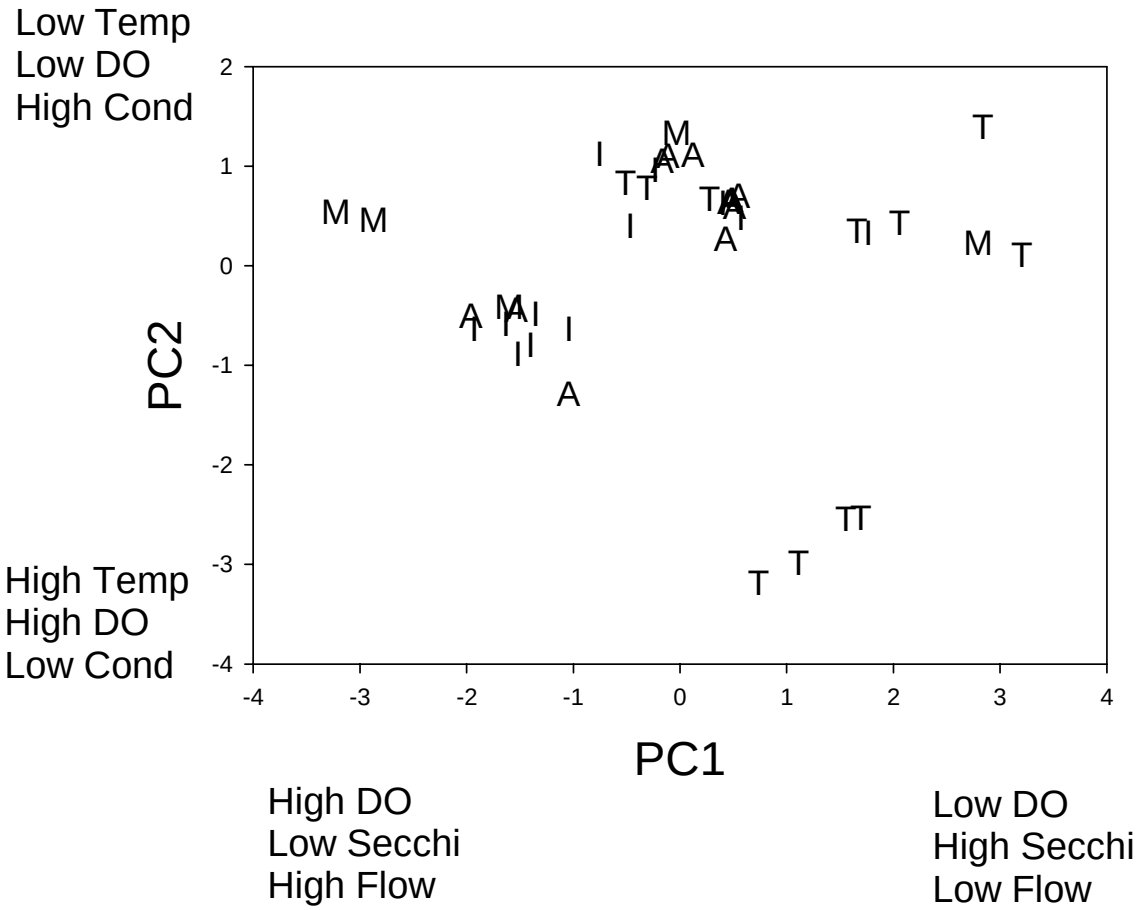


Figure 2-5. Mean number of freshwater drum, channel catfish, and blue catfish captured per hour with variable depth electrofishing in artificial, island, main, and tributary sites in Smithland Pool, Ohio River during winter through late spring 2002 and 2003. Statistics are results of a two way ANOVA exploring the effects of sampling session (Date) and habitat type (Habitat) on fish abundance.

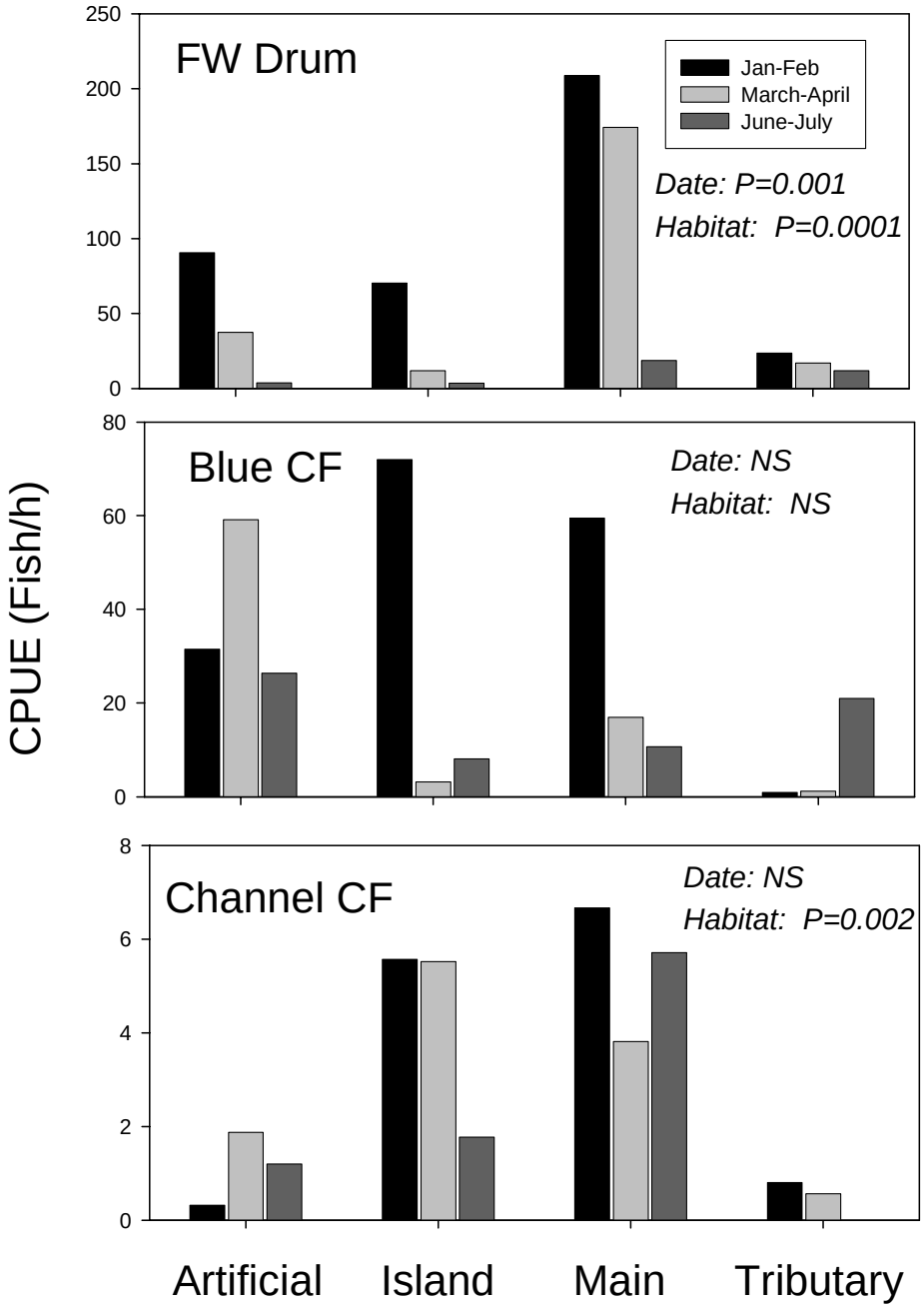


Figure 2-6. Results of principle components analysis for fish species assemblage structure as a function of habitat type (artificial, island, main channel, and tributary) and sampling session during winter through late spring 2002 in Smithland Pool, Ohio River. Relative abundances of all species sampled were included in the analysis (see Table XX). Major loadings were for species found in tributaries. Note that sites either in or adjacent to the main channel contained low numbers of these species. The arrows show that tributary assemblages became more similar to those in other sites by June. A similar pattern did not arise during winter 2003.

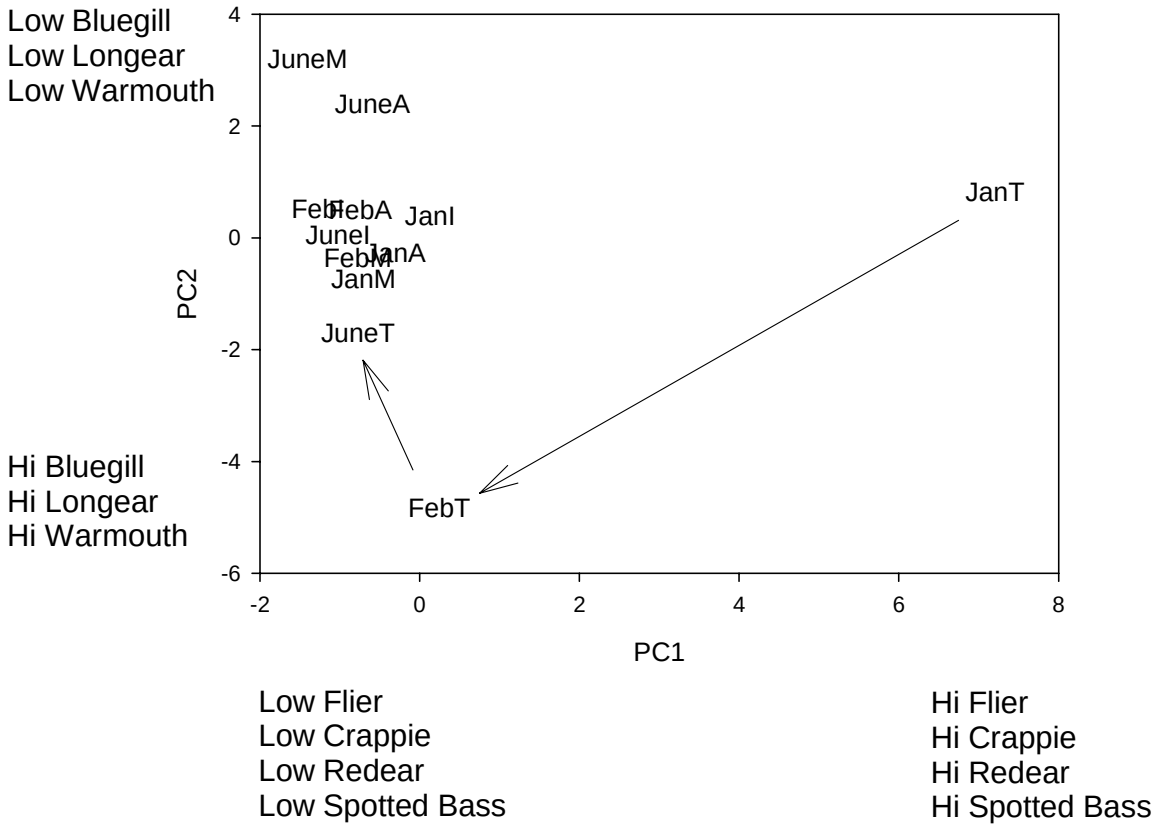


Figure 2-7. Results of non-metric multidimensional scaling ordination for Smithland Pool during winter 2002. Abundances (CPE) of the three fish species and habitat-specific water quality were quantified at each site. Water quality had little effect on the ordination. Conversely, freshwater drum were associated with main channel sites, blue catfish with artificial sites, and channel catfish with island sites. No structure was detected in the 2003 data set.

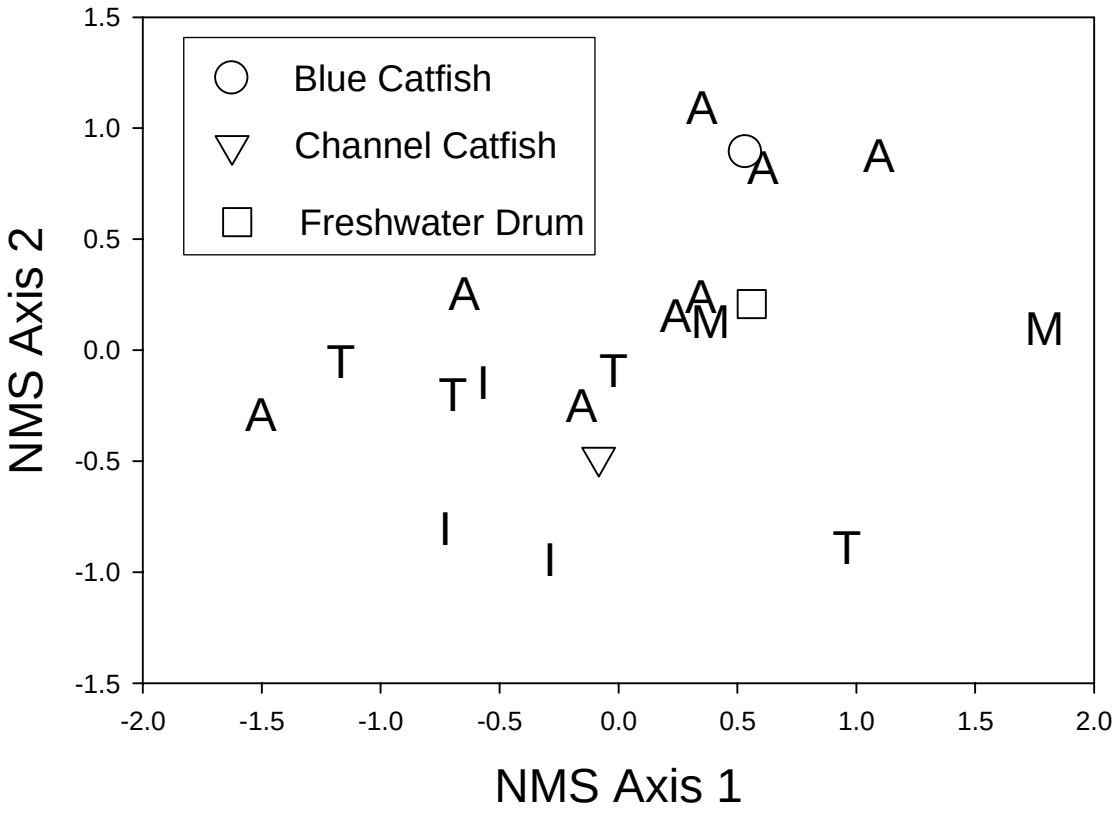


Figure 2-8. Mean total length (mm) of freshwater drum, channel catfish, and blue catfish in artificial, island, main, and tributary sites during winter through late spring 2002 and 2003 in Smithland Pool, Ohio River. An ANOVA for freshwater drum revealed that fish in tributary sites were smaller than at other sites.

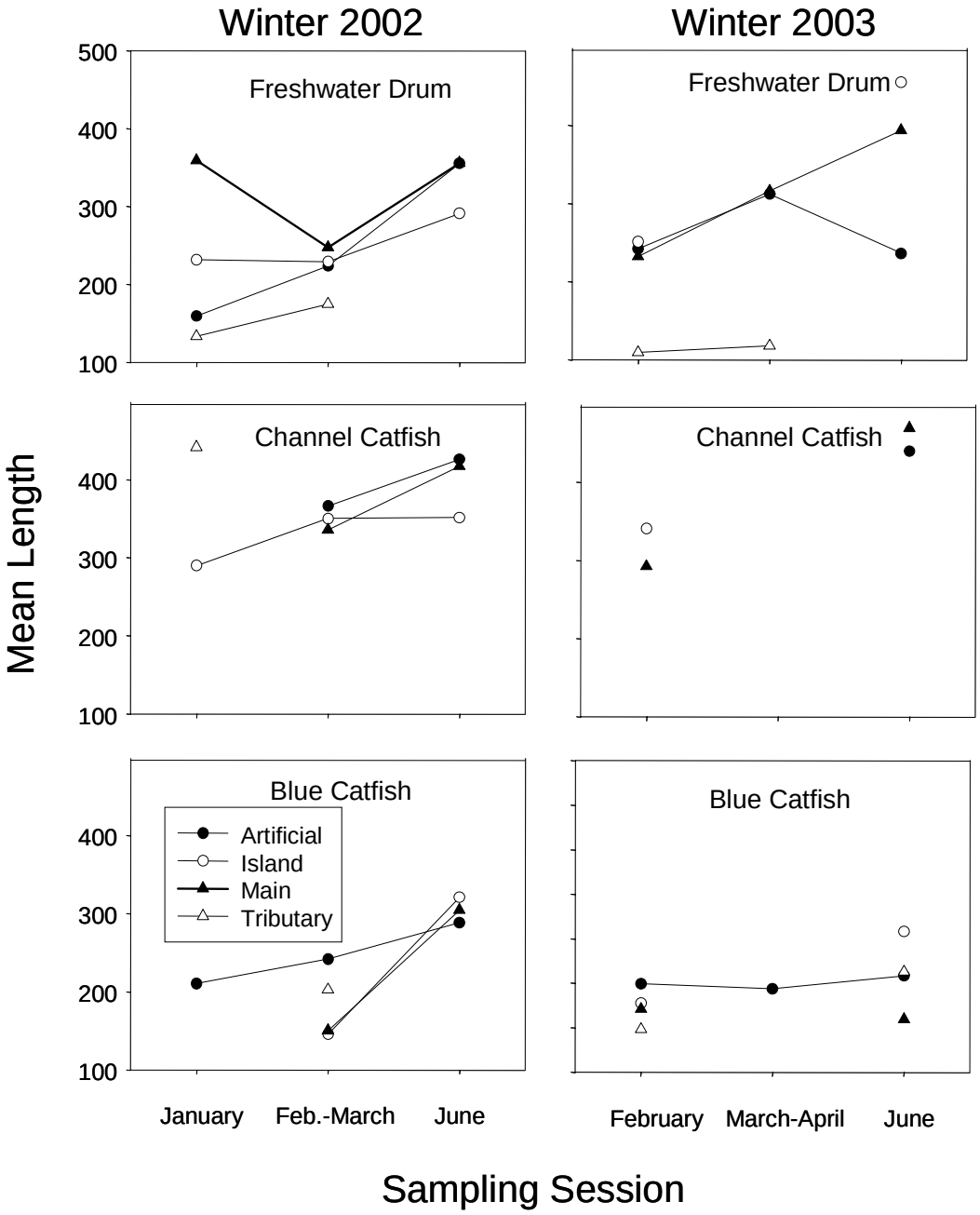


Figure 2-9. Number of species during winter through spring 2002 and 2003 as a function of temperature in Smithland Pool, Ohio River.

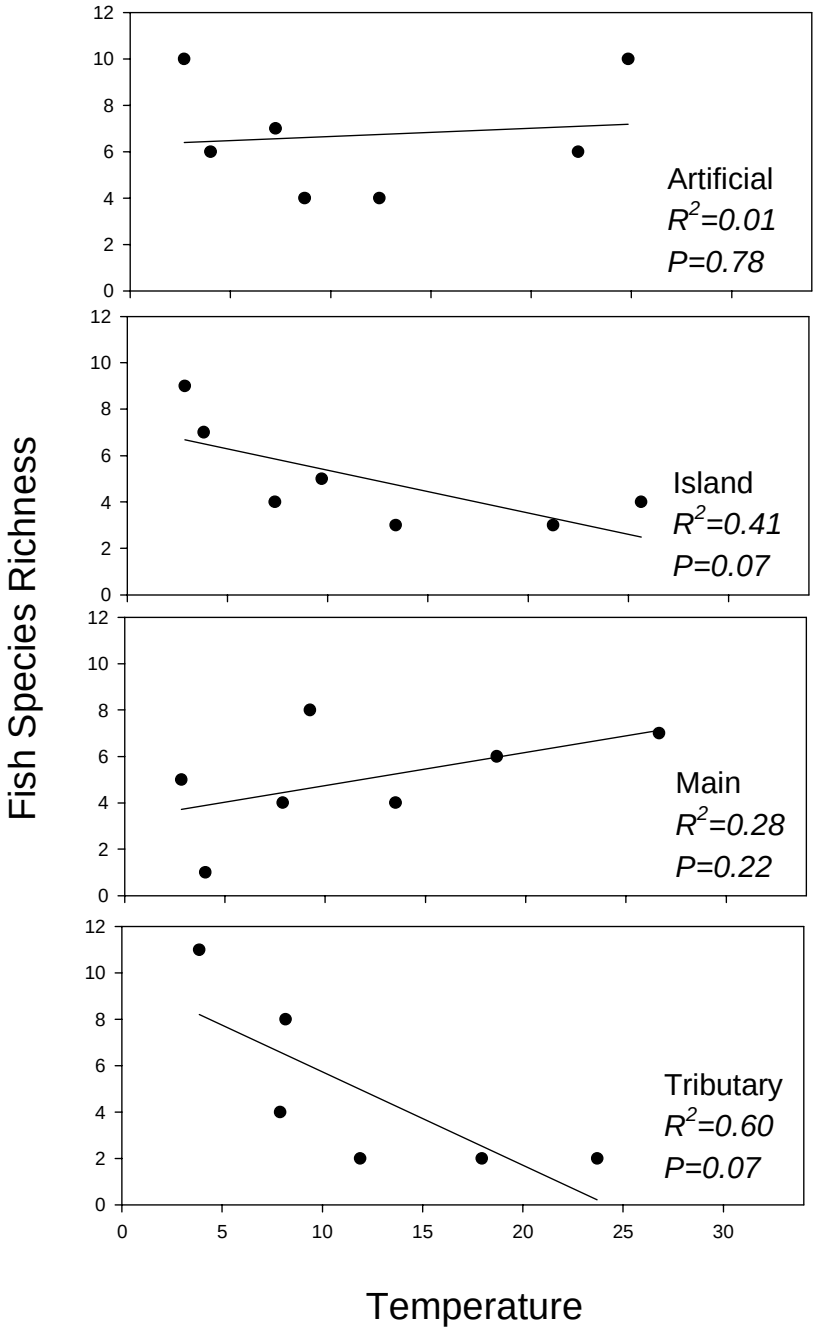


Figure 2-10. Number of species during winter through spring 2002 and 2003 as a function of dissolved oxygen concentration (mg/L) in Smithland Pool, Ohio River.

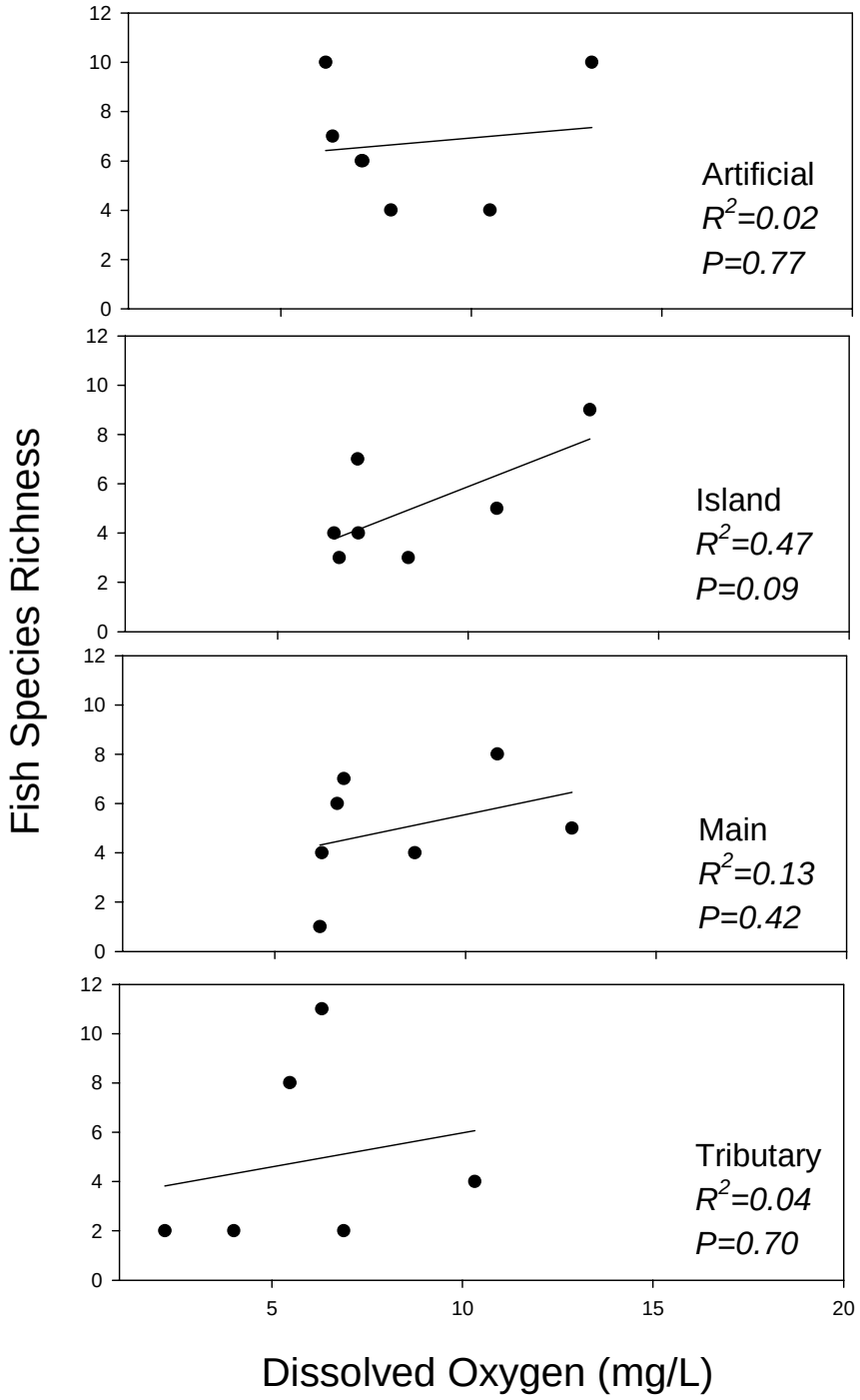


Figure 2-11. Number of species during winter through spring 2002 and 2003 as a function of flow (m/s) in Smithland Pool, Ohio River.

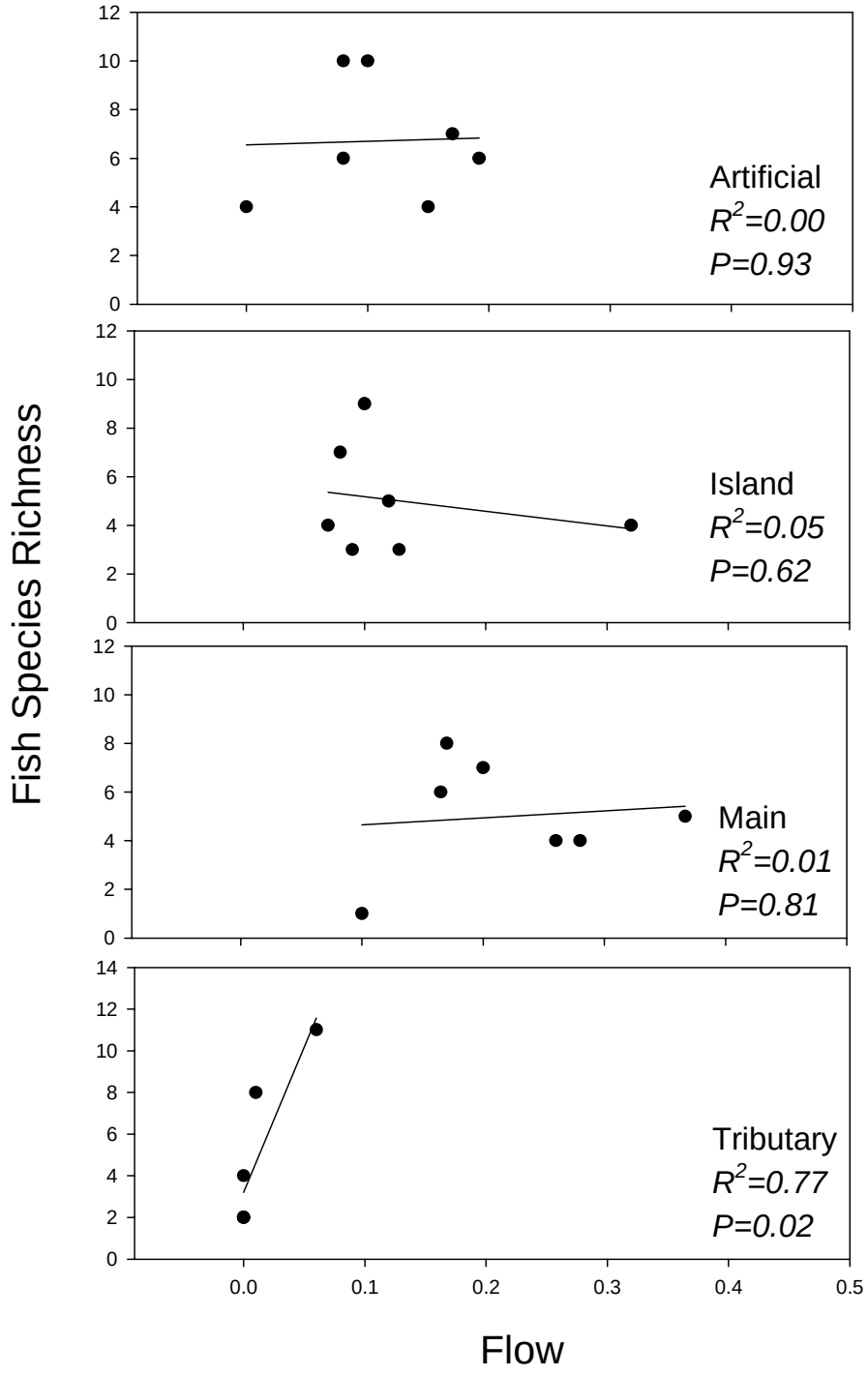


Figure 2-12. Length at age for freshwater drum, channel catfish, crappie, and white bass in Smithland Pool, Ohio River during winter through late spring 2002 (solid symbols) and 2003 (open symbols).

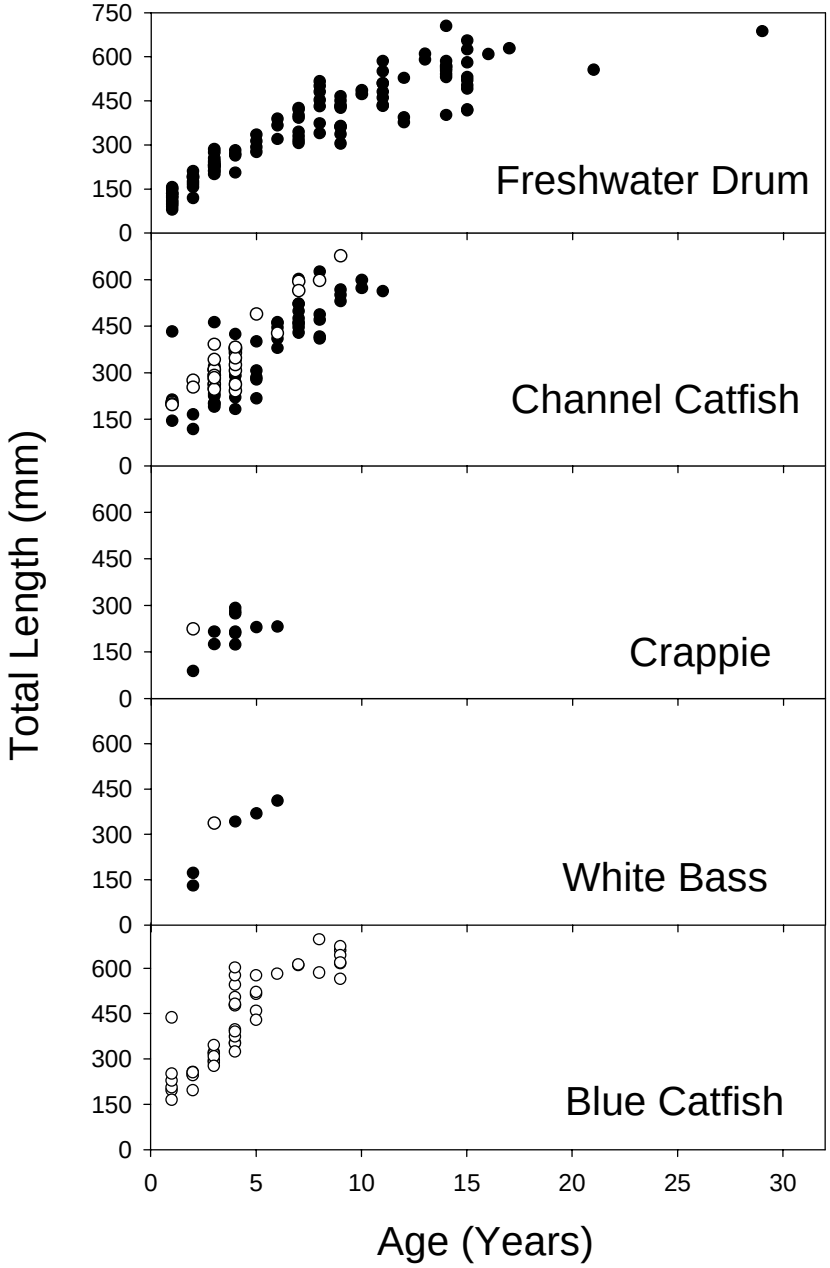


Figure 2-13. Length frequency distribution for freshwater drum in Smithland Pool, Ohio River during winter through spring 2002.

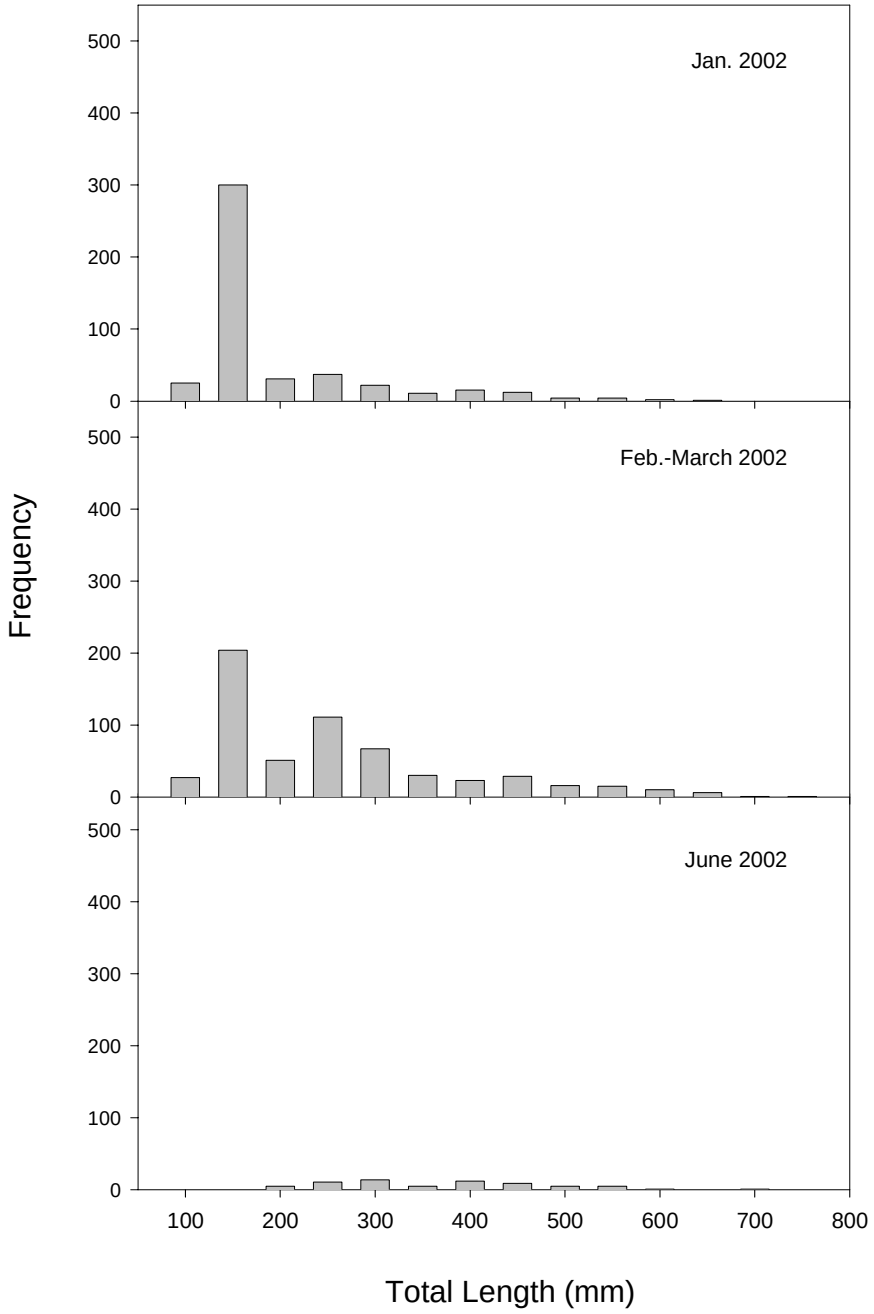


Figure 2-14. Length frequency distribution for freshwater drum in Smithland Pool, Ohio River during winter through spring 2003.

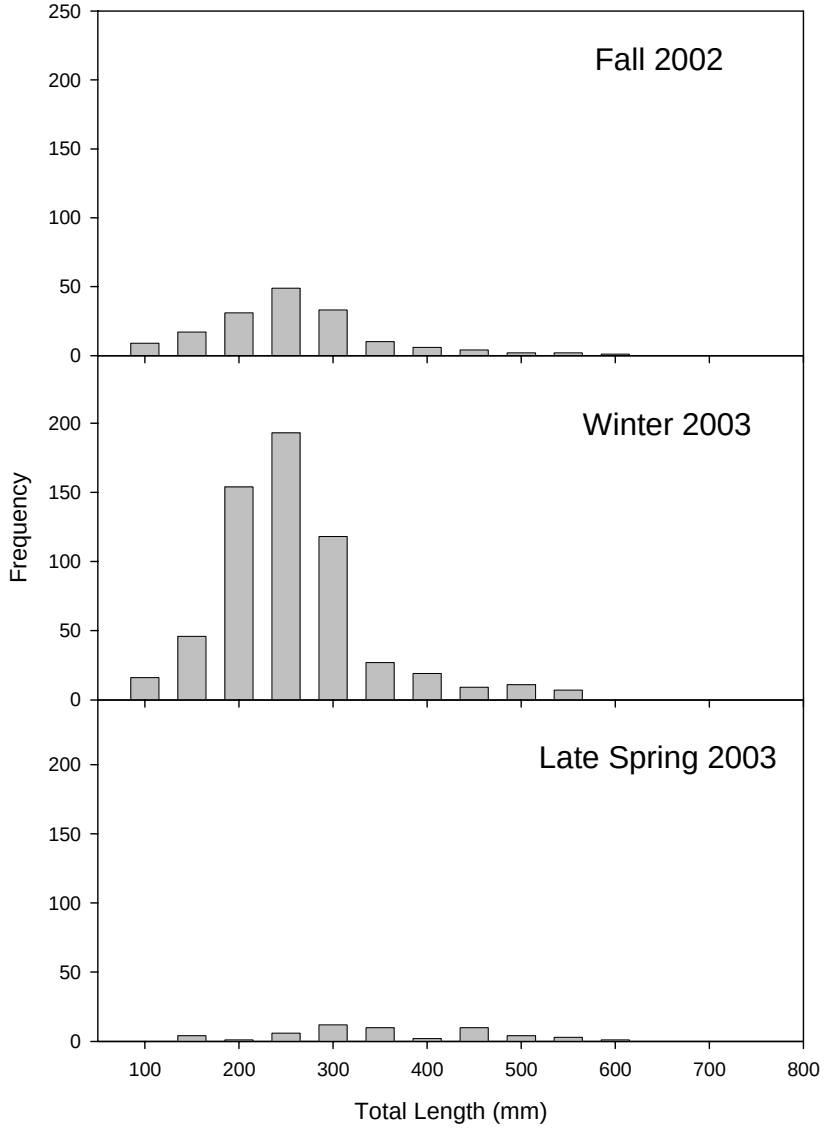


Figure 2-15. Relative weights (Wr) of freshwater drum sampled during three periods in Smithland Pool, Ohio River during winter 2002.

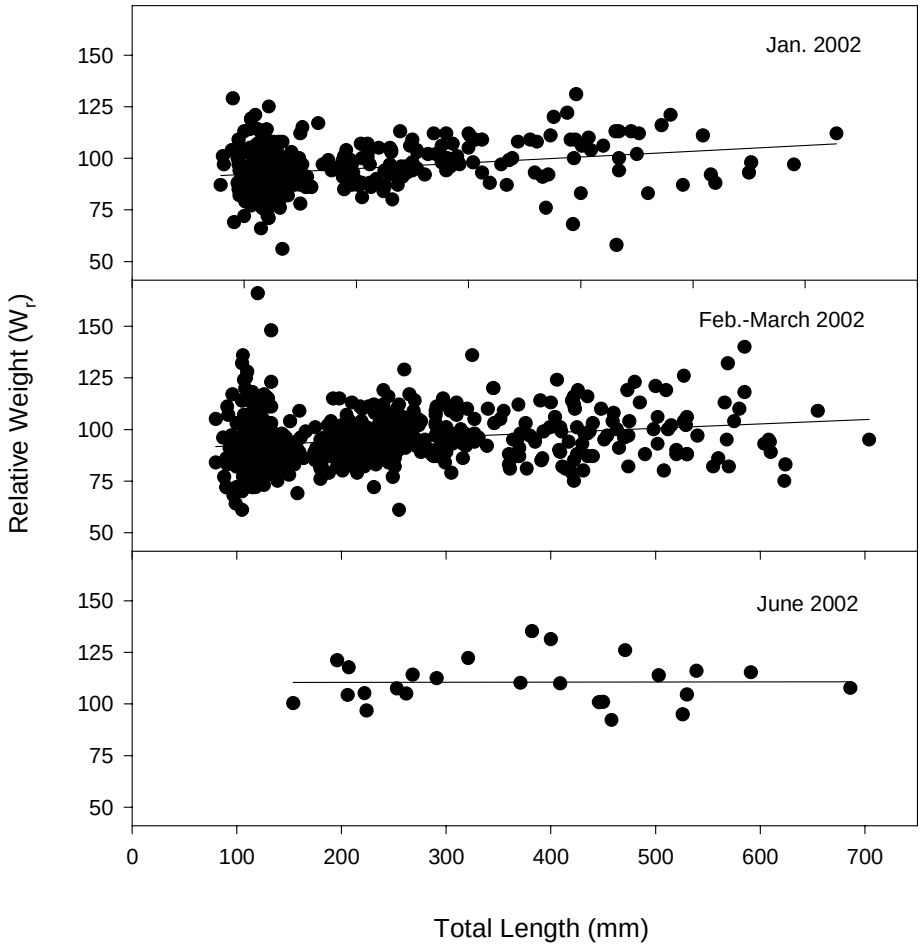


Figure 2-16. Relative weights (Wr) of freshwater drum sampled during four periods in Smithland Pool, Ohio River during winter 2003.

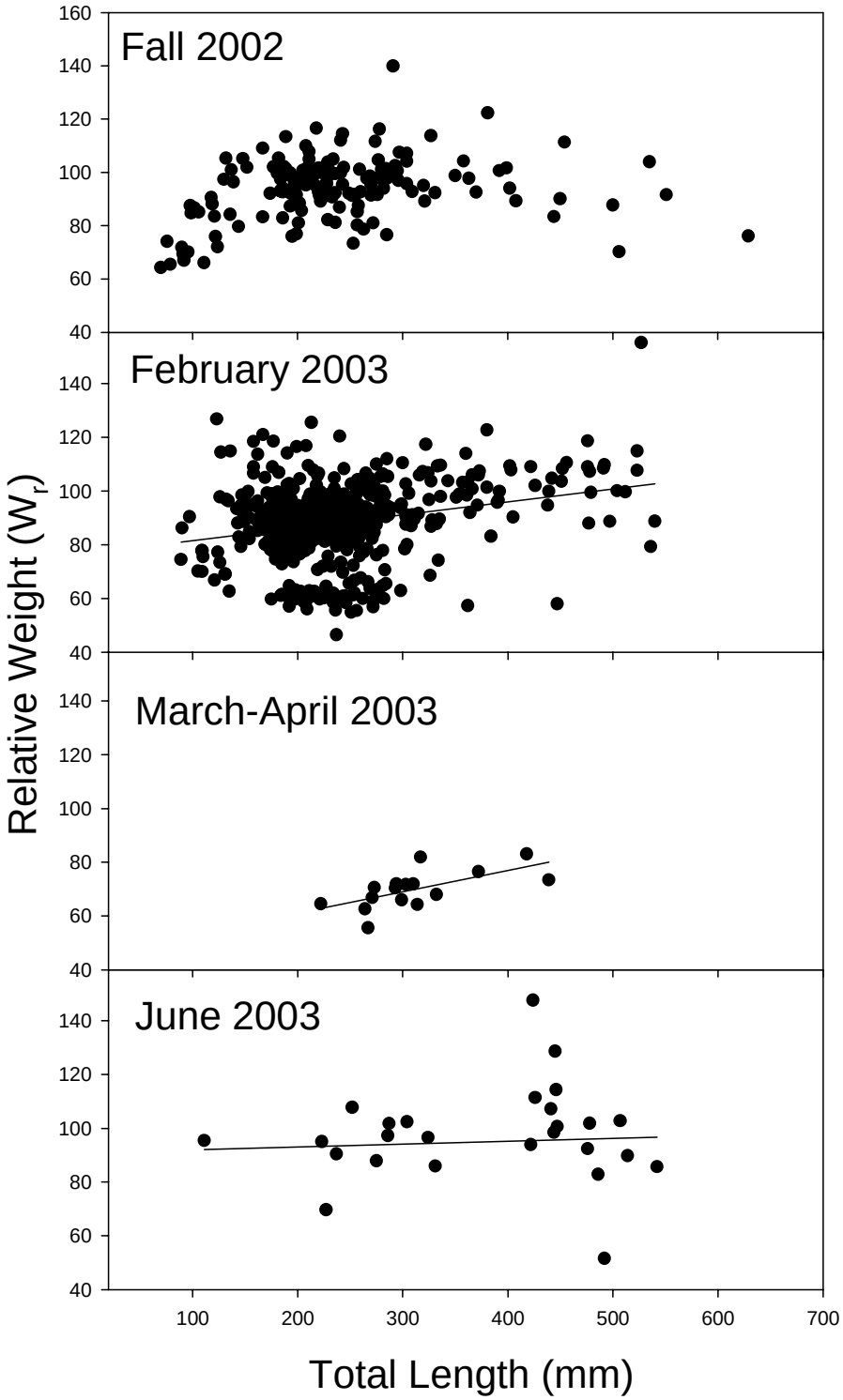


Figure 2-17. Proportion of freshwater drum with empty stomachs as a function of 50 mm length class during the first two sampling sessions of winter 2002 in Smithland Pool, Ohio River. Each length class is comprised of 3-8 individuals.

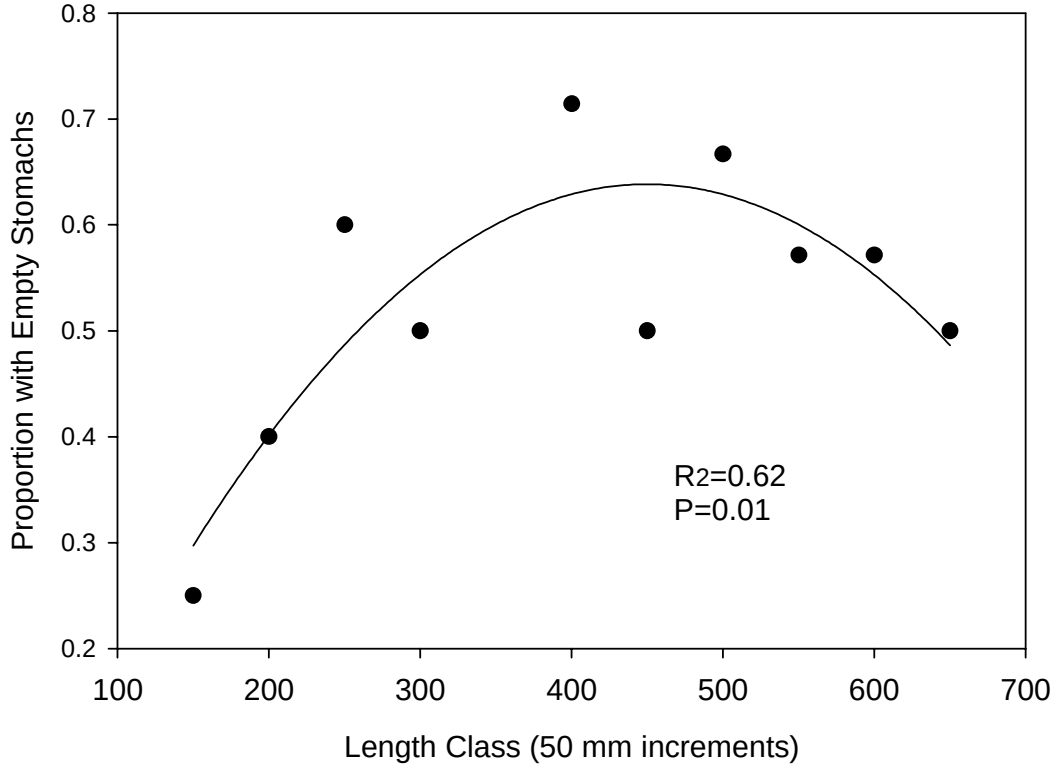


Figure 2-18. Length frequency distribution for channel catfish in the Smithland Pool of the Ohio River during winter through late spring 2002.

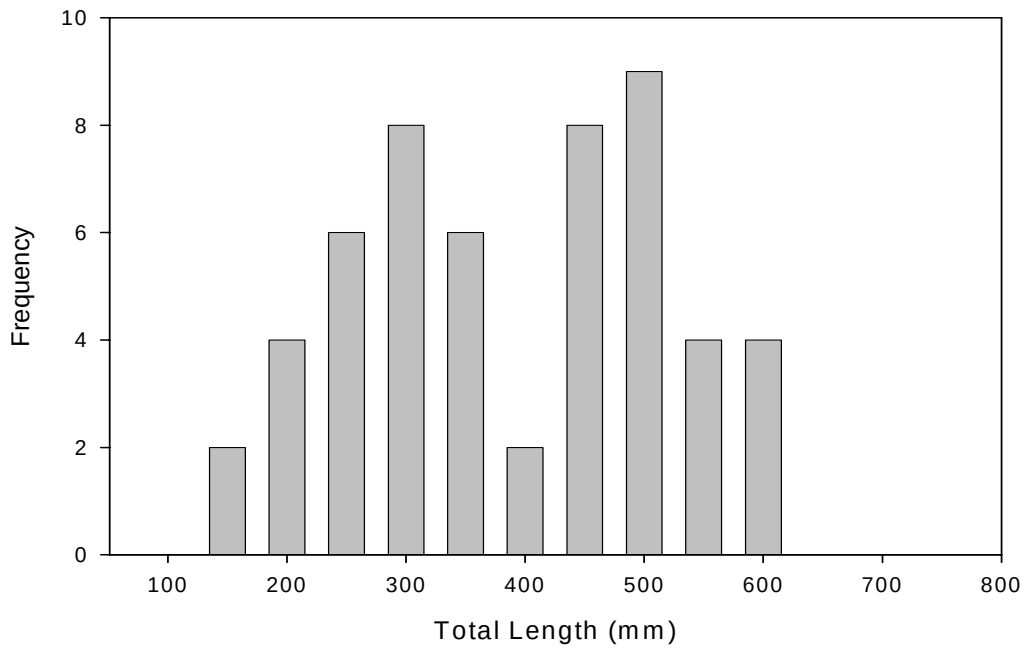


Figure 2-19. Length frequency distribution for channel catfish in the Smithland Pool of the Ohio River during winter through late spring 2003.

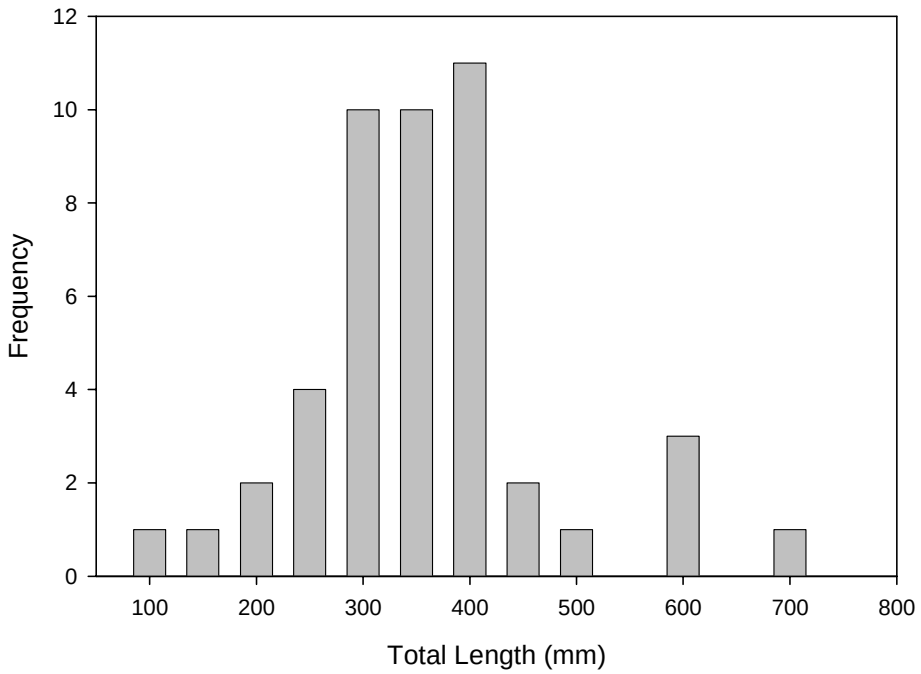


Figure 2-20. Relative weight (Wr) as a function of total length of channel catfish during winter through late spring 2002 in Smithland Pool, Ohio River.

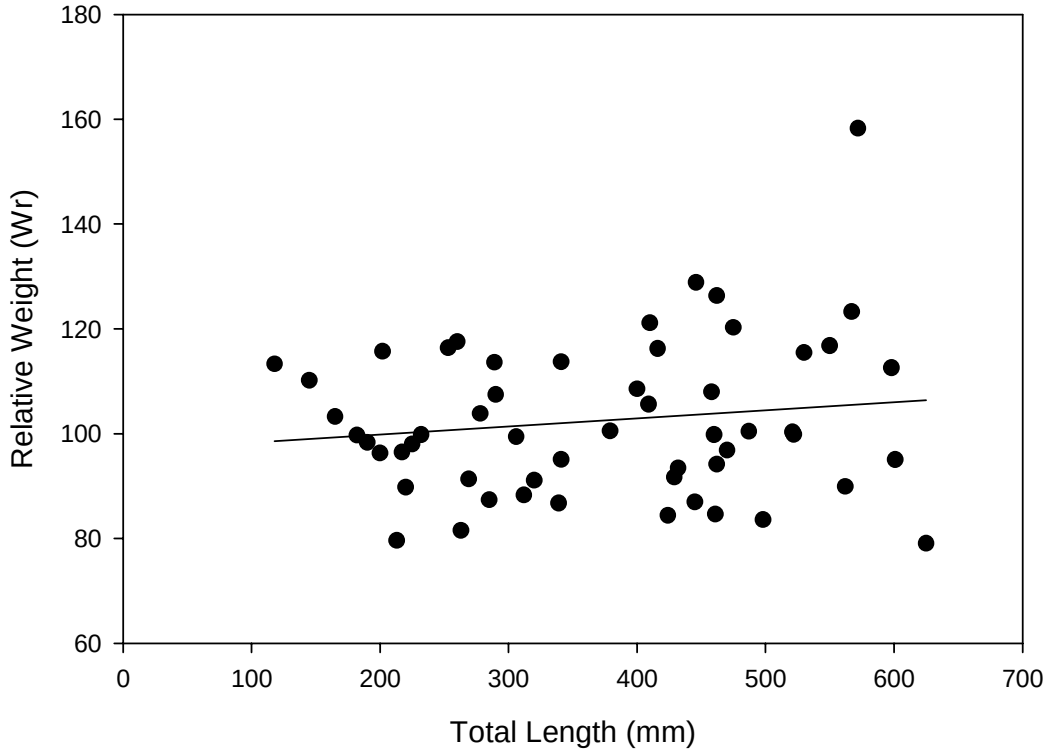


Figure 2-21. Relative weight (Wr) as a function of total length of channel catfish during fall 2002 through late spring 2003 in Smithland Pool, Ohio River.

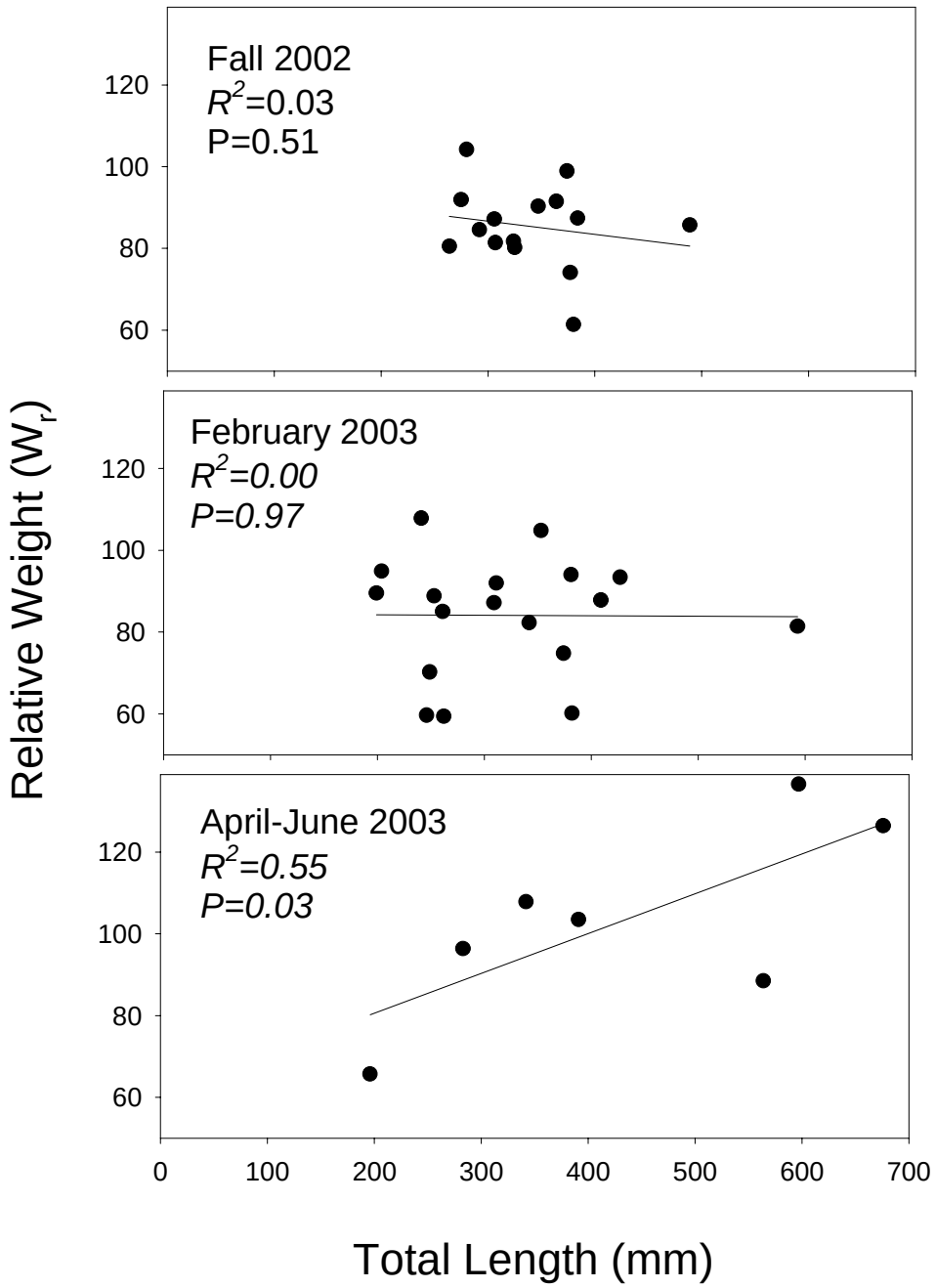


Figure 2-22. Length frequency distribution for blue catfish in the Smithland Pool of the Ohio River during winter through late spring 2002.

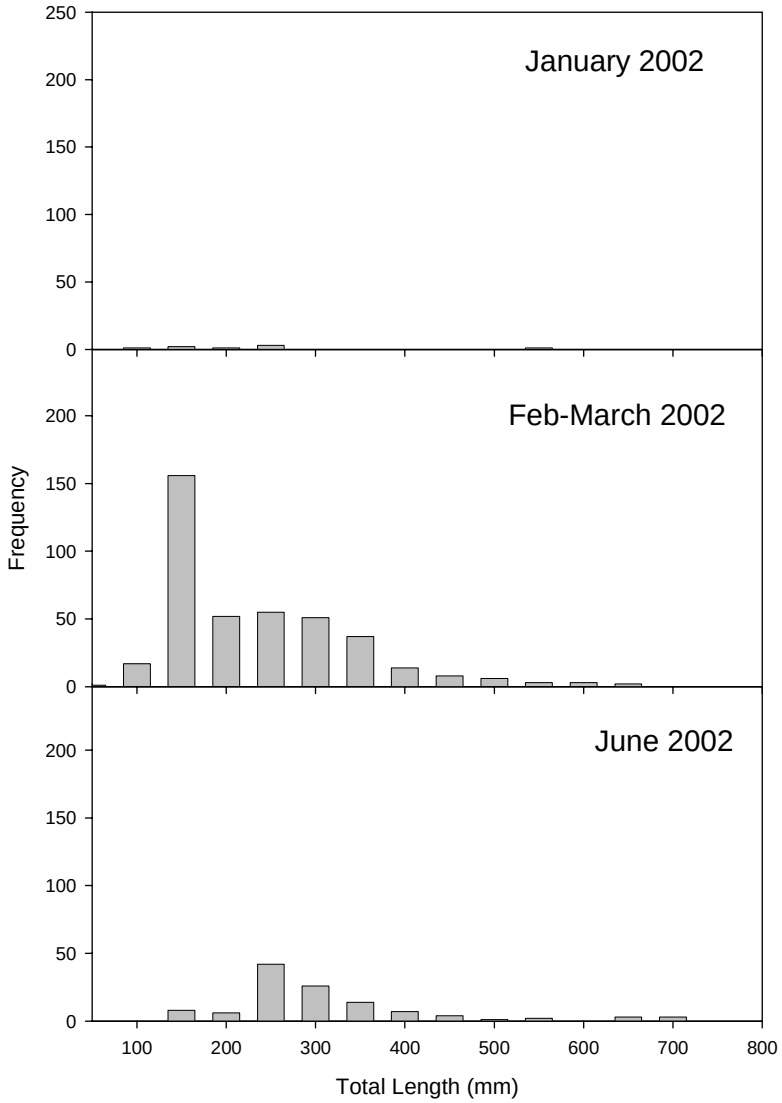


Figure 2-23. Length frequency distribution for blue catfish in the Smithland Pool of the Ohio River during winter through late spring 2003.

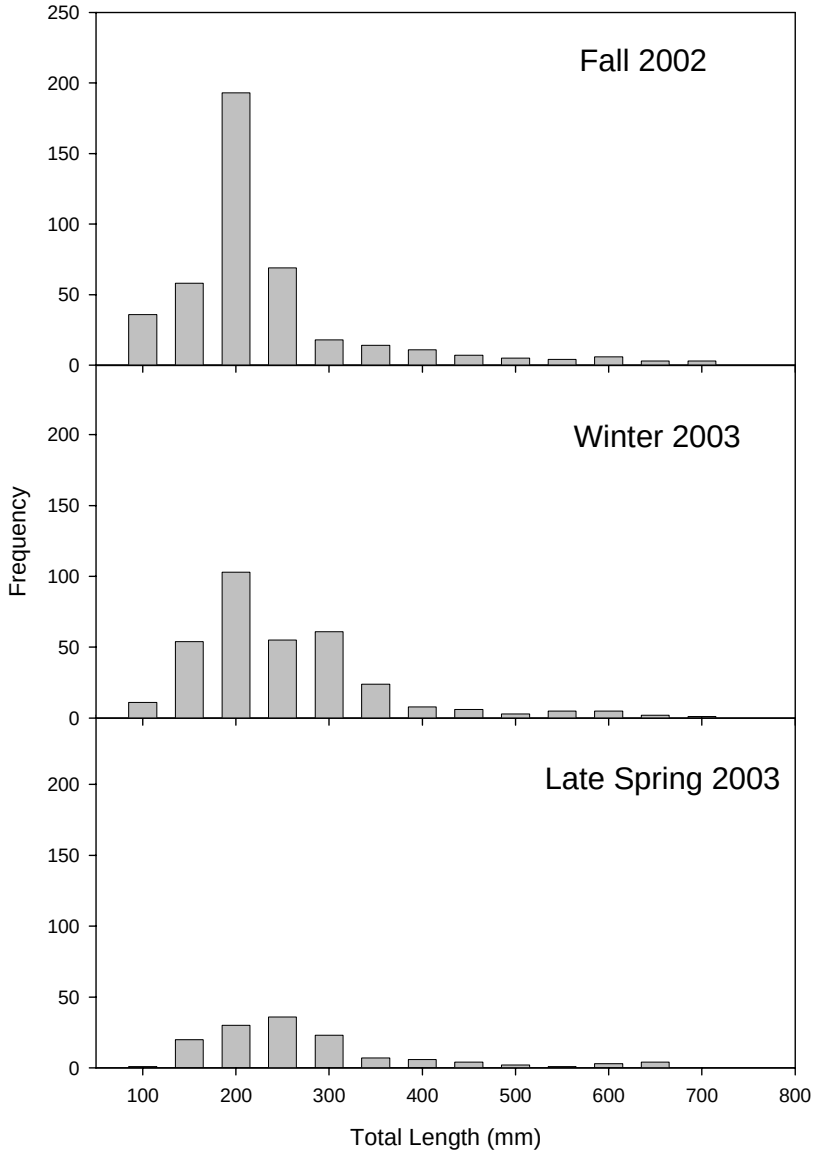


Figure 2-24. Blue catfish lengths versus weights during winter 2002. An analysis of covariance (ANCOVA) revealed that intercepts of lines differed among dates, with the lowest intercept occurring during the June 2002 sampling period.

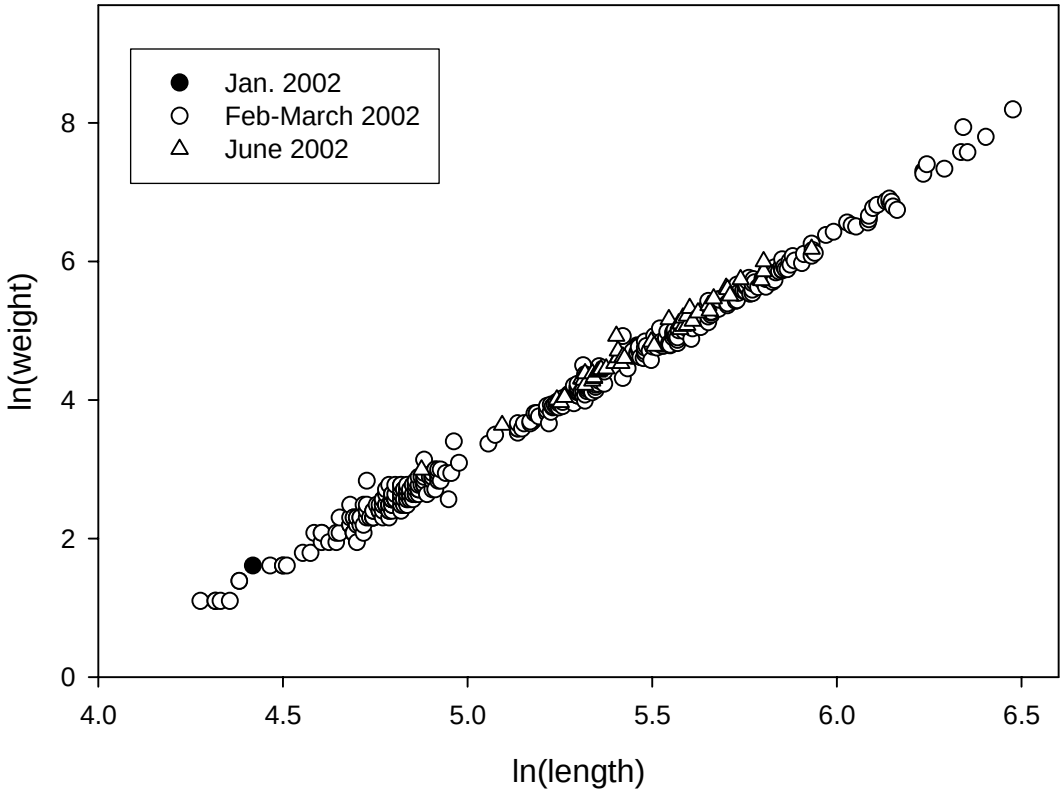
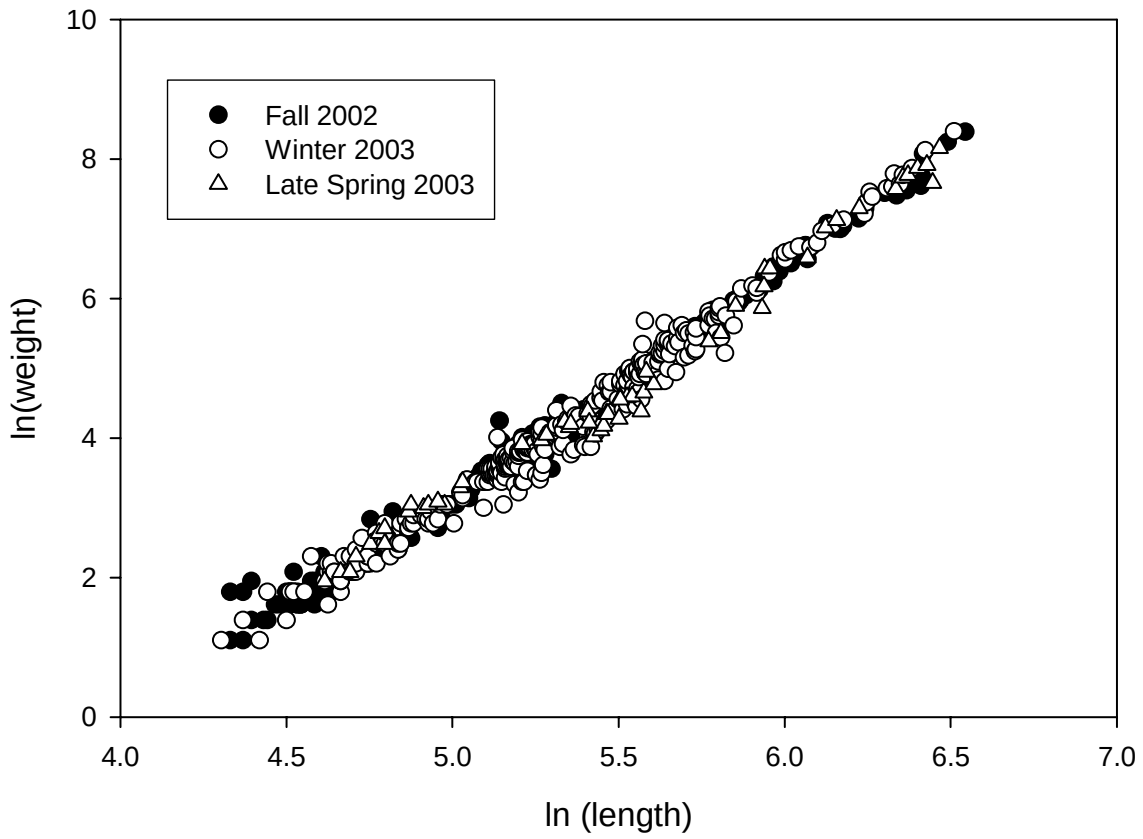


Figure 2-25. Blue catfish lengths versus weights during fall 2002 through winter 2003. An analysis of covariance (ANCOVA) revealed that intercepts of lines differed among dates, with the lowest intercept occurring during the fall 2002 sampling period.



Chapter 3 – Belleville Pool Field Sampling 2001-2003

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INTRODUCTION

Fishes enter a torpor-like state in winter (Crawshaw 1984) where metabolic rates and consequently, respiration and activity rates are low (Carlson 1992, Cunjak 1996, Bodensteiner and Lewis 1992). The inability of a fish to expend energy in cold temperatures makes them susceptible to adverse physiochemical conditions, such as low dissolved oxygen concentrations and strong current velocities (Cunjak 1996). Mortality rates of fishes can be high during low water temperatures in winter (Bodensteiner and Lewis 1992, Lyons 1997); however, fishes select refuge habitats to survive winter (Johnson et al. 1998). Given the link between winter temperature and fish mortality, fishery managers need to locate and protect winter refuge habitats.

Despite early calls for wintertime fish research (Hubbs and Trautman 1935), little is known about winter habitat preferences of fishes in temperate river systems (Hubbs and Trautman 1935, Nielsen et al. 1986, Sheehan et al. 1994). Sheehan et al. (1994) and Garvey et al. (2002; Chapter 1) reviewed the literature on species tolerance to velocity and temperature in large rivers, and reported low tolerance to high velocities at temperatures below 4 ºC. Species should partition habitat during winter largely as a function of their relative tolerance to winter temperatures, flow velocity, and minimum dissolved oxygen concentration (Johnson et al. 1998). In our study on Belleville Pool, macrohabitats of the Ohio River provide habitat-specific combinations of these three important factors. We identified five main habitat types (Table 3-1, see Vallazza et al.

1994 and Cray 1999 for similar delineations). Based on research cited herein and in Sheehan et al. (1994) and Garvey et al. (2002; Chapter 1), backwaters, island habitats, tributary confluences, and deep hole habitats provide winter refuges for riverine fishes.

Objectives

Our objective was to (1) determine species/habitat associations among main channel, tributary mouth, backwater, head of island, tail of island, and deep hole habitats during winter in Belleville Pool, Ohio River. A secondary objective was to determine abiotic habitat characteristics associated with fish habitat use. This research was conducted as partial fulfillment of a Master's degree (see completed thesis, Appendix 1).

LITERATURE REVIEW

Winter habitats of fishes in large rivers

Physiochemical tolerance limits influence range distributions and habitat use. Within the range of a species, seasonal variations in physiochemical factors are often extreme, such as cold winter conditions in temperate climates. During seasonal extremes, animals select refuge habitats where physiochemical factors are unlikely to exceed tolerance limits. In large temperate river systems, extremely low water temperatures during winter coupled with high flows increase mortality rates of fishes (Bodensteiner and Lewis 1992, Lyons 1997). Low levels of dissolved oxygen also increase mortality of fishes, and occur typically during ice-cover of backwater areas. Many fishes forage infrequently during cold winter extremes, and select refuges that minimize energy depletion. Fishes often increase fat-reserves before winter; hence, reducing mortality associated with energy depletion. However, energy reserves may not suffice given long

winters or energy expenditures due to disturbance, such as variation in river flows or boat traffic (Nielsen et al. 1986).

Temperature and flow

During winter, riverine fishes select habitats with relatively high temperatures and low flows. Riverine fishes overwinter in velocity shelters (Logsdon 1993, Bodensteiner and Lewis 1994, Johnson et al. 1998) and areas with warmer temperatures and lower flows than mainstem river sections, such as off-channel coves, marinas, embayments and industrial warm-water outflows (Raibley et al. 1997, Sheehan et al. 1994, Knights et al. 1995, Gent et al. 1995). Also, backwater areas with relatively warmer temperatures and lower flows provide winter habitats (Bodensteiner and Lewis 1992, Raibley et al. 1997, Sheehan and Rasmussen 1999).

Sheehan et al (1990) examined temperature and flow requirements for several fishes common in the Ohio River, such as gizzard shad (*Dorosoma cepedianum)*, channel catfish (*Ictalurus punctatus*), and freshwater drum (*Aplodinotus grunniens*). Gizzard shad, channel catfish, and freshwater drum occupy relatively low velocity areas during winter (Heese and Newcomb 1982, Newcomb 1989, Sheehan et al 1990, Bodensteiner and Lewis 1994, Logsdon 1993). Gizzard shad are vulnerable to winter die-offs during low water temperatures (Miller 1960). Garvey (2002; Chapter 1) reviewed over 300 articles on the winter ecology of riverine fishes and reported temperature preferences of $ 4 °C for many species in large rivers, such as green sunfish (*Lepomis cyanellus*), bluegill (*Lepomis macrochirus*), and freshwater drum. Some species, such as channel catfish, black crappie (*Pomoxis nigromaculatus*), and walleye (*Stizostedion vitreum*), can maintain swimming abilities at temperatures < 4 °C (Sheehan et al. 1990). Temperature

and flow preferences during winter, and swimming abilities during low temperatures are unknown for most riverine fishes.

Dissolved oxygen

Abiotic factors other than water temperature and flow velocity likely influence the suitability of winter habitats. Backwater areas can become anoxic and unsuitable as overwintering areas (Bodensteiner and Lewis 1992, Knights et al. 1995, Johnson et al. 1998). Low DO levels can result in fish die-offs when backwater areas become isolated from the main channel during low water levels in winter (Raibley et al. 1997). In the West Virginia section of the Ohio River, dissolved oxygen is reduced by water pollution near cities, but normally remains above critical levels (Pearson and Krumholz 1984).

Gear Use and Comparisons

Passive gears, such as hoop nets, gill nets, traps (Hubert 1996) and active gears , such as electrofishers and trawls (Hayes et al. 1996) are used to sample fishes in large rivers. Gear use should reflect seasonal variation in fish behavior. For example, passive gears may be ineffective for inactive fishes during winter. Bottom trawling in large rivers is complicated by benthic debris, whereas electrofishing near the surface fails to sample benthic areas. Most fishes are inactive and benthic during winter, so active and benthic-oriented gears are logical choices, such as a variable-depth AC electrofisher (Newcomb 1989). Regardless of gear type and seasonal affects, detection probabilities and sampling efficiency are low for most riverine fishes (Thompson et al. 1998).

Sampling Efficiency

Sampling efficiency, the percent of the population captured by sampling, is difficult to quantify. Sampling efficiency of a gear type can be examined by sampling with other gears or toxicants. Few gears, however, provide a 100% probability of detecting all individuals within an area of an open system, such as a single habitat type within a large river. Results from gear comparisons are often not definitive. For example, one could interpret low captures from two gears as evidence for low fish abundance or one could argue that both gears sample inefficiently.

Conductivity, flow velocity, water temperature, and biological factors affect electrofishing efficiency. Low conductivity decreases electrofishing efficiency (Kolz et al. 1998). High flow velocity moves fishes away from netters and reduces capture success. Additionally, species have variable vulnerability to electrofishing because of morphological, physiological, and behavioral differences (Kolz et al. 1998). Small fishes are less vulnerable to electrofishing (Reynolds 1996).

Electrofishing gears and configurations, such as AC versus DC and electrode position, also influence sampling efficiency. In variable-depth AC electrofishers, the electrical field occurs between electrodes rather than between boat and electrodes as in traditional DC electrofishers. If electrodes from variable-depth AC boats are near the river bottom, then the gear becomes specific to bottom habitat (because of electrode placement), so fishes in the water column are less vulnerable. In contrast, DC electrofishing boats typically deploy electrodes near the surface, and are ineffective at sampling benthic areas in deep habitats.

METHODS

Study area description

The Belleville Pool of the Ohio River, created by Belleville Lock and Dam (rkm 328.1), is bound upstream by Willow Island Lock and Dam (rkm 260.2). The 67.9 km pool averages 404.5 m wide, 7.3 m deep, and comprises 2850 ha of surface area (ORSANCO 1994). The deepest section of the pool (15 m) lies directly upstream of Belleville Lock and Dam. A navigation channel (2.7 m deep) is maintained for commercial barge traffic by the United States Army Corps of Engineers (USACE) (ORSANCO 1994). Two other large rivers, the Muskingum River in Ohio, and the Little Kanawha River in West Virginia are navigable tributaries of the Ohio River.

The riparian zone is a mixture of hardwood forests, urban and industrial frameworks, and agricultural settings. Most large floodplains near Belleville Pool are heavily urbanized. The two largest population centers along Belleville Pool are Parkersburg, WV (confluence of the Little Kanawha and Ohio rivers) and Marietta, OH (junction of Muskingum and Ohio rivers). Riparian areas unaffected by human settlement are steep forested hillsides that restrict lateral flow away from the mainstem Ohio River.

Habitat type classifications

We classified habitat types as main channel, deep hole, backwater, island head, island tail, tributary, wing dam, and embayment. Vallazza et al. (1994) and Cray (1999) discussed similar habitats, and our classification scheme (see Table 3-1) is further described below. Main channel habitats are used as commercial navigation routes, and typically have shallow near-shore areas and deeper mid-channel sections. Deep hole habitats are deep areas created by dredging or natural scour within main channel or

backwater areas. Backwater, island head, and island tail habitats are associated with islands. Backwater habitats are not typically used for barge navigation and occur between an island and the mainland. Seven backwater areas (associated with seven islands) occur within the Belleville Pool. Habitats near the upstream and downstream ends of each island are island head and island tail habitats, respectively. Embayment habitats are shallow bay-like areas connected to the main channel by tributary or artificial channel. Wing dams (and other artificial flow barriers) create near-shore habitats with low water velocities.

Selection and description of study sites

Initially, we selected six main channel sites, six tributary confluences, six backwater areas, six head of islands, six tail of islands, and three deep hole sites (Figure 3-1; see coordinates in Table 3-2). Main channel and tributary sites were selected randomly within Belleville Pool and stratified relative to their abundance in the upper and lower half. We added two main channel sites, three tributary sites, three deep hole sites, one wing dam (artificial) site, and an embayment (Figure 3-1; Table 3-2). Depths of main channel and backwater sites ranged from 3 to 9 m, and included near-shore mid-channel transects. Tributary habitats were 2 to 9 m deep, and included near-shore areas and deeper scour holes. Depths of deep hole habitats ranged from 7 to 14 m, and those of island head and tail habitats ranged from 2 to 6 m. Island size differed among Newberry (0.4 km long), Blennerhasset (6.4 km long), Neal (2.4 km long), Halfway (1.6 km long), Muskingum (3.2 km long) and Marietta (4.8 km long), but sample areas within backwater, head, and tail habitats were similar among islands. Depths, flows, and water quality of each habitat type are presented with results.

Sampling methodology

Abiotic data

At each sample site, we used a YSI 6820 meter or a Hydrolab Surveyor 4 to measure specific conductivity, dissolved oxygen (DO), pH, salinity, and temperature depth profiles at 1m intervals. Turbidity was estimated with secchi disk (near surface), and a YSI 6820 meter along 1 m depth profiles during the December 2002 and January 2003 sample sessions. We measured flow velocity with a Marsh-McBirney Flowmate 2000 at the surface (depths < 1.5 m) or at 2 m.

Bottom contour and depth profiles for each transect at each site were recorded by sonar during peddle time. Tidbit dataloggers recorded water temperatures every 30 minutes at three main-channel (RM180, RM196, and near head of Marietta Island) and three back-channel (Blennerhasset, Newberry, and Neal Islands) sites during February 2002 through March 2003. Presence/absence of large woody debris was recorded for each site.

Fish sampling

Fishes were sampled with a variable-depth AC electrofishing boat for depths of 2-10 meters (Grunwald 1983, Newcomb 1989). Our boat is an 18 ft flat-bottom (7 ft wide) aluminum jon boat with a 5 kilowatt Honda 3-phase AC generator. Three electrodes (2 m sections of 1.25 inch diameter corrugated conduit) are attached to 14-gauge 3-strand pre-insulated solid wire. The wire from the three electrodes connects to an electrical junction box, which is wired to the generator. A ground wire connects the boat and generator. Amp output is turned off by the generator's on/off switch or by a safety footswitch (controlled by the boat operator). If needed, we reduce amp output by taping the electrodes, i.e., amps decrease when the electrode surface is covered with electrical tape.

The amp output is monitored by inline amp gauges and/or clip-on amp gauges. Output is generally above 7 amps, and typically 9-10 amps.

Electrodes were weighted and lowered to the river bottom off a boom on the bow. We attempted to get the electrodes near bottom without making contact. One, two, or three transects were electrofished in the direction of the river current lasting up to10-minutes (peddle time) for each sampling location. During peddle time with the bow upstream, we allowed the boat to drift with the river current. This maintained electrodes near the river bottom, but caused longer transects during higher flows. In backwater and main channel habitats, the three transects represented shallow, intermediate, and deep water areas and were sampled near each shore and in mid-channel. Peddle time and number of transects varied with habitat availability. Often, we sampled two transects within the small areas of island head and island tail habitats, or one transect within scour holes of tributary habitats. During or after peddle time, researchers in a chase boat or the electrofishing boat netted fishes from the water surface.

Fish data

Fishes were captured, identified to species, measured (nearest millimeter total length, TL), and weighed. Weights for large fishes (over 1kg) were taken to the nearest 25g with a Pesola spring scale (5 kg maximum). Smaller fishes (less than 1 kg) were weighed to the nearest 1g with a Homs spring dial scale (1kg maximum). Channel catfish, black crappie, white crappie (*Pomoxis annularis*), hybrid striped bass (*Morone saxatilis x Morone chrysops*) and freshwater drum were weighed and frozen for removal of spines or otoliths. Ages of channel catfish were determined with sections of pectoral

spines, whereas ages of other species were based on otoliths. We used at least two observers for age estimation.

Data management procedures

We archived copies of field notes, lab data, and electronic data files and recorded metadata for electronic data files. Data, stored primarily in Excel spreadsheets, were checked for accuracy after transfer from field notes.

Statistical methods

Site occupancy rates

Abundance or presence/absence estimates are often biased (underestimated) unless adjusted with detection probabilities (MacKenzie and Kendall 2002). We used occupancy rate models (a method that incorporates detection probabilities) to estimate the proportion of sites occupied by freshwater drum and channel catfish using presence/absence data (MacKenzie et al. 2002). Specifically, we used Program MARK to estimate maximum likelihoods of two parameters: the probability of detection (p) and the proportion of sites occupied by a species (ψ). The proportion of sites occupied by a species could be estimated as the fraction of sites with species detections over the total number of sites. For example, if freshwater drum were collected in 10 of 20 tributary habitats, then one estimate of ψ is 10/20 or 0.5. This estimate, however, is biased (low) if the probability of detection is less than 1 (nondetection may not equal absence). Detection probabilities can be estimated with data from multiple visits to each site, and used to adjust ψ. If a species was detected on the second sample occasion, but not on the

first and third occasions, then the likelihood of ψ given detection probabilities (p) for site *i* would be as follows:

$$L(\psi, p) = \psi_i (1 - p_{i1}) p_{i2} (1 - p_{i3})$$

The likelihood for a capture history of three occasions without detection at site k would be as follows:

$$L(\psi, p) = \psi_k \prod_{t=1}^{3} (1 - p_{kt}) + (1 - \psi_k)$$

Selection of occupancy rate models followed an information-theoretic approach based on Kullback-Leibler information and likelihood theory (Burnham and Anderson 1998). A set of candidate models for estimates of p and ψ were selected before analysis. Biologically-reasonable hypotheses were used to develop the set of candidate models and were examined under a multiple working hypotheses framework (Chamberlin 1965). We modeled parameter ψ as unique for each habitat type or constant across habitat types, with notation as ψ (habitat) and ψ (.), respectively. Detection probabilities were modeled as (1) unique for each site, (2) constant across sites, (3) with time as a covariate, or (4) with abiotic covariates of conductivity, depth, DO, temperature, or velocity. Additional models with interaction terms were not considered given our sparse (many zeros) data set.

Candidate models were fit to the data using Program MARK, and selected based on a second order adjustment to Akaike's information criterion (AICc; Burnham and Anderson 1998), where

$\mathrm{AIC_c} = -2\log\left(L(\hat{\theta})\right) + 2K + \frac{2\mathrm{K}(\mathrm{K}+1)}{(\mathrm{n}-\mathrm{K}-1)}$, and n = sample size, K = number of model parameters. The model likelihoods were determined by comparing Akaike model

weights (as described below). The AICc values were rescaled as simple differences, where $\Delta_i = AIC_{ci} - \min AIC_c$. Then the likelihood of model *i*, given the data, is $L(M_i|\underline{x}) = \exp(-\frac{1}{2}\Delta_i)$, and normalized to sum to 1, as $w_i = \frac{\exp(-\frac{1}{2}\Delta_i)}{\sum_{r=1}^{R}\exp(-\frac{1}{2}\Delta_i)}$. The w_i values can be interpreted as probabilities, where the relative likelihood of model i versus model j is w_i/w_j. For example, given weights of 0.9 for model i and 0.1 for model j, then the model i is nine times more likely than model j.

We estimated p and ψ as a weighted average across all models, where weight is a function of model fit (Burnham and Anderson 1998; Buckland et al. 1997). Model averaging eliminates the need to select the single best model, allowing the uncertainty of model selection to be incorporated into the variance of parameter estimates (Burnham and Anderson 1998).

Multivariate descriptive and exploratory analysis

Following occupancy rate estimation, we used canonical correspondence analysis (CCA) to explore relationships between species and abiotic variables. Canonical correspondence analysis is a constrained ordination approach, and allows concurrent analysis of species abundance, site, and environmental (abiotic) data (ter Braak 1995). A square root transformation of abundance data minimized affects of a few high abundance values (McGarigal et al. 2000). We conducted CCAs using an Excel macro with data from February - April 2002 and December 2002 – March 2003, separately (macro obtained from Eric Smith, Virginia Polytechnic Institute and State University).

Sampling efficiency

Sampling efficiency, the percent of the population captured by sampling, is important in studies of animal abundance. Poor sampling efficiency will provide low (biased) estimates of abundance. Sampling efficiency of a gear type is difficult to quantify, but can be examined by sampling with other gears or toxicants. Few gears, however, provide 100% detection probabilities for all individuals or all species within open systems, such as macrohabitats of large rivers. Researchers at Southern Illinois University (SIU, Garvey et al. 2002, Chapter 2) conducted a companion study on winter habitat used by fishes in Smithland Pool, and we compared sampling efficiencies of the SIU and WVU boats. Additionally, we compared sonar, gill nets, DC electrofishing, and multiple pass removals with data collected by AC gear.

We attempted to corroborate abundance data from February 2002 – March 2003 with concurrent electrofishing and sonar surveys. We used sonar images to estimate fish abundance prior to electrofishing and to assess gear efficiency. A stern-mounted sonar device recorded fish abundance along with bottom contour profiles of each transect. Electrofishing was conducted by moving the boat backward, and the recorded sonar image was captured immediately preceding the passage of the bow-mounted electrofishing electrodes.

We used experimental gill nets at 11 sites and a Smith-Root DC electrofishing boat at one site for comparison with the variable-depth AC electrofishing boat. Gill nets were five panels (8 by 32 feet) with 3 to 12 inch stretched mesh. Anchored gill nets (a passive method) will likely be unsuccessful at capturing inactive fishes during winter. The use of gill nets will not provide an estimate of our electrofishing gear efficiency, but it may indicate species-specific vulnerabilities to gear types. For example, species

captured with gill nets and not with electrofishing would support gear-specific differences. Comparing abundance data collected by DC electrofishing (with electrical field near the water surface) and variable-depth AC electrofishing boat (with electrical field near river bottom) also has limitations, and is restricted to relatively shallow habitats. In December 2002, we compared DC and AC electrofishing boats at the Blennerhasset Island tail.

We conducted multiple-pass removal samples at Bull Creek (January 2003 and March 2003) and main channel RM 165 (March 2003). We examined the relationship between fish size and estimates of detection probabilities. Although fishes were free to move in and out of the sample area, we believe low water temperatures and short time periods (approximately 10 minutes) between electrofishing passes minimized fish movements. Detection probabilities were estimated using the closed capture option in Program MARK, where four models were fit to the three-pass removal data. Among-species differences in detection probabilities were not important to our analysis, so we combined species to increase sample size, and separated fishes into two size groups (<300mm, >300mm). Standard removal models (Otis et al. 1978; White et al. 1982), and models reflecting fish size were selected with AIC and information theoretic methods as described above. Detection probabilities from the three-pass sample were parameterized as (1) equal among sample occasions and between size groups, (2) equal among sample occasions with unequal size groups, (3) equal for second and third sample occasions with equal size groups, and (4) equal for second and third sample occasions with unequal size groups. Analyses of two-pass samples were restricted to the first two models (listed above).

RESULTS

Effort and Sample dates

First sample phase (February, March, and April of 2002)

Thirty-seven sites were sampled during February, March, and April of 2002, including nine tributary confluences, six backwater areas, six head of islands, six tail of islands, seven main channel sites, and three deep main channel sites (Table 3-2). Sites were sampled from one to four times across four sample sessions (session 1, February 16 – 22; session 2, March 9 – 25; session 3, April 4 – 7; session 4, April 14 - 15). Based on higher temperatures, session 4 was not representative of winter conditions.

Second sample phase (December 2002, January 2003, March 2003)

During December 2002, January 2003, and March 2003, we sampled six tributary confluences, six backwater areas, six head of islands, six tail of islands, six main channel sites, and six deep main channel sites (Table 3-2). Sites were sampled from one to three times across the three sample sessions (session 1, December 12-17; session 2, January 10 – 19; session 3, March 1 – 17). Samples during March were interrupted by high flows and occurred during March 1 – 2 and March 16 – 17). We added a shallow embayment site (Little Sand Creek) in December 2002, and a wing dam, main channel, and deep hole sites in January 2003 (Table 3-2). Mean depths of sample transects (estimated with 50 randomly-selected depth measurements) were lowest for head and tail island habitats and highest for deep hole habitats (Table 3-3).

Abiotic data

Abiotic data are summarized in Table 3-4. Water temperatures (Celsius) ranged

from 4.4 to 5.5, 5.5 to 7.7, 8.7 to 11.2, and 11.5 to 15.2 during our first, second, third, and fourth sampling sessions of 2002, and from 1.9 to 5.1 in December 2002, 0.4 to 3.6 in January 2003, and 1.95 to 11.24 in March 2003. The high temperature in March (11.24 C) was from the embayment habitat, whereas all other habitats had water temperatures below 6.4 C. Temperatures measured along 1 m depth profiles differed typically less than one degree Celsius (see Welsh et al. 2003 for specific profiles). Tidbit dataloggers recorded similar water temperatures among three main-channel and three back-channel sites during February 2002 through March 2003 (Table 3-5; Figure 3-2, 3-3). Turbidity ranged from 2.4 to 214 (NTU) in December 2002, 1.2 to 75.1 in January 2003, and 17.9 to 119.9 in March 2003, whereas secchi disk readings ranged from 0.15 to 2.15 m in December 2002, 0.33 to 1.6 m in January 2003, and 0.16 to 0.78 in March 2003. Turbidity and secchi readings were not taken during the February – April 2002 sample sessions because of equipment failure and oversight. Dissolved oxygen (mg/L) ranged from 13 to 13.9, 7.3 to 9.3, 6.6 to 12.5, and 9.9 to 12.3 during our first, second, third, and fourth sampling sessions in 2002. Dissolved oxygen ranged from 6.5 to 9.5 in December 2002, 12.1 to 14.6 in January 2003, and 11.07 to 13.79 in March 2003. Specific conductivity (uS/cm) ranged from 285 to 496, 244 to 408, 89 to 434, and 136 to 597 during the first, second, third, and fourth sampling sessions of 2002, and from 153 to 570 in December 2002, 321 to 520 in January 2003, and 185 to 545 in March 2003.

Flow velocity (m/s) at the surface (depths < 1.5 meters) or at 2 meters depth ranged from 0.04 to 0.38, 0 to 1.0, 0 to 1.1, and 0 to 1.15 during our first, second, third, and fourth sampling sessions of 2002, and from 0.0 to 1.0 in December 2002, 0.0 to 0.84 in January 2003, and 0 to 1.25 in March 2003. River stages at Marietta depict high flows during our sample periods (Figure 3-4). Instream structures (i.e. logs near water surface)

were present within sampling transects of tributaries (Lee Creek, Little Hocking River), backwaters (Halfway, Marietta, Neal, Newberry), Island heads (Marietta, Newberry), Island tails (Blennerhasset, Marietta, Muskingum), and main channels (river miles 165, 180, 192, 194).

Fish habitat use

Species composition (both years)

We sampled 515 transects and captured 28 species with a variable-depth AC electrofisher during February 2002 through March 2003 (Table 3-6). Relative numbers of common species were similar to those from previous lock rotenone samples between RM 100 – 200 (Pearson and Krumholz 1984); freshwater drum and channel catfish were most abundant. Seventeen species were captured with a DC electrofisher from Little Sand Creek embayment. Thirty-two species were captured (based on all gears) during February 2002 through March 2003.

Species composition by habitat type and sample event

During the first phase (February – April 2002), we sampled 248 transects and captured 15 species (Table 3-7; see Welsh et al. for specific catch data). No fishes were detected at 194 transects. Channel catfish, freshwater drum, and gizzard shad were most abundant. We captured 119 channel catfish during February – April 2002, and percentages by habitat type were as follows: 63% tributary, 14% backwater, 5% island head, 2% island tail, 16% main channel, and 0% deep hole. Percentages of freshwater drum (N=174) by habitat type were as follows: 90% tributary, 2% backwater, 2% island head, 0% island tail, 6% main channel, and 0% deep hole. Tributary habitats had highest

species abundances and the highest species richness, including gizzard shad, mooneye (*Hiodon tergisus*), common carp (*Cyprinus carpio*), emerald shiner (*Notropis atherinoides*), spottail shiner (*Notropis hudsonius*), highfin carpsucker (*Carpiodes velifer*), river carpsucker (*Carpiodes carpio*), quillback (*Carpiodes cyprinus*), channel catfish, orangespotted sunfish (*Lepomis humilis*), bluegill, white bass (*Morone chrysops*), walleye, and freshwater drum. The number of fishes collected in tributary confluences made up 83% of all individuals collected. No fishes were collected from the three deep hole sites.

During the second sample phase, fishes were not detected with variable-depth AC sampling at 71 of 88 transects in December 2002, 68 of 88 transects in January 2003, and 58 of 91 transects in March 2003. Although this seems to be a high rate of nondetection or species absence, it is consistent with samples from early 2002. Total species captured was similar between sample phases with 15 species captured in early 2002 and 23 species captured during December 2002-March 2003. Species presence in backwater and main channel habitats during December 2002 through March 2003 exceeded that from early 2002 samples. In an embayment habitat (Little Sand Creek, December 2002 through March 2003), we sampled 17 species (890 individuals) from two near-shore transects with a Smith-Root DC electrofishing boat. This included nine species not captured with our AC gear during December 2002 – March 2003 (bowfin, *Amia calva*; spotted sucker, *Minytrema melanops*; western mosquitofish, *Gambusia affinis*; white crappie; green sunfish; pumpkinseed, *Lepomis gibbosus;* warmouth, *Lepomis gulosus*; orangespotted sunfish; and bluegill). With these species, a total of 32 species was sampled during December 2002 through March 2003. The two near-shore transects in the embayment were shallow (< 1 m depth) with LWD, and could not be sampled with our variable-depth

AC electrofishing boat. We sampled one transect in the embayment (away from shore with 2 m depth) with the variable-depth AC electrofishing boat and captured one freshwater drum.

We captured 83 channel catfish during December 2002 through March 2003, and percentages by habitat type were 16% (tributary), 31% (backwater), 0% (island head), 0% (island tail), 52% (main channel), and 1% (deep hole). Percentages of freshwater drum (N=296) by habitat type were 37% (tributary), 7% (backwater), 0% (island head), 0.3% (island tail), 50% (main channel), 1% (deep hole), 2% (embayment), and 2% (wing dam). The highest species richness (N = 11) was taken from the embayment habitat in December 2002. Tributary habitats contained the highest species richness (N=13) in January 2003. Most species of tributary habitats in January came from one site, Bull Creek, whereas the embayment habitat was not sampled in January due to ice-cover. During March 2003, 16 and 10 species were sampled from embayment and tributary habitats, respectively. Although no species were collected from deep hole sites during February – April 2002, we captured three species (channel catfish, spotted bass, and freshwater drum) from a deep hole site near Marietta Island in December 2002.

Species composition by gear type

The primary gear was variable-depth AC electrofishing (515 transects; 28 species), whereas DC electrofishing (9 transects) and gillnets (11 sets) were used infrequently. Results from DC electrofishing at the Blennerhasset Island tail (December 2002) and gill nets (11 sites) were compared to variable-depth AC gear (summarized below), whereas DC electrofishing in the embayment was used to sample a unique habitat

(nearshore embayment; inaccessible to the AC gear). We fished the Little Sand Creek embayment three times (during December 2002 and March 2003) with the DC electrofishing boat and captured 17 species. Nine of these species were not captured with AC gear during December through March 2003.

Size distribution, length-weight comparison, and ages

Size distributions of abundant species were depicted for both field seasons (combined and separate; Figures 3-5 through 3-7). The range of lengths and presence of multiple length frequency modes indicate several year classes within samples. However, we captured primarily adults (except for Little Sand Creek embayment), but juvenile freshwater drum were captured in tributary, backwater, main channel, and embayment habitats. In general, size distributions by gear, month, or habitat were inhibited by small sample sizes. Data from the embayment habitat (DC gear), however, are presented separately for orangespotted sunfish, bluegill, and white crappie (Figure 3-8; see Appendix 1, Lenz 2003).

Age-length relationships were examined for channel catfish, white bass, white crappie, and freshwater drum (Figures 3-9 through 3-12). Lenz (2003) reported von Bertalanffy growth models of channel catfish, white bass, and freshwater drum (Appendix 1). Mean lengths (variances and sample sizes in parentheses) of white crappie (ages 1 through 4) were 7.6 (1.08, 18), 13.8 (2.44, 25), 19.4 (5.28, 9), 28.4 (1.6, 10) cm, respectively. Mean lengths of white bass (ages 1 through 4) were 11.2 (NA, 1), 18.8 (3.36, 16), 27.8 (0.84, 10), 30.4 (1.3, 5) cm, respectively. Mean lengths (cm) of channel catfish (ages 0 through 9) were as follows: 12.4 (NA, 1), 23.8 (9.7, 5), 24.8 (39.7, 11), 35.6 (19.4, 48), 38.4 (40.7, 13), 45.6 (37.8, 23), 50.5 (55.5, 6), 54 (6.0, 6), 53 (NA, 1), 62

(32.0, 2). The oldest freshwater drum was estimated at 22 years (77 cm TL); ages 0 to 14 had mean lengths of 5.5 (0.5, 2), 8 (1.61, 60), 17.3 (8.2, 40), 23.8 (2.5, 50), 28.6 (5.59, 47), 31.6 (5.43, 20), 37.9 (8.1, 12), 45.0 (27.6, 6), 44.8 (63.6, 5), 48.7 (5.9, 8), 49 (32.0, 2), 48 (36.0, 5), 54.7 (21.2, 7), 58.7 (37.3, 3), 61.0 (8.0, 2). High variances, in part, reflect uncertainty from small sample sizes.

Relative abundance (CPUE)

With data combined for February 2002 through March 2003, CPUE (fish/hour) was highest for gizzard shad (10.6), freshwater drum (9.9), channel catfish (4.2), bluegill (3.4), emerald shiner (3.0), white crappie (1.5), smallmouth buffalo (1.4), orangespotted sunfish (1.0), and white bass (0.96) (Tables 3-8, 3-9, 3-10). The CPUE estimates for gizzard shad, emerald shiner, white crappie, and sunfish were largely influenced by catches within the Little Sand Creek embayment. The estimates for smallmouth buffalo and white bass were influenced by a single sample at a wing dam.

When separated by habitat types and sample events (excluding the embayment), CPUE was generally highest for tributaries (see Tables 26-34 in Welsh et al. 2003). During December 2002 and January 2003, however, CPUE for channel catfish and freshwater drum (the two species with highest abundances) increased in backwater and main channel habitats. A single sample from a wing dam habitat provided highest CPUE (fish/hour) estimates for carp (5.2), black buffalo (5.2), smallmouth buffalo (90.0), white bass (5.2), and freshwater drum (52.6).

Results of occupancy rate modeling

Site occupancy rate models were used to estimate detection probabilities (p) and the proportion of sites occupied (ψ) by freshwater drum in tributary, backwater, and main channel habitats. Models with depth, flow, and constant detection probabilities received highest weights for freshwater drum (Table 3-11). Model-averaged estimates of ψ were highest for tributaries during February through early April 2002, but were highest for main channel habitats during December 2002 through March 2003 (Table 3-12). Habitat specific parameters for ψ were unestimable for other species because of sparse data.

Results of multivariate exploratory analysis

Relationships among species abundances and environmental variables (flow, temperature, conductivity, depth, and turbidity) were depicted in CCA triplots (Figures 3-13, 3-14). For data from February 2002 through April 2002, the relationship among low flows, tributaries, and abundance of freshwater drum were emphasized along the axis of flow. To a lesser extent, channel catfish were also associated with areas of low flow velocities. Similarly, flow was the major axis and tributary habitats were associated with low flows from December 2002 through March 2003; flow, temperature, and conductivity depicted similar gradients. Higher flows, temperatures, and conductivities in main channel and backwater areas, however, were associated with the two species of highest abundance (freshwater drum and channel catfish) during December 2002 through March 2003. No relationship occurred among species, habitat types, and turbidity. Depth was associated with deep hole habitats, but not with species.

Sample efficiency

Sonar images were used to assess gear efficiency by comparison of the number of fishes viewed by sonar and the number of fishes collected at each site. We did not find a relationship between the number of fishes viewed by sonar and the number of fishes collected at each site during both seasons. During the 2002 season, the two methods were consistent during 91 transect samples, where no fishes were viewed on sonar and no fishes were collected (this includes the three deep main channel sites). Also, the number of fishes viewed on sonar equaled the number of fishes collected during six transects. However, 44 transects had a higher number of fishes viewed on sonar than collected, whereas the number of fishes collected exceeded the number of fishes viewed on sonar at 28 sample locations. Similarly, during the 2003 season, the two methods were consistent (no fishes collected or viewed) during 125 transect samples. The number of fishes viewed on sonar equaled the number of fishes collected during seven transects. Forty-three transects had a higher number of fishes viewed than collected, whereas the number of fishes collected exceeded the number of fishes viewed at 34 sample locations.

Other methods to assess sampling efficiency included comparison of the WVU variable-depth AC electrofishing boat with (1) a similar boat used by SIU, (2) a Smith-Root DC electrofishing boat, and (3) anchored gillnets. The variable-depth AC electrofishing boats of SIU and WVU are similar in construction and sampled with similar efficiency during comparison. Eleven gill nets were fished during the December 2002 through March 2003 sample sessions (Table 3-13). Three gill nets were set overnight at Bull Creek (tributary habitat), Marietta Island head, and river mile 167 (main channel) in December and were fished for a combined total of 76.85 hours. In January, three gill nets

were fished during the daytime at Neal Island head, tail, and backwater sites for a combined total of 14 hours. During March 2003, three gill nets were fished (Lee Creek, Hocking River, and Newberry Island tail) for 16.75 hours, collectively. Seven of the 11 gill net sets caught no fish, yielding the same results as the AC electrofishing efforts. The gill net at Bull Creek caught three fishes (two sauger and a shorthead redhorse) and none were captured with AC gear. At Neal Island backwater, the AC gear produced four fishes (three channel catfish and a freshwater drum) and the gill net caught one (a mooneye). In March, two carp were captured with a gill net at Lee Creek, whereas six freshwater drum and one gizzard shad were captured with AC gear.

In December 2002, DC and AC electrofishing boats were compared at the Blennerhasset Island tail and the embayment. We captured four fishes (a freshwater drum, two mooneye, and a sauger) from three transects sampled with the variable-depth AC electrofishing boat at the Blennerhasset Island tail in December 2002. We repeated the transects with a Smith-Root DC electrofishing boat and captured a silver chub (*Macrhybopsis storeriana*) and a smallmouth buffalo.

A three-pass removal sample at Bull Creek during January 2003 provided another look at sampling efficiency for the variable-depth AC gear. We captured 57, 6, and 1 fishes over 300 mm TL during three passes, respectively. Fishes under 300 mm TL from the three passes were 39, 31, and 1, respectively. The best approximating model parameterized detection probabilities as equal for second and third sample occasions with unequal size groups. The detection probability (with SE and 95% CI in parentheses) of small fishes (< 300 mm TL) for the first pass was 0.55 (0.06, 0.43 to 0.66), whereas the combined estimate for the second and third passes was 0.97 (0.03, 0.81 to 1.0). Detection probabilities of large fishes (> 300 mm TL) for the first and subsequent passes

were 0.89 (0.04, 0.79 to 0.95) and 0.88 (0.12, 0.46 to 0.98), respectively. Two-pass removals at Bull Creek (March 2003) and main channel RM 165 (March 2003) yielded 28 and 4, and 34 and 11 individuals, respectively. We were unable to model data from Bull Creek (March 2003) due to small sample size; however, detection probability for fishes >300 mm TL (p = 0.85, 95%CI = 0.62 to 0.95) exceeded that for smaller fishes (p = 0.69, 95%CI = 0.36 to 0.88) from the best approximating model for RM 165.

DISCUSSION

Species/habitat associations

Canonical correspondence analysis and abundance estimates depicted low-velocity tributary habitats with highest abundances and richness of fishes during our February 2002 through March 2003 sample sessions. The proportion of tributary sites occupied by species was consistently higher than that of Island head, Island tail, and deep hole habitats. We believe that fishes used tributary habitats because of low velocities. Average surface velocity (m/s) for tributary confluences (0.10) was lower than those of backwater (0.58), island head (0.57), island tail (0.30), main channel (0.56), and deep hole (0.65) habitats. Carlson (1992) and Braaten and Guy (1999) also reported low-velocity tributary confluences as important winter refuges. During the December 2002 sample, water temperatures were consistently between 3 and 5 ºC for all habitats. In January 2003, all tributary habitats were below 3 ºC, except for Bull Creek (3.2 ºC) and Sugar Camp Run (3.2 ºC) which had highest estimates of abundance and richness. Although other unmeasured variables may explain fish use of tributary habitats during winter, we believe that low velocities are important, except when water temperatures fall below 3 ºC.

Backwater and main channel habitats were similar in many physiochemical measurements, including flow velocity, temperature, and depth. In some large rivers, backwater areas have warmer water temperatures and provide a shelter from current velocity during winter (Bodensteiner and Lewis 1992, Johnson et al. 1998, Raibley et al. 1997, Sheehan and Rasmussen 1999). The backwaters in the upper Ohio River valley are not characteristic of other large river backwaters that are slow-moving isolated sloughs. Our sample efforts did not find high abundance or diverse fish assemblages in backwater and main channel habitats, except when water temperatures in low-velocity tributary habitats were below 4 ºC. Our data indicate that many large river fishes trade low-velocity habitats for relatively high-velocity areas when water temperatures of low-velocity areas drop below 4 ºC. During our coldest sampling events (December 2002 and January 2003), the abundances of several species increased in backwater or main channel habitats, such as gizzard shad, mooneye, carp, smallmouth buffalo, channel catfish, and freshwater drum (as supported by occupancy rate models). Fishes in backwater and main channel habitats were primarily captured in near-shore transects, and taken rarely from mid-channel transects. Consequently, estimates of occupancy rates in island backwaters and main channels were decreased by low catches in mid-channel transects.

Few embayments occur within Belleville Pool, but our data from Little Sand Creek embayment support their importance as winter refuge habitats. We captured high abundances of juvenile sunfish (bluegill, green, orangespotted, pumpkinseed, and warmouth), juvenile white crappie, and juvenile gizzard shad in the low-velocity embayment habitat. Additionally, three juvenile freshwater drum were captured in the embayment habitat. Within other habitats, we captured mostly adult fishes (possibly from size selectivity of electrofishing gear). Juvenile fishes suffer higher mortality than

adults at critically low water temperatures (Post et al. 1998, Wright et al. 1999, Fullerton et al. 2000, Jackson and Noble 2000, Bodensteiner and Lewis 1994); consequently, our sampling gear (if selectivity is an issue) missed an important component of winter fish/habitat relations, i.e., winter habitats of juvenile fishes. Our finding of juvenile fishes in a low-velocity habitat is consistent with other literature (Bodensteiner and Lewis 1992, Braaten and Guy 1999); however, we did capture juvenile freshwater drum in relatively high-velocity backwater and main channel habitats.

Dissolved oxygen, conductivity, and turbidity were not associated with differential habitat use among habitat types. Although dissolved oxygen concentrations may decline in some backwater areas during winter (Gent et al. 1995, Knights et al. 1995), data herein and those from Pearson and Krumholz (1984) indicate that DO remains relatively high in Belleville Pool. It is unlikely that DO influenced fish presence during our study, given similar and high DO values among habitat types and sample events. Similarly, the range of conductivity during our sample periods did not likely influence fish presence. Conductivity, however, is known to affect electrofishing efficiency, and its importance to estimates of detection probabilities of freshwater drum is discussed under sampling efficiency. Analyses did not support turbidity (based on secchi and NTU measurements) as an influence on habitats used by fishes.

Sample efficiency and gear selectivity

Our efforts with variable-depth AC electrofishing produced primarily freshwater drum and channel catfish. In a companion study in the lower Ohio River (Smithland Pool) during winter 2001/2002, the catch was predominantly blue catfish (*Ictalurus furcatus*) and freshwater drum (Garvey et al. 2002; Chapter 2). Sheehan et al. (1990)

used variable-depth AC electrofishing gear to capture a diversity of species, and Newcomb (1989) predominantly captured channel catfish, common carp, freshwater drum, river carpsucker, and goldeye (*Hiodon alosoides*) using variable depth AC electrofishing gear. Deepwater electrofishing gear targets fish species on or near the river bottom, and this likely explains the relatively high numbers of catfish and freshwater drum; however, we did capture 28 species with our AC gear.

A comparison of our sonar images with the number of fishes collected indicated that the gear was often inefficient at capturing all fishes (when fishes were present); however, this is probably true for most gear types. The sonar method has limitations, in part, because sample area of sonar (with 36 degree cone) differs with water depth, and rarely equals the sample area of the electrofisher. Also, interpreters of sonar graphs can overlook fishes near the river bottom or count images of logs or other objects. Data from gill nets and DC electrofishing did not support poor sampling efficiency of the variable-depth AC electrofishing boat. However, this type of gear comparison has limitations, given that gill nets and DC electrofishing may have poor sampling efficiency. Sampling efficiency for the DC electrofishing boat was high at near-shore areas within the embayment habitat; however, the AC electrofishing gear could not access this near-shore shallow habitat. Possibly, shallow near-shore areas within the six habitat types provide important over-winter habitats, but were not sampled during our study.

Estimates of detection probabilities may be useful in assessing sample efficiency. Detection probabilities in site occupancy models, however, are defined as the probability that a species is detected, and not as the probability that a gear type detects a species. However, conductivity and flow models of detection probabilities received low weights; hence, the data did not support an association with sampling efficiency, conductivity, and

water velocity.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Based on data from six habitats (backwater, island head, island tail, main channel, and tributary), fishes primarily used low-velocity habitats at tributary mouths during winter conditions. Consequently, the importance of habitats at tributary confluences should be emphasized within management plans. Some species, however, used areas with higher velocities and relatively warmer temperatures during periods when low-velocity tributary habitats were below 4 ºC. Embayment and wing dam habitats had relatively high abundances and species richness, but were underrepresented in our study (because of inaccessibility or unavailability). Although one embayment and one wing dam were evaluated during our study, we believe that these habitats are important winter refuges, and if possible, should be emphasized in management and future studies on winter habitats used by fishes in the Ohio River. Additionally, future studies during winter should evaluate near-shore areas of all habitat types, which may provide insights into habitats used by juvenile fishes. Additionally, studies need to address impacts of habitat disturbances on fish survival during winter, including high flow events and barge traffic.

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Table 3-1. Description of macrohabitats within Belleville Pool, Ohio River.

Habitat type	Description
Main Channel	Area extending from shore including the center of the channel.
Backwater	Area between an island and the shore without barge traffic.
Island head	Area adjacent to the upstream end of an island.
Island tail	Area adjacent to the downstream end of an island.
Tributary	Area encompassing a tributary mouth and its connection to the main channel.
Embayment	A shallow bay-like area connected to the main channel.
Artificial wing dam	A near-shore area of low velocity created by an artificial barrier.
Deep hole	Dredged or natural scour areas within the main channel or back channel.

Table 3-2. Site locations and sample dates of habitat types within Belleville Pool, Ohio River.

			Month/Date					
Site, by habitat type	Latitude	Longitude	2002 Feb	2002 Mar	2002 Apr	2002 Dec	2003 Jan	2003 Mar
Tributary								
1) Bull Cr.	39.20.19.5	81.22.13.8		25	6, 15	12	11	2
2) Duck Cr.	39.24.17.8	81.25.38.1		9, 24	6, 15	12	11	2
3) Lee Cr.	39.09.00.5	81.44.28.5	16, 22		4, 7	15	18	1
4) Little Hocking R.	39.15.46.7	81.41.38.5	17		5, 7	16	13	17
5) Little Kanawha R.	39.15.51.1	81.34.04.9		15	5, 14	16	19	16
6) Hocking R.	39.11.02.9	81.45.15.6	16, 22		4, 7	15	18	1
Backwater								
1) Blennerhasset	39.16.14.1	81.38.45.3		14	5, 14	16	19	17
2) Halfway	39.21.11.8	81.32.46.6		24	6, 15	17	10	16
3) Neal	39.18.29.9	81.33.19.8		15	6, 14	17	10	16
4) Newberry	39.13.12.4	81.41.32.0	17		5, 7	15	18	1
5) Marietta	39.23.41.6	81.25.18.4		25	6, 15	13	12	2
6) Muskingum	39.21.44.7	81.30.37.4		24	6, 15	17	19	16
Island head/tail								
1) Blennerhasset head	39.16.10.2	81.35.40.9		14	5, 14	16	19	17
2) Blennerhasset tail	39.16.29.3	81.39.38.0		14	5, 14	16	19	17
3) Halfway head	39.21.23.6	81.32.20.3		24	6, 15	17	10	16
4) Halfway tail	39.20.55.0	81.32.59.5		24	6, 15	17	10	16
5) Neal head	39.18.51.1	81.33.31.9		15	6, 14	17	10	16
6) Neal tail	39.17.43.7	81.33.44.5		24	5, 14	17	10	16
7) Newberry head	39.13.16.7	81.41.32.8	17		5, 7	16	18	1
8) Newberry tail	39.13.13.0	81.41.41.2	17	11	5, 7	15	18	1
9) Marietta head	39.23.03.8	81.24.30.6			6, 15	12	12	2
10) Marietta tail	39.24.31.2	81.26.48.3		9, 25	6, 15	12	12	2
11) Muskingum head	39.22.36.5	81.29.36.3		24	6, 15	17	19	16
12) Muskingum tail	39.21.34.3	81.31.25.3		24	6, 15	13	10	16
Main Channel								
1) River Mile 165	39.20.23.8	81.22.12.7		25	6, 15	12	12	2
2) River Mile 167	39.21.51.0	81.23.54.4		25	6, 15	12	12	2
3) River Mile 180	39.20.07.0	81.33.18.3		24	6.15	17	10	16
4) River Mile 184	39.16.31.2	81.33.56.6		24	6, 14	17	19	16
5) River Mile 192	39.15.38.3	81.41.29.1		14	5, 7	16	13	17
6) River Mile 194	39.13.38.4	81.41.21.0		14	5, 7	16	18	1
Deep Hole								
1) River Mile 170 #1	39.23.38.2	81.25.08.3		25	6,15	13	11	2
2) River Mile 170 #2	39.23.42.9	81.25.15.3				13	11	2
2) River Mile 180	39.19.56.6	81.33.27.7		24	6,15	17	10	16
3) River Mile 198	39.11.13.9	81.44.34.4	22	14	7	15	18	1

Table 3-2. Continued.

			Month/Date					
	Latitude	Longitude	2002 Feb	2002 Mar	2002 Apr	2002 Dec	2003 Jan	2003 Mar
Extra								
1) Moore's Run	39.22.40.4	81.29.51.4		24				
2) Williams 2-Mile Cr.	39.23.15.0	81.28.46.8		24				
3) Sugarcamp Run	39.21.39.0	81.24.06.0		24			11	
4) River Mile 176	39.21.45.0	81.31.11.4			6			
5) Embayment	39.13.57.0	81.41.10.8				15		1, 17
6) Wing Dam	39.22.16.1	81.24.04.8					11	
7) shoreline below Lee Cr.	39.08.54.0	81.44.29.4					9	
8) River Mile 170 DH #3	39.23.49.1	81.25.24.0					11	2
9) River Mile 170 DH #4	39.24.10.0	81.25.52.5					11	2

Table 3-3. Mean depths of transects with standard deviations, SD, (based on randomly-selected depths from each transect).

Site, by habitat	Transect	Mean depth (m)	SD
Tributary			
Bull Cr.	1	3.53	1.07
Duck Cr.	1	4.7	1.32
Hocking R.	1	6.87	0.78
	2	7.56	1.5
	3	6.95	0.74
Lee Cr.	1	5.04	1.43
	2	3.91	1.43
L. Hocking R.	1	3.85	1.26
L. Kanawha R.	1	8.69	0.66
	2	9.04	0.35
	3	9.06	0.46
Backwater			
Blennerhasset Is.	1	5.12	0.49
	2	8.94	0.25
	3	3.2	0.62
Halfway Is.	1	4.58	1.03
	2	6.36	0.23
	3	5.16	0.5
Neal Is.	1	5.84	0.47
	2	7.51	0.17
	3	5.2	0.47
Newberry Is.	1	7.26	0.43
	2	6.44	0.35
	3	3.48	0.54
Marietta Is.	1	4.54	0.48
	2	5.17	0.49
	3	3.31	0.59
Muskingum Is.	1	4.64	0.52
	2	5.16	0.49
	3	4.42	0.6

Table 3-3. Continued.

Island Head			
Blennerhasset Is.	1	2.77	0.44
	2	2.71	0.4
	3	2.06	0.21
Halfway Is.	1	2.51	0.42
	2	2.72	0.36
Neal Is.	1	4.52	0.43
	2	2.57	0.36
	3	2.74	0.36
Newberry Is.	1	2.66	0.35
	2	2.81	0.36
	3	2.02	0.3
Marietta Is.	1	2.85	0.37
	2	2.1	0.26
	3	2.83	0.48
Muskingum Is.	1	2.88	0.42
	2	2.87	0.43
	3	3.73	0.47
Island Tail			
Blennerhasset Is.	1	2.5	0.25
	2	2.08	0.28
	3	2.98	0.34
Halfway Is.	1	2.93	0.41
	2	3.02	0.43
Neal Is.	1	3.28	0.41
	2	3.4	0.44
	3	2.12	0.23
Newberry Is.	1	2.01	0.35
	2	2.11	0.25
Marietta Is.	1	2.05	0.29
	2	2.96	0.32
	3	2.03	0.31
Muskingum Is.	1	2.96	0.24
	2	3	0.29
	3	2.95	0.26

Table 3-3. Continued.

Main Channel			
River Mile 165	1	4	0.39
	2	7.64	0.3
	3	3.92	0.48
River Mile 167	1	5.19	0.38
	2	6.28	0.37
	3	8.75	0.53
River Mile 180	1	4.8	0.47
	2	9	0.61
	3	6.75	0.74
River Mile 184	1	7.4	0.54
	2	9.5	0.51
	3	7.47	0.41
River Mile 192	1	3.92	0.43
	2	7.98	0.48
	3	3.17	0.6
River Mile 194	1	3.85	0.55
	2	9.56	0.48
	3	3.77	0.43
Deep hole			
River Mile 170 #1	1	8.66	0.65
River Mile 170 #2	1	8.83	0.45
River Mile 170 #3	1	7.96	0.76
River Mile 170 #4	1	7.75	0.5
River Mile 180	1	10.51	0.47
River Mile 198	1	13.19	1.15

Table 3-4. Habitat data by site and habitat type for sample sessions from February 2002 through March 2003 in Belleville Pool, Ohio River (* indicates data not available). Dissolved oxygen (DO), pH, specific conductivity, and turbidity are average values from 1 m depth profiles.

Site	Habitat	Date	Temp (C)	DO (mg/L)	pH	sp. Cond. uS/cm	Flow (m/s)	Turb. (NTU)	Secchi (m)
Lee Cr.	tributary	2/16/2002	4.65	13.45	7.38	295	0.07	*	*
Lee Cr.	tributary	2/22/2002	5.36	13.12	7.8	354.3	*	*	*
Lee Cr.	tributary	4/4/2002	9.02	7.86	7.2	250.9	0	*	*
Lee Cr.	tributary	4/7/2002	8.84	9.86	7.26	251.7	0.15	*	*
Lee Cr.	tributary	12/15/2002	4.51	6.63	6.8	317.4	0.10	160.8	0.2
Lee Cr.	tributary	1/18/2003	1.44	13.81	7.5	427.4	0.03	17.5	0.94
Lee Cr.	tributary	3/1/2003	1.98	11.66	6.7	214.5	0.01	37	0.53
Hocking R.	tributary	2/16/2002	4.56	13.04	7.6	467.8	0.05	*	*
Hocking R.	tributary	2/22/2002	5.03	13.43	7.62	495.9	*	*	*
Hocking R.	tributary	4/4/2002	10.97	6.6	7.45	421.5	0.06	*	*
Hocking R.	tributary	4/7/2002	9.06	8.97	7.49	434.2	0.1	*	*
Hocking R.	tributary	12/15/2002	3.41	6.48	6.7	437.0	0.20	167.6	0.15
Hocking R.	tributary	1/18/2003	0.86	13.06	7.40	508.1	0.00	8.5	0.72
Hocking R.	tributary	3/1/2003	2.86	11.39	6.7	387.3	0.29	27	0.51
L. Hocking R.	tributary	2/17/2002	4.6	13.64	7.49	337.5	0.04	*	*
L. Hocking R.	tributary	4/5/2002	9.59	10.05	7.34	287.1	0.05	*	*
L. Hocking R.	tributary	4/7/2002	9.07	12.5	7.31	319.2	0.08	*	*
L. Hocking R.	tributary	12/16/2002	4.05	*	7.3	311.8	0.06	42.7	0.3
L. Hocking R.	tributary	1/13/2003	2.52	13.71	7.6	432.3	0.04	26.3	0.52
L. Hocking R.	tributary	3/17/2003	6.54	12.43	7.4	400.4	0.00	94	0.19
L. Kanawha R.	tributary	3/15/2002	7.58	8.19	7.42	283	0.05	*	*
L. Kanawha R.	tributary	4/5/2002	10.15	9.65	7.08	89.3	0.1	*	*
L. Kanawha R.	tributary	4/14/2002	13.07	10.56	7.19	200.4	0.14	*	*
L. Kanawha R.	tributary	12/16/2002	5.03	*	7.2	171.3	0.35	63.9	0.34
L. Kanawha R.	tributary	1/19/2003	0.83	14.13	7.8	327.3	0.06	9.3	1.61
L. Kanawha R.	tributary	3/16/2003	6.35	11.36	7.4	315.8	0.15	25	0.78
Bull Cr.	tributary	3/25/2002	7.53	8.21	7.32	292.6	0.03	*	*
Bull Cr.	tributary	4/6/2002	8.9	10.09	7.2	241.9	0.21	*	*
Bull Cr.	tributary	4/15/2002	12.85	9.59	7.28	217.1	0	*	*
Bull Cr.	tributary	12/12/2002	3.04	7.64	8.0	366.8	0.03	7.8	1.54
Bull Cr.	tributary	1/11/2003	3.24	13.55	7.2	397.0	0.23	69.4	0.33
Bull Cr.	tributary	3/2/2003	2.67	12.60	7.5	306.0	0.05	101	0.24
Duck Cr.	tributary	3/9/2002	6.64	8.97	7.42	389.6	0	*	*
Duck Cr.	tributary	3/24/2002	6.82	7.98	7.37	355.1	0	*	*
Duck Cr.	tributary	4/6/2002	8.94	10.12	7.25	244.4	0.72	*	*
Duck Cr.	tributary	4/15/2002	16.3	7.79	7.52	597.3	0.09	*	*
Duck Cr.	tributary	12/12/2002	4.39	7.45	7.1	414.8	0.03	3.3	0.22
Duck Cr.	tributary	1/11/2003	2.68	13.86	7.2	430.7	0.00	43.6	0.43
Duck Cr.	tributary	3/2/2003	3.88	11.38	7.1	499.6	0.28	93	0.24
Moore's Run	tributary	3/24/2002	6.28	8.15	7.43	324.1	0	*	*
Sugarcamp Run	tributary	3/24/2002	7.42	8.04	7.26	325.2	0.34	*	*
Sugarcamp Run	tributary	1/12/2003	3.23	13.55	7.4	402.8	0.05	51	0.32
Williams Two-Mile Cr.	tributary	3/24/2002	5.57	7.31	7	244.1	0	*	*

Table 3-4. Continued.

Site	Habitat	Date	Temp (C)	DO (mg/L)	pH	sp. Cond. uS/cm	Flow (m/s)	Turb. (NTU)	Secchi (m)
Newberry	island tail	3/11/2002	5.93	7.86	7.5	359.7	0.19	*	*
Newberry	island tail	4/5/2002	8.71	10.78	7.44	253.4	0.32	*	*
Newberry	island tail	4/7/2002	8.76	10.11	7.26	254.3	0.32	*	*
Newberry	island tail	12/15/2002	4.66	9.57	6.6	316.0	0.20	133.0	0.18
Newberry	island tail	1/18/2003	1.51	13.40	7.52	433.7	0.10	6.1	1.31
Newberry	island tail	3/1/2003	2.23	12.78	6.9	356.3	0.29	113	0.29
Newberry	island head	3/11/2002	8.71	7.73	7.5	356.8	0.21	*	*
Newberry	island head	4/5/2002	8.75	10.56	7.44	252.6	0.41	*	*
Newberry	island head	4/7/2002	8.75	12.19	7.29	252.4	0.41	*	*
Newberry	island head	12/15/2002	4.73	7.44	6.7	293.9	1.00	175.3	0.118
Newberry	island head	1/18/2003	1.51	13.12	7.52	433.0	0.19	6.1	1.31
Newberry	island head	3/1/2003	2.20	12.96	7.0	365.3	0.49	105	0.49
Blennerhasset	island tail	3/14/2002	7.45	9.33	7.96	403.9	0.04	*	*
Blennerhasset	island tail	4/5/2002	8.96	10.75	7.13	255	0.3	*	*
Blennerhasset	island tail	4/14/2002	11.95	11.89	7.34	310.9	0.08	*	*
Blennerhasset	island tail	12/16/2002	3.57	*	7.3	488.0	0.21	49.2	0.49
Blennerhasset	island tail	1/19/2003	1.21	12.15	7.6	456.3	0.06	12.5	1.02
Blennerhasset	island tail	3/17/2003	5.31	13.63	7.6	475.0	0.37	66	0.32
Blennerhasset	island head	3/14/2002	7.61	9.19	7.94	408.2	0.2	*	*
Blennerhasset	island head	4/5/2002	8.96	10.49	7.12	245.3	0.48	*	*
Blennerhasset	island head	4/14/2002	12.03	11.64	7.46	317.6	0.42	*	*
Blennerhasset	island head	12/16/2002	3.59	*	7.3	463.0	0.60	48.8	0.31
Blennerhasset	island head	1/19/2003	1.23	13.60	7.8	459.7	0.18	7.5	1.31
Blennerhasset	island head	3/17/2003	5.39	13.78	7.7	471.5	0.82	74	0.22
Neal	island tail	3/24/2002	7.14	8.05	7.18	332.3	0.27	*	*
Neal	island tail	4/5/2002	8.98	10.38	7.23	247	0.68	*	*
Neal	island tail	4/14/2002	11.6	11.7	7.43	272.1	0.09	*	*
Neal	island tail	12/17/2002	3.72	*	7.2	420.3	0.00	60.0	0.35
Neal	island tail	1/10/2003	3.54	13.50	7.2	405.0	0.12	60	0.46
Neal	island tail	3/16/2003	4.85	12.66	7.2	461.5	0.56	43	0.26
Neal	island head	3/24/2002	7.26	8.1	7.18	329.3	0.45	*	*
Neal	island head	4/5/2002	8.98	10.43	7.22	249.2	0.98	*	*
Neal	island head	4/14/2002	11.54	11.85	7.36	274.3	0.65	*	*
Neal	island head	12/17/2002	3.61	*	7.2	423.0	0.66	80.3	0.32
Neal	island head	1/10/2003	3.56	13.48	7.1	406.0	0.62	44.7	0.44
Neal	island head	3/16/2003	4.82	13.17	7.2	466.8	0.98	43	0.24
Halfway	island tail	3/24/2002	7.46	8.31	7.47	404.9	0.3	*	*
Halfway	island tail	4/6/2002	9.62	10.22	7.57	371.8	0.16	*	*
Halfway	island tail	4/15/2002	14.48	9.04	7.62	432.3	0.43	*	*
Halfway	island tail	12/17/2002	3.66	*	7.1	538.0	0.26	39.9	0.42
Halfway	island tail	1/10/2003	3.29	13.48	7.1	506.0	0.23	38.6	0.49
Halfway	island tail	3/16/2003	4.98	12.84	7.3	532.0	0.34	139	0.18
Halfway	island head	3/24/2002	7.49	8.23	7.57	403.6	0.48	*	*
Halfway	island head	4/6/2002	9.57	10.21	7.6	373	0.83	*	*
Halfway	island head	4/15/2002	14.47	9.12	7.61	369.2	0.56	*	*
Halfway	island head	12/17/2002	3.66	*	7.3	540.0	0.57	43.4	0.42
Halfway	island head	1/10/2003	3.28	13.37	7.2	507.5	0.50	36.4	0.42
Halfway	island head	3/16/2003	5.09	12.73	7.5	539.7	0.82	134	0.18

Table 3-4. Continued.

Site	Habitat	Date	Temp (C)	DO (mg/L)	pH	sp Cond. uS/cm	Flow (m/s)	Turb. (NTU)	Secchi (m)
Muskingum	island tail	3/24/2002	7.51	8.04	7.24	338.4	0.65	*	*
Muskingum	island tail	4/6/2002	8.92	10.66	7.05	246.3	0.76	*	*
Muskingum	island tail	4/15/2002	11.92	9.85	7.44	284	0	*	*
Muskingum	island tail	12/13/2002	4.47	8.47	7.2	443.0	0.23	6.5	1.35
Muskingum	island tail	1/10/2003	3.59	13.49	7.3	407.0	0.21	45.6	0.41
Muskingum	island tail	3/16/2003	5.01	13.17	7.4	480.0	0.18	38	0.42
Muskingum	island head	3/24/2002	7.51	8.12	7.24	335.2	1.02	*	*
Muskingum	island head	4/6/2002	8.91	10.58	7.08	246.2	0.86	*	*
Muskingum	island head	4/15/2002	11.58	10.35	7.32	264.2	0.96	*	*
Muskingum	island head	12/17/2002	3.56	*	7.2	427.0	0.84	66.8	0.36
Muskingum	island head	1/19/2003	1.23	13.52	7.8	457.0	0.15	10.8	1.25
Muskingum	island head	3/16/2003	4.97	13.20	7.5	483.3	1.13	42	*
Marietta	island tail	3/25/2002	7.31	8.25	7.27	288.3	0.26	*	*
Marietta	island tail	4/6/2002	9.04	10.38	7.2	241	0.38	*	*
Marietta	island tail	4/15/2002	11.71	10.9	7.45	267.3	0.73	*	*
Marietta	island tail	12/12/2002	4.81	7.38	7.2	400.0	0.10	3.1	1.5
Marietta	island tail	1/12/2003	3.15	13.89	7.3	397.0	0.04	32.8	0.42
Marietta	island tail	3/2/2003	2.31	13.00	7.4	366.0	0.57	114	0.24
Marietta	island head	3/25/2002	7.3	8.32	7.27	286.5	0.46	*	*
Marietta	island head	4/6/2002	8.89	10.41	7.22	242.6	0.54	*	*
Marietta	island head	4/15/2002	11.88	10.7	7.35	268.8	0.86	*	*
Marietta	island head	12/12/2002	4.59	7.24	7.2	400.0	0.16	3.2	2.01
Marietta	island head	1/12/2003	3.10	13.49	7.3	395.0	0.43	31.2	0.49
Marietta	island head	3/2/2003	2.31	13.34	7.4	365.0	0.60	114	0.24
River Mile 194	main channel	3/14/2002	7.44	9.07	7.8	393.4	0.13	*	*
River Mile 194	main channel	4/5/2002	8.7	10.56	7.44	252.6	0.41	*	*
River Mile 194	main channel	4/7/2002	8.8	12.33	7.25	243.6	0.55	*	*
River Mile 194	main channel	12/16/2002	3.70	*	7.2	523.0	0.60	36.8	0.2
River Mile 194	main channel	1/18/2003	1.23	12.05	7.56	434.3	0.05	10.9	1.14
River Mile 194	main channel	3/1/2003	2.38	12.62	7.0	366.2	0.22	93	0.2
River Mile 192	main channel	3/14/2002	7.24	9.07	7.8	393.4	0.13	*	*
River Mile 192	main channel	4/5/2002	8.7	10.49	7.44	253.2	0.4	*	*
River Mile 192	main channel	4/7/2002	8.84	12.29	7.24	256.4	0.69	*	*
River Mile 192	main channel	12/16/2002	3.70	*	7.2	523.0	0.60	36.8	0.2
River Mile 192	main channel	1/13/2003	2.63	13.90	7.5	462.4	0.33	28.3	0.52
River Mile 192	main channel	3/17/2003	5.30	13.26	7.5	492.6	0.70	110	0.16
River Mile 184	main channel	3/24/2002	7.28	8.25	7.28	335	0.42	*	*
River Mile 184	main channel	4/6/2002	8.98	10.38	7.23	247	0.95	*	*
River Mile 184	main channel	4/14/2002	11.5	11.65	7.38	267.7	0.53	*	*
River Mile 184	main channel	12/17/2002	3.75	*	6.9	496.8	0.81	41.6	0.32
River Mile 184	main channel	1/19/2003	1.49	13.76	7.7	471.0	0.13	11.2	1.26
River Mile 184	main channel	3/16/2003	4.74	12.60	7.3	494.3	1.25	83	0.26
River Mile 180	main channel	3/24/2002	7.27	8.07	7.27	333.7	0.48	*	*
River Mile 180	main channel	4/6/2002	8.98	10.32	7.3	249.9	1.13	*	*
River Mile 180	main channel	4/15/2002	11.66	8.07	7.27	333.7	0.48	*	*
River Mile 180	main channel	12/17/2002	3.66	*	7.0	421.9	0.78	75.3	0.31
River Mile 180	main channel	1/10/2003	3.58	13.45	7.4	404.5	0.84	41.7	*
River Mile 180	main channel	3/16/2003	4.85	12.87	7.3	498.0	1.00	91	0.22
River Mile 176	main channel	4/6/2002	9.35	10.18	7.49	363.2	0.79	*	*

Table 3-4. Continued.

Site	Habitat	Date	Temp (C)	DO (mg/L)	pH	sp. Cond. uS/cm	Flow (m/s)	Turb. (NTU)	Secchi (m)
River Mile 167	main channel	3/25/2002	7.3	8.25	7.27	288.3	0.46	*	*
River Mile 167	main channel	4/6/2002	9.02	10.43	7.18	244.7	0.63	*	*
River Mile 167	main channel	4/15/2002	12	10.3	7.26	273.5	1.15	*	*
River Mile 167	main channel	12/12/2002	4.62	7.18	7.2	399.0	0.23	3	2
River Mile 167	main channel	1/12/2003	3.21	13.56	7.4	401.0	0.43	32.1	0.54
River Mile 167	main channel	3/2/2003	3.92	10.37	7.3	400.0	0.21	18	0.18
River Mile 165	main channel	3/25/2002	7.3	8.22	7.27	288.3	0.45	*	*
River Mile 165	main channel	4/6/2002	8.98	10.35	7.25	246.8	0.79	*	*
River Mile 165	main channel	4/15/2002	12	10.29	7.26	272.5	1.11	*	*
River Mile 165	main channel	12/12/2002	4.60	7.34	7.3	398.0	0.23	3.3	1.85
River Mile 165	main channel	1/12/2003	3.10	13.58	7.9	397.2	0.39	3.6	0.42
River Mile 165	main channel	3/2/2003	2.42	12.86	7.3	361.3	0.37	111	0.2
River Mile 198	deep hole	2/22/2002	5.42	13.64	7.55	373	*	*	*
River Mile 198	deep hole	3/14/2002	7.24	9.07	7.8	393.4	*	*	*
River Mile 198	deep hole	4/7/2002	8.83	12.25	7.24	258.3	*	*	*
River Mile 198	deep hole	12/15/2002	3.70	*	7.2	523.0	0.60	36.8	0.2
River Mile 198	deep hole	1/18/2003	1.55	12.48	7.6	431.1	0.15	11.3	1.1
River Mile 198	deep hole	3/1/2003	2.32	12.44	7.0	349.7	0.35	97	0.18
River Mile 180	deep hole	3/24/2002	7.26	8.07	7.27	333.7	0.48	*	*
River Mile 180	deep hole	4/6/2002	8.98	10.32	7.3	249.9	1.13	*	*
River Mile 180	deep hole	4/15/2002	11.66	8.07	7.27	333.7	0.48	*	*
River Mile 180	deep hole	12/17/2002	3.66	*	7.0	421.9	0.78	75.3	0.31
River Mile 180	deep hole	1/10/2003	3.58	13.45	7.4	404.5	0.84	41.7	*
River Mile 180	deep hole	3/16/2003	4.85	12.87	7.3	498.0	1.00	91	0.22
River Mile 170 #1	deep hole	3/25/2002	7.3	8.32	7.27	286.5	0.39	*	*
River Mile 170 #1	deep hole	4/6/2002	8.99	10.3	7.17	244.4	0.92	*	*
River Mile 170 #1	deep hole	4/15/2002	11.87	10.7	7.35	268.8	0.82	*	*
River Mile 170 #1	deep hole	12/13/2002	4.49	8.38	7.3	371.8	0.43	4.5	*
River Mile 170 #1	deep hole	1/11/2003	3.23	13.71	7.5	398.0	0.64	39.9	0.42
River Mile 170 #1	deep hole	3/2/2003	2.31	12.87	7.2	363.0	0.60	116	0.21
River Mile 170 #2	deep hole	12/13/2002	4.49	8.38	7.3	371.8	0.43	4.5	*
River Mile 170 #2	deep hole	1/11/2003	3.23	13.71	7.5	398.0	0.64	39.9	0.42
River Mile 170 #2	deep hole	3/2/2003	2.31	12.87	7.2	363.0	0.60	116	0.21
River Mile 170 #3	deep hole	12/13/2002	4.49	8.38	7.3	371.8	0.43	4	*
River Mile 170 #3	deep hole	1/11/2003	3.23	13.71	7.5	398.0	0.64	40	0.42
River Mile 170 #3	deep hole	3/2/2003	2.32	13.22	7.2	363.3	0.61	121	0.25
River Mile 170 #4	deep hole	12/13/2002	4.49	8.38	7.3	371.8	0.43	4	*
River Mile 170 #4	deep hole	1/11/2003	3.23	13.71	7.5	398.0	0.64	40	0.42
River Mile 170 #4	deep hole	3/2/2003	2.32	13.22	7.2	363.3	0.61	121	0.25
Newberry	backwater	3/11/2002	4.4	7.74	7.5	356.2	0.2	*	*
Newberry	backwater	4/5/2002	8.7	10.78	7.44	253.4	0.32	*	*
Newberry	backwater	4/7/2002	8.74	10.07	7.26	243.6	0.67	*	*
Newberry	backwater	12/15/2002	4.73	7.44	6.7	293.9	1.00	175.3	0.18
Newberry	backwater	1/18/2003	1.57	13.00	7.52	432.6	0.06	11	1.36
Newberry	backwater	3/1/2003	2.31	12.68	6.8	345.0	0.59	99	0.22
Blennerhasset	backwater	3/14/2002	7.1	9.14	7.78	366.5	0.14	*	*
Blennerhasset	backwater	4/5/2002	8.96	10.75	7.13	255	0.44	*	*
Blennerhasset	backwater	4/14/2002	11.86	11.3	7.44	288.5	0.33	*	*
Blennerhasset	backwater	12/16/2002	3.59	*	7.3	463.0	0.60	48.8	0.29

Table 3-4. Continued.

Site	Habitat	Date	Temp (C)	DO (mg/L)	pH	sp. Cond. uS/cm	Flow (m/s)	Turb. (NTU)	Secchi (m)
Blennerhasset	backwater	1/19/2003	1.18	13.35	7.8	453.3	0.16	11.7	1.1
Blennerhasset	backwater	3/17/2003	5.18	13.68	7.5	463.4	0.69	56	0.32
Neal	backwater	3/15/2002	7.42	9.13	7.56	382.3	0.18	*	*
Neal	backwater	4/6/2002	8.98	10.38	7.23	247	0.93	*	*
Neal	backwater	4/14/2002	11.46	11.83	7.42	260.8	0.63	*	*
Neal	backwater	12/17/2002	3.66	*	7.2	419.0	0.66	72.8	0.34
Neal	backwater	1/10/2003	3.54	13.49	7.3	404.2	0.59	44.9	0.45
Neal	backwater	3/16/2003	4.81	12.94	7.2	459.1	0.64	39	0.39
Halfway	backwater	3/24/2002	7.49	8.23	7.57	403.6	0.42	*	*
Halfway	backwater	4/6/2002	9.81	10.28	7.57	381.9	0.77	*	*
Halfway	backwater	4/15/2002	14.47	9.04	7.62	432.3	0.76	*	*
Halfway	backwater	12/17/2002	4.54	*	7.2	568.3	0.50	36.3	0.41
Halfway	backwater	1/10/2003	4.03	13.42	7.1	539.0	0.49	36	0.48
Halfway	backwater	3/16/2003	5.13	12.70	7.3	534.7	0.60	136	0.18
Muskingum	backwater	3/24/2002	7.5	8.04	7.24	338.4	0.92	*	*
Muskingum	backwater	4/6/2002	8.91	10.58	7.08	246.2	0.76	*	*
Muskingum	backwater	4/15/2002	11.58	10.35	7.32	264.2	0.82	*	*
Muskingum	backwater	12/17/2002	3.71	*	7.1	425.0	0.81	70.1	0.36
Muskingum	backwater	1/19/2003	1.18	13.36	7.8	453.7	0.18	10.8	1.22
Muskingum	backwater	3/16/2003	4.99	13.18	7.3	476.8	0.95	37	*
Marietta	backwater	3/25/2002	7.3	8.32	7.27	286.5	0.39	*	*
Marietta	backwater	4/6/2002	8.99	10.3	7.17	244.4	0.92	*	*
Marietta	backwater	4/15/2002	11.87	10.7	7.35	268.8	0.82	*	*
Marietta	backwater	12/13/2002	4.49	8.38	7.3	371.8	0.43	4.5	*
Marietta	backwater	1/11/2003	3.23	13.71	7.6	398.0	0.64	39.9	0.42
Marietta	backwater	3/2/2003	2.37	13.06	7.2	360.2	0.62	116	0.24
L. Sandy Cr.	embayment	12/15/2002	4.08	7.41	6.9	257.3	0.00	65.8	*
L. Sandy Cr.	embayment	3/1/2003	2.95	11.16	7.3	257.0	0	55.00	0.39
L. Sandy Cr.	embayment	3/17/2003	11.24	11.75	7.7	350.0	0	84.00	0.25
Wing Dam	artificial	1/11/2003	3.26	14.61	7.2	400.7	0.10	50	37

Table 3-5. Sites of temperature loggers in Belleville Pool, Ohio River, during 2002 and 2003. Loggers at river mile 196 and Neal Island were not recovered in 2003.

Site Location	Habitat	Water column placement
Blennerhasset Is.	Backwater	Bottom
Newberry Is.	Backwater	Bottom
Neal Is.	Backwater	Bottom
River Mile 196	Main channel	Near surface
River Mile 184	Main channel	Near surface
Marietta Is. Head	Main channel	Near surface

Table 3-6. Total number of fishes caught at each habitat type in the Belleville Pool, Ohio River, during sample sessions from February 2002 – March 2003.

Species	Island Head	Island Tail	Back water	Main	Tributary	Deep hole	Wing Dam	Embay-ment	Total
Black Buffalo	0	0	0	0	0	0	1	0	1
Black Crappie	0	0	0	0	1	0	0	2	3
Bluegill	0	0	0	0	1	0	0	164	165
Bowfin	0	0	0	0	0	0	0	1	1
Channel Catfish	6	2	43	62	88	1	0	0	202
Common Carp	0	1	3	2	6	0	1	3	16
Emerald Shiner	0	0	0	0	7	0	2	137	146
Flathead Catfish	0	0	0	1	0	0	0	0	1
Freshwater Drum	3	3	26	157	270	3	7	6	475
Gizzard Shad	0	0	2	13	60	0	1	430	506
Golden Redhorse	0	0	0	0	1	0	0	0	1
Green Sunfish	0	0	0	0	0	0	0	7	7
Highfin Carpsucker	0	0	0	0	4	0	0	0	4
Hybrid Striped Bass	0	0	0	6	14	0	0	0	20
Largemouth Bass	0	0	0	1	0	0	0	3	4
Mooneye	0	5	7	4	2	0	0	0	18
Mosquitofish	0	0	0	0	0	0	0	1	1
Ohio Lamprey	0	0	1	0	0	0	0	0	1
Orangespotted Sunfish	0	0	0	0	1	0	0	49	50
Pumpkinseed	0	0	0	0	0	0	0	5	5
Quillback	0	0	0	0	4	0	0	0	4
River Carpsucker	0	0	2	2	21	0	1	4	30
Rock Bass	0	0	1	0	0	0	0	0	1
Sauger	0	1	0	0	2	0	0	0	3
Shorthead Redhorse	0	0	0	1	0	0	1	0	2
Silver Chub	0	4	4	6	0	0	0	0	14
Smallmouth Buffalo	0	2	10	12	30	0	12	1	67
Spottail Shiner	0	0	0	0	1	0	0	0	1
Spotted Bass	0	0	0	0	0	2	0	0	2
Spotted Sucker	0	0	0	0	0	0	0	2	2
Walleye	0	0	0	0	3	0	0	0	3
Warmouth	0	0	0	0	0	0	0	5	5
White Bass	1	0	3	4	37	0	1	0	46
White Crappie	0	0	0	1	0	0	0	70	71
Total	10	18	102	272	553	6	27	890	1878

Table 3-7. Total number of fishes caught at each habitat type in the Belleville Pool, Ohio River, during sample sessions from February – April 2002.

Species	Island Head	Island Tail	Back water	Main	Tributary	Deep hole	Total
Bluegill	0	0	0	0	1	0	1
Channel Catfish	6	2	17	19	75	0	119
Common Carp	0	0	0	0	4	0	4
Emerald Shiner	0	0	0	0	7	0	7
Flathead Catfish	0	0	0	1	0	0	1
Freshwater Drum	3	2	4	10	160	0	179
Gizzard Shad	0	0	0	1	57	0	58
Highfin Carpsucker	0	0	0	0	2	0	2
Mooneye	0	3	1	1	2	0	7
Orangespotted Sunfish	0	0	0	0	1	0	1
Quillback	0	0	0	0	2	0	2
River Carpsucker	0	0	0	0	15	0	15
Spottail Shiner	0	0	0	0	1	0	1
Walleye	0	0	0	0	2	0	2
White Bass	0	0	0	0	4	0	4
Total	9	7	22	32	333	0	403

Table 3-8. Fish caught per hour (CPUE) within each habitat type in the Belleville Pool, Ohio River, during February 2002 through March 2003.

	Habitat types								
	Island		Back	Main		Deep	Wing	Embay-	
Species	Head	Tail	water	channel	Trib	hole	dam	ment	Total
Black Buffalo	0	0	0	0	0	0	7.52	0.00	0.02
Black Crappie	0	0	0	0	0.16	0	0	1.36	0.06
Bluegill	0	0	0	0	0.16496	0	0	111.87	3.44
Bowfin	0	0	0	0	0	0	0	0.68	0.02
Channel Catfish	1.80	0	3.45	3.44	14.52	0.48	0	0.00	4.21
Common Carp	0	0.23	0.24	0.11	0.99	0	7.52	2.05	0.33
Emerald Shiner	0	0	0	0	1.15	0	15.04	93.45	3.05
Flathead Catfish	0	0	0	0	0	0	0	0.00	0.02
Freshwater Drum	0.90	0.69	2.08	8.71	44.54	1.43	52.63	4.09	9.91
Gizzard Shad	0	0	0.16	0.72	9.90	0	8	293.32	10.56
Golden Redhorse	0	0	0	0	0.16496	0	0	0.00	0.02
Green Sunfish	0	0	0	0	0	0	0	4.77	0.15
Highfin Carpsucker	0	0	0	0	0.66	0	0	0.00	0.08
Hybrid Striped Bass	0	0	0	0.33	2	0	0	0.00	0.42
Largemouth Bass	0	0.00	0.00	0.06	0	0	0	2.05	0.08
Mooneye	0	1.15	0.56	0.22	0.33	0	0	0.00	0.38
Mosquitofish	0	0	0	0	0	0	0	0.68	0.02
Ohio Lamprey	0	0	0.08	0	0	0	0	0.00	0.02
Orangespotted Sunfish	0	0	0	0	0	0	0	33.42	1.04
Pumpkinseed	0	0	0	0	0	0	0	3.41	0.10
Quillback	0	0	0	0	0.66	0	0	0.00	0.08
River Carpsucker	0	0	0.16	0.11	3	0	8	2.73	0.63
Rock Bass	0	0	0.08	0	0	0	0	0.00	0.02
Sauger	0	0	0	0	0.33	0	0	0.00	0.06
Shorthead Redhorse	0	0	0	0.06	0	0	8	0.00	0.04
Silver Chub	0	0.92	0.32	0.33	0	0	0	0.00	0.29
Smallmouth Buffalo	0	0.46	0.80	0.67	4.95	0	90	0.68	1.40
Spottail Shiner	0	0	0	0	0.16	0	0	0.00	0.02
Spotted Bass	0	0	0	0	0	0.95	0	0.00	0.04
Spotted Sucker	0	0	0	0	0	0	0	1.36	0.04
Walleye	0	0	0	0	0.49	0	0	0.00	0.06
Warmouth	0	0	0	0	0	0	0	3.41	0.10
White Bass	0.30	0	0.24	0.22	6.10	0	7.52	0.00	0.96
White Crappie	0	0	0	0.06	0	0	0	47.75	1.48
Total	2.99	4.12	8.17	15.09	91.22	2.86	203.01	607.09	39.18

Table 3-9. Fish caught per hour (CPUE) within each habitat type in the Belleville Pool, Ohio River, during February - April 2002.

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	water	channel	Trib	hole	Total
Bluegill	0	0	0	0	0.34	0	0.05
Channel catfish	4.08	1.87	3.79	2.11	25.84	0	5.84
Common carp	0	0	0	0	1.38	0	0.19
Emerald shiner	0	0	0	0	2.76	0	0.39
Flathead catfish	0	0	0	0.11	0	0	0.05
Freshwater drum	2.04	0.93	0.89	1.11	55.12	0	8.64
Gizzard shad	0	0	0	0.11	19.64	0	2.80
Highfin carpsucker	0	0	0	0	0.69	0	0.10
Hybrid striped bass	0	0	0	0	1.38	0	0.19
Mooneye	0	1.40	0.22	0.11	0.69	0	0.34
Orangespotted Sunfish	0	0	0	0	0.34	0	0.05
Quillback	0	0	0	0	0.69	0	0.10
River carpsucker	0	0	0	0	5.17	0	0.72
Walleye	0	0	0	0	1	0	0.10
Total	6.12	4.20	4.91	3.55	114.73	0	19.55

Table 3-10. Fish caught per hour (CPUE) within each habitat type in the Belleville Pool, Ohio River, during December 2002 through March 2003.

	Habitat types								
	Island		Back	Main		Deep	Wing	Embay-	
Species	Head	Tail	water	channel	Trib	hole	dam	ment	Total
Black Buffalo	0	0	0	0	0	0	7.52	0.00	0.04
Black Crappie	0	0	0	0	0.32	0	0	1.36	0.11
Bluegill	0	0	0	0	0	0	0	111.87	6.10
Bowfin	0	0	0	0	0	0	0	0.68	0.04
Channel Catfish	0	0	3.29	4.77	4.11	0.87	0	0.00	3.09
Common Carp	0	0.45	0.38	0.22	0.63	0	7.52	2.05	0.45
Emerald Shiner	0	0	0	0	0	0	15.04	93.45	5.17
Freshwater Drum	0	0.45	2.78	16.32	34.81	2.60	52.63	4.09	11.01
Gizzard Shad	0	0	0.25316	1.33	0.95	0	7.52	293.32	16.67
Golden Redhorse	0	0	0	0	0.32	0	0	0.00	0.04
Green Sunfish	0	0	0	0	0	0	0	4.77	0.26
Highfin Carpsucker	0	0	0	0	0.63	0	0	0.00	0.07
Hybrid Striped Bass	0	0	0	0.67	3.16	0	0	0.00	0.60
Largemouth Bass	0	0	0	0.11	0	0	0	2.05	0.15
Mooneye	0	0.90	0.76	0.33	0	0	0	0.00	0.41
Mosquitofish	0	0	0	0	0	0	0	0.68	0.04
Ohio Lamprey	0	0	0.13	0	0	0	0	0.00	0.04
Orangespotted Sunfish	0	0	0	0	0	0	0	33.42	1.82
Pumpkinseed	0	0	0	0	0	0	0	3.41	0.19
Quillback	0	0	0	0	0.63	0	0	0.00	0.07
River Carpsucker	0	0	0.25	0.22	1.90	0	7.52	2.73	0.56
Rock Bass	0	0	0.13	0	0	0	0	0.00	0.04
Sauger	0	0.45	0	0	0.63	0	0	0.00	0.11
Shorthead Redhorse	0	0	0	0.11	0	0	7.52	0.00	0.07
Silver Chub	0	1.80	0.51	0.67	0	0	0	0.00	0.52
Smallmouth Buffalo	0	0.90	1.27	1.33	9.49	0	90.23	0.68	2.49
Spotted Bass	0	0	0	0	0	1.73	0	0.00	0.07
Spotted Sucker	0	0	0	0	0	0	0	1.36	0.07
Walleye	0	0	0	0	0.31646	0	0	0.00	0.04
Warmouth	0	0	0	0	0	0	0	3.41	0.19
White Bass	0.53	0	0.38	0.44	11.71	0	7.52	0.00	1.71
White Crappie	0	0	0	0.11	0	0	0	47.75	2.64
Total	0.53	4.95	10.13	26.64	69.62	5.20	203.008	607.09	54.89

Table 3-11. Selection statistics for occupancy rate models fit to freshwater drum data including the second order adjustment to Akaike's Information Criterion (AICc), rescaled differences (Delta AICc), Akaike model weights, model likelihoods, number of model parameters (K) and model deviance.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	K	Model Deviance
{p(depth) psi(hab*yr)}	213.68	0	0.506	1	8	196.03
{p(.) psi(hab*yr)}	215.20	1.52	0.236	0.47	7	199.93
{p(flow) psi(hab*yr)}	217.03	3.35	0.095	0.19	8	199.37
{p(temp) psi(hab*yr)}	217.56	3.88	0.073	0.14	8	199.90
{p(cond) psi(hab*yr)}	217.58	3.90	0.072	0.14	8	199.93
{p(hab*yr) psi(hab*yr)}	220.27	6.59	0.019	0.04	12	192.51

Table 3-12. Actual and model-averaged estimates of the proportion of sites within three habitat types occupied by freshwater drum (ψ).

	Actual value with p = 1		Model-averaged with p < 1	
Habitats	ψ	SE	ψ	SE
Year 1				
Backwater	0.03	0.06	0.11	0.13
Main channel	0.11	0.08	0.42	0.27
Tributary	0.33	0.11	0.78	0.24
Year 2				
Backwater	0.15	0.06	0.36	0.37
Main channel	0.26	0.07	0.82	0.06
Tributary	0.21	0.10	0.56	0.33

Table 3-13. Results of gill net sampling at 11 sites on Belleville Pool. Site coordinates are in Table 3-2.

Site	Habitat Type	Date Set	Time Set	Date Pulled	Time Pulled	hours fished	Species captured: Mooneye	Sauger	Shorthead Redhorse	Carp
Bull Cr.	Tributary	12/12/2002	16:30	12/13/2002	10:00	17.5		2	1	
Marietta Is.	Is. Head	12/12/2002	16:45	12/13/2002	10:30	17.75				
River Mile 167	Main Channel	12/12/2002	16:15	12/13/2002	10:15	18				
Marietta Is. DH #1	Deep Hole	12/13/2002	13:20	1/12/2002	*	*				
Muskingum Is.	Is. Tail	12/13/2002	14:00	12/14/2002	13:40	23.6**				
Neal Is.	Is. Head	1/10/2003	12:00	1/10/2003	15:45	3.75				
Neal Is.	Is. Tail	1/10/2003	10:30	1/10/2003	16:15	5.75				
Neal Is.	Backwater	1/10/2003	11:30	1/10/2003	16:00	4.5	1			
Lee Cr.	Tributary	3/1/2003	11:30	3/1/2003	18:00	6.5				2
Hocking R.	Tributary	3/1/2003	12:15	3/1/2003	18:00	5.75				
Newberry Is.	Is. Tail	3/1/2003	13:00	3/1/2003	17:30	4.5				

*floats submerged during high flows in Dec., recovered in Jan., no fish present.

**Net tangled in LWD during high flows and cut into pieces during removal.

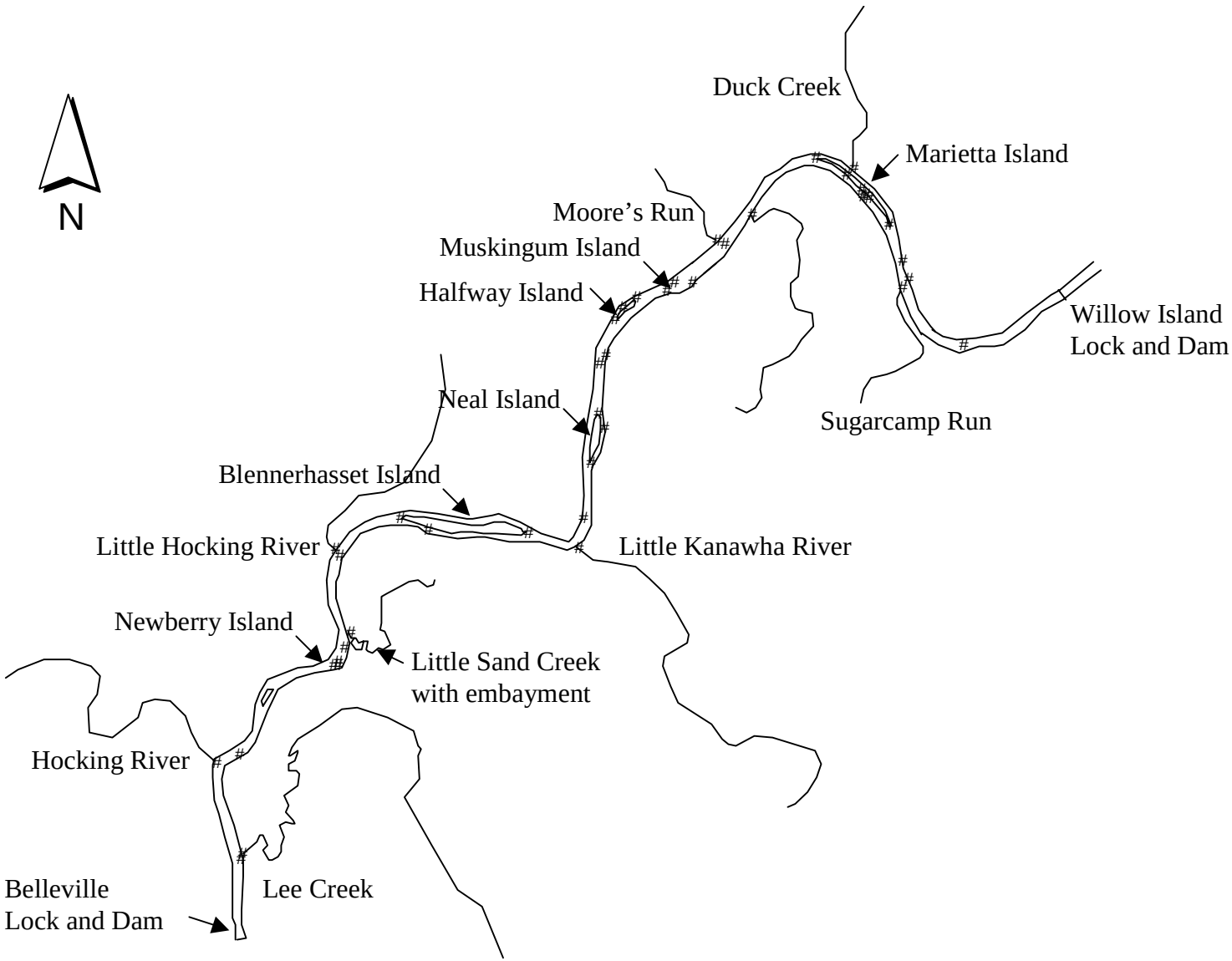
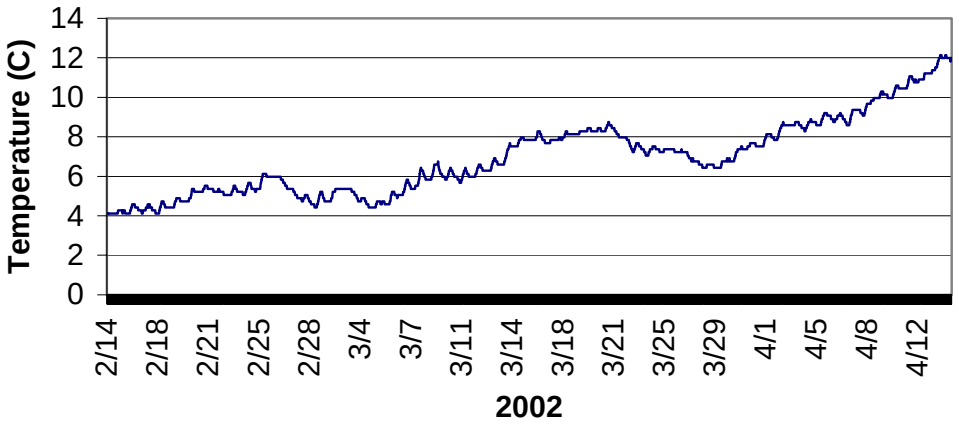


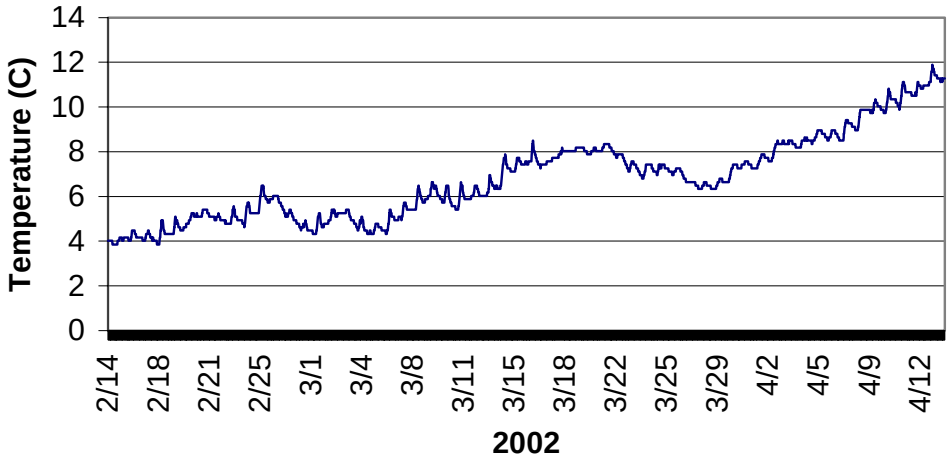
Figure 3-1. Locations of sample sites within Belleville Pool.

Figure 3-2. Temperature logger data from six sites in Belleville Pool, Ohio River, from 15 February 2002 to 15 April 2002.

Blennerhasset Island backwater



Newberry Island Backwater



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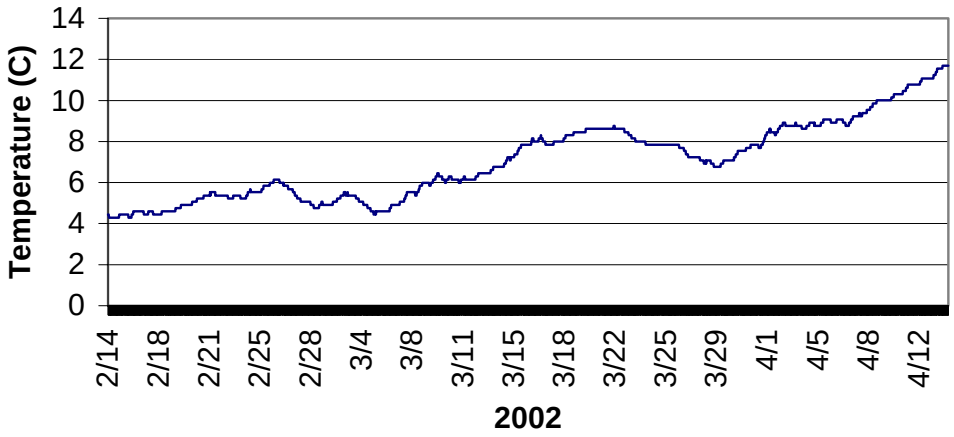

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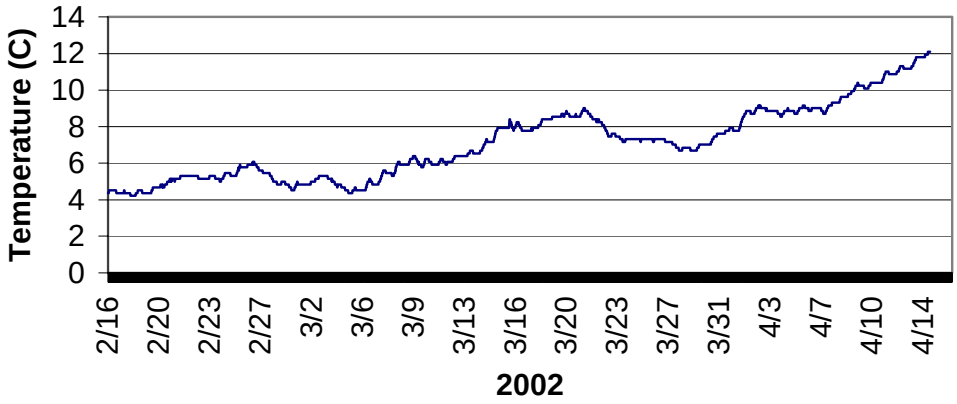

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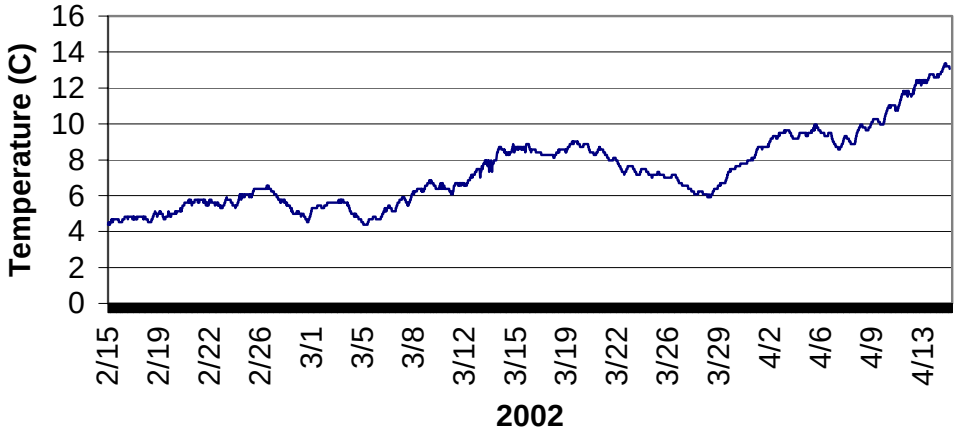

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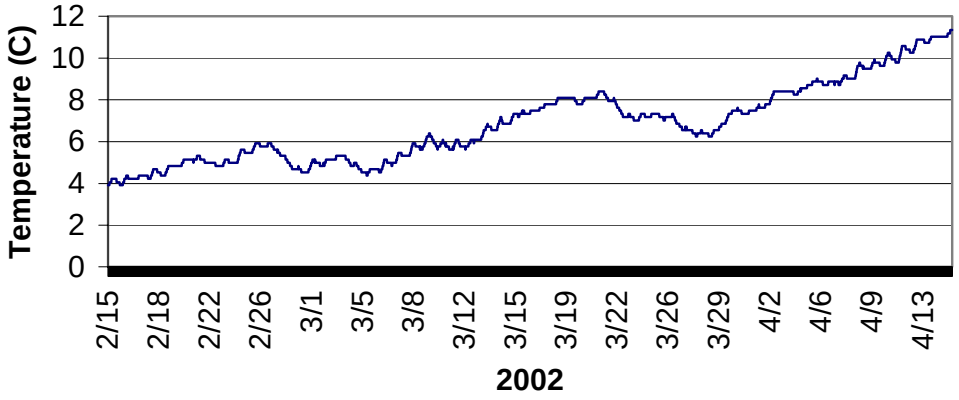

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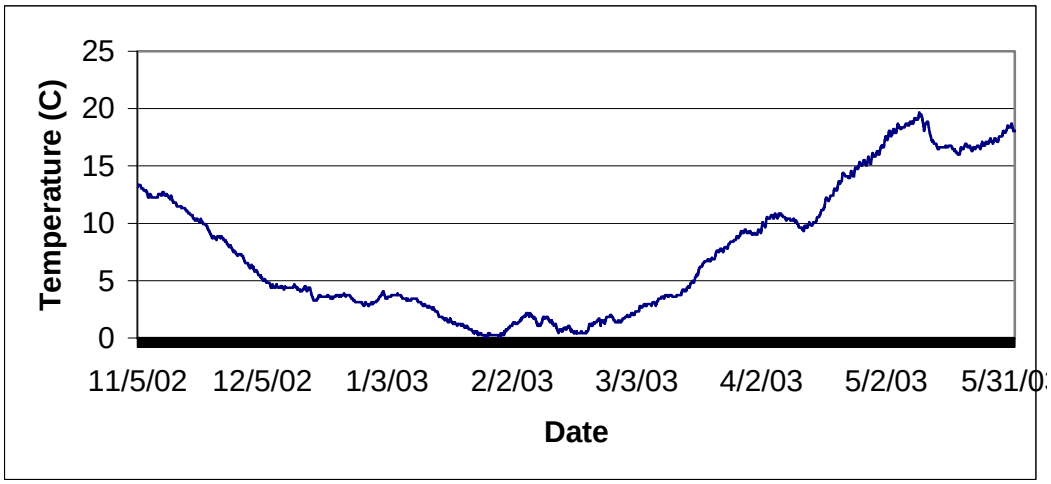

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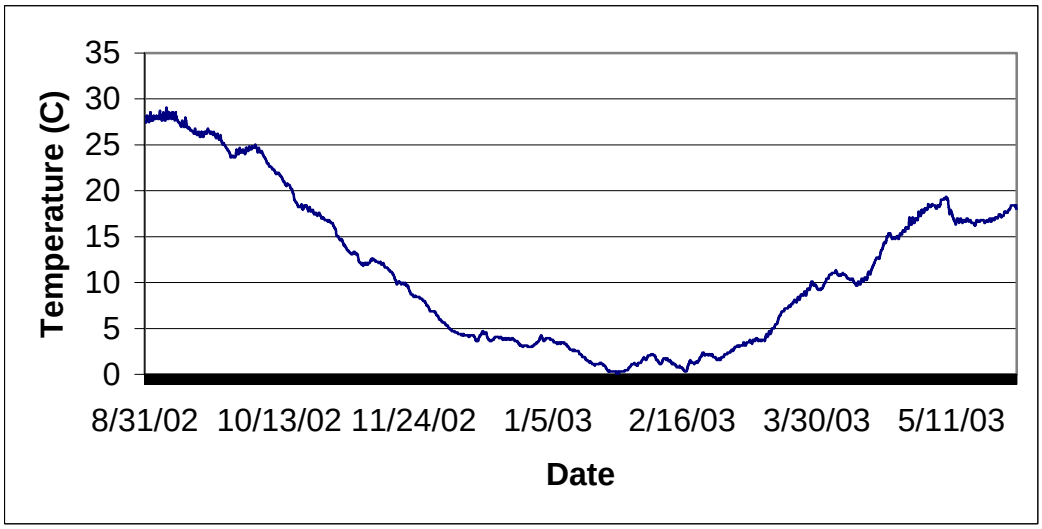

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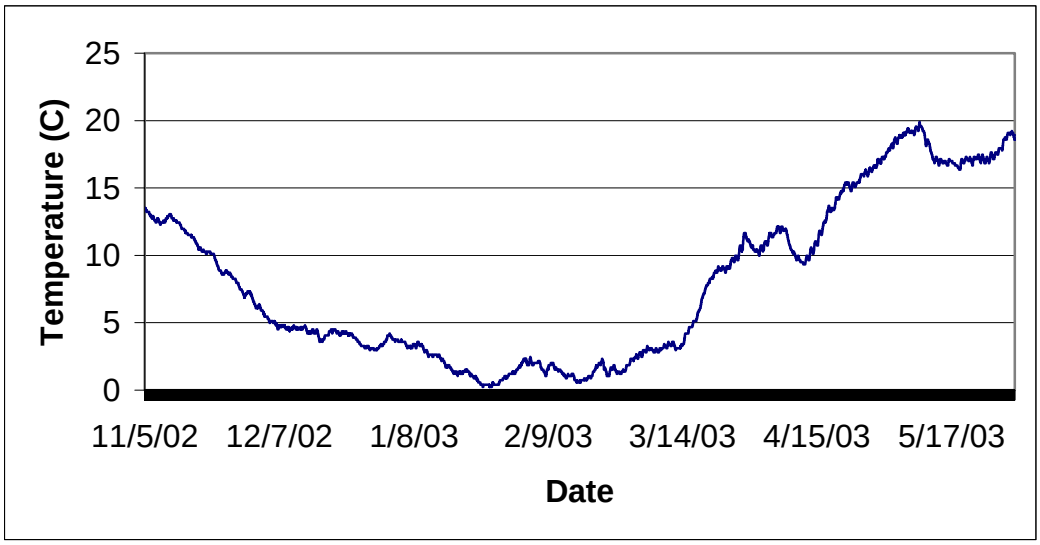

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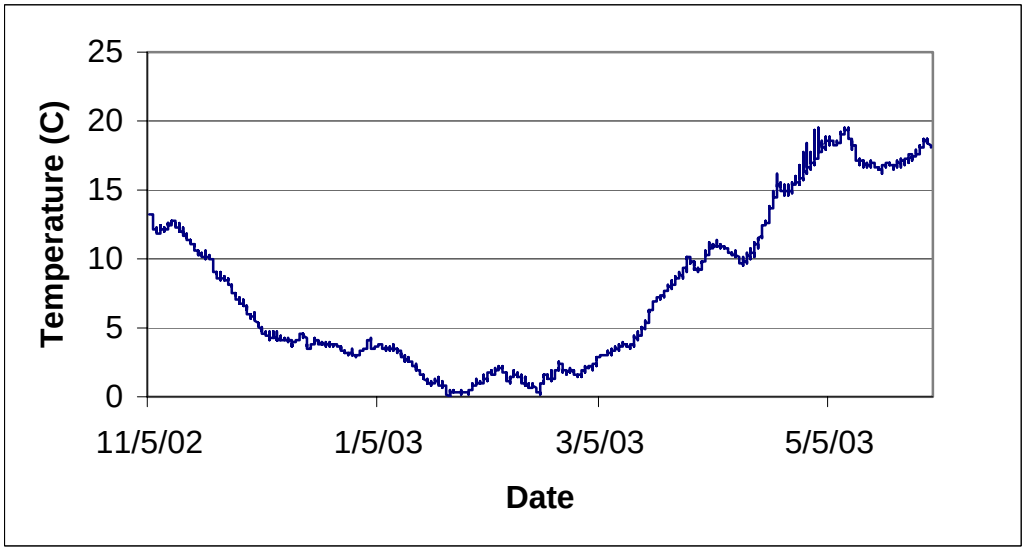

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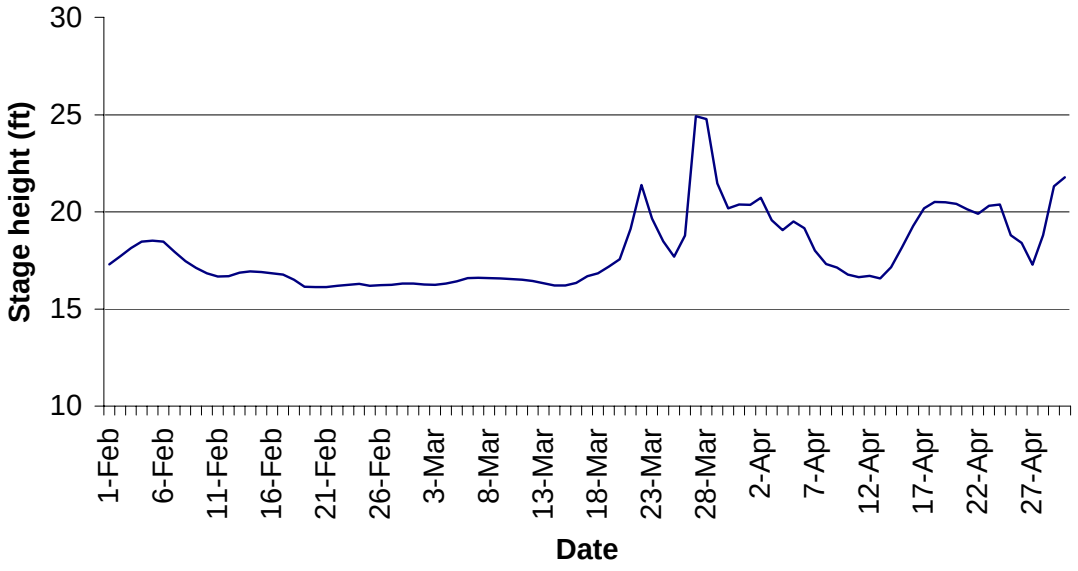

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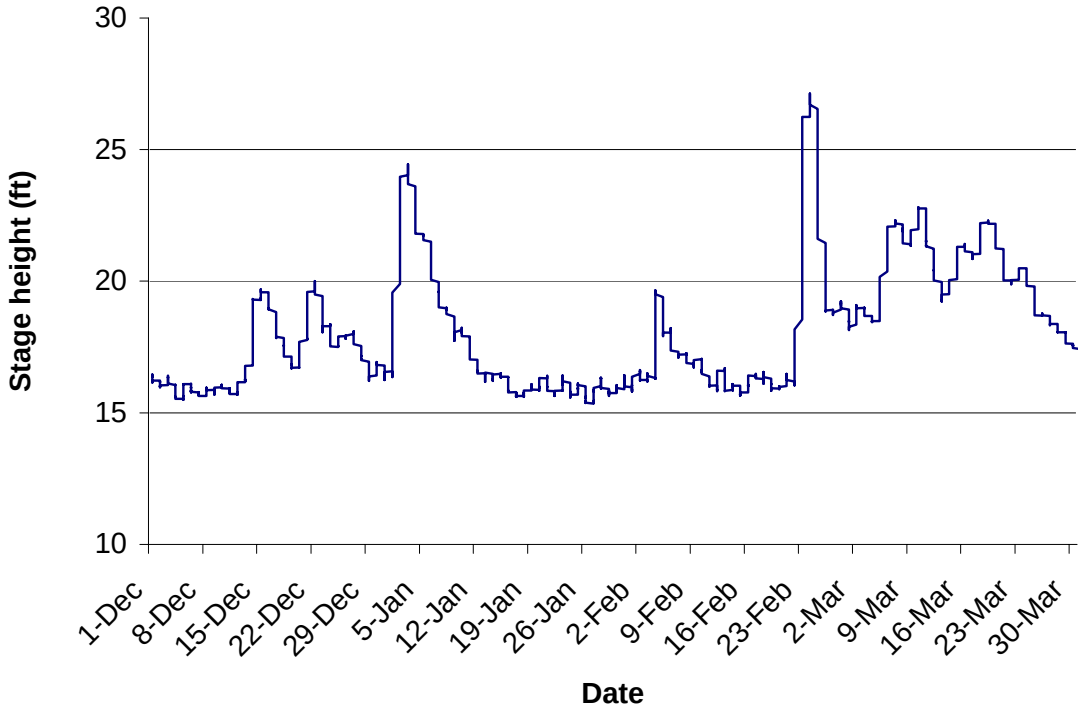

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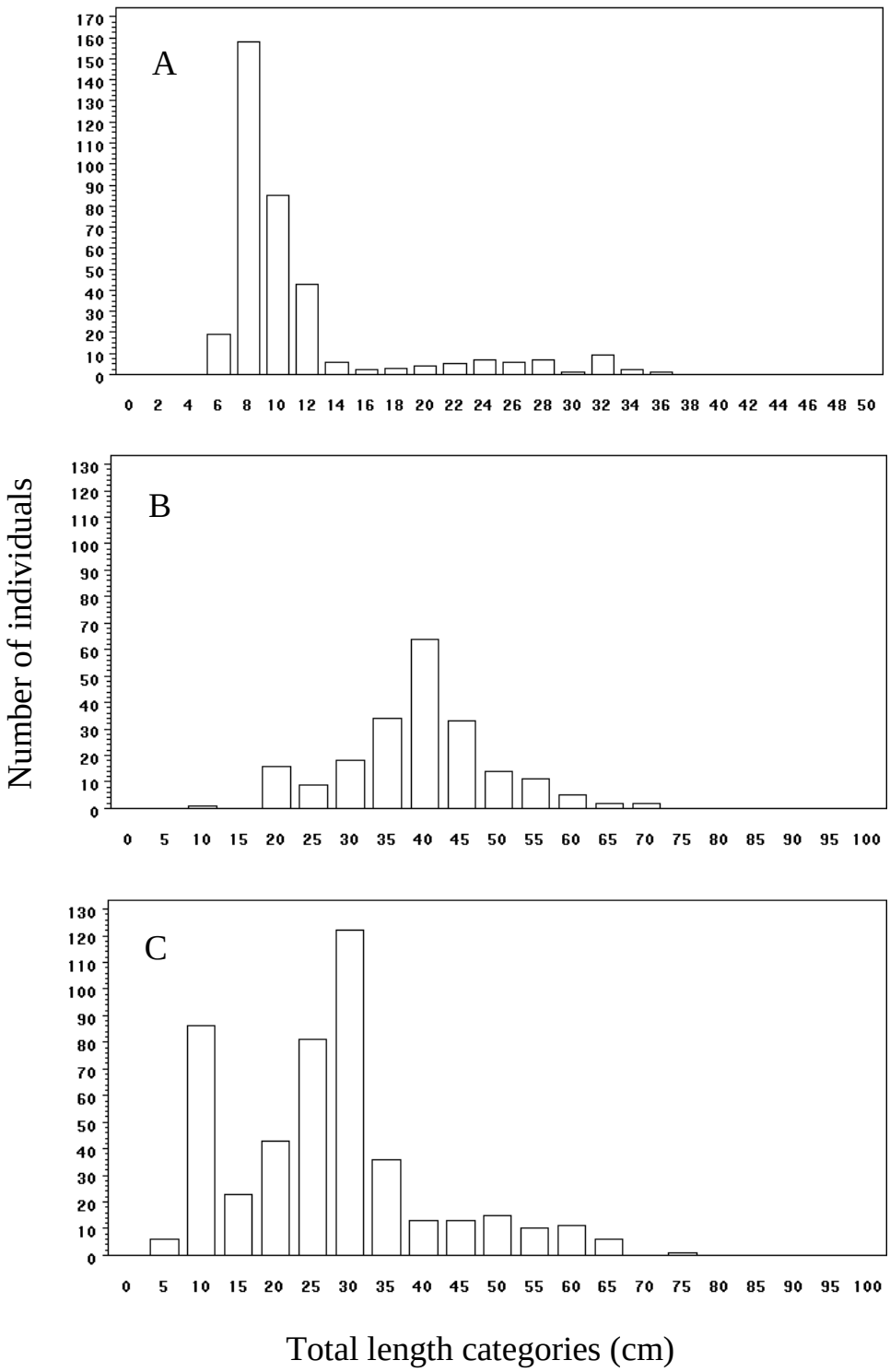

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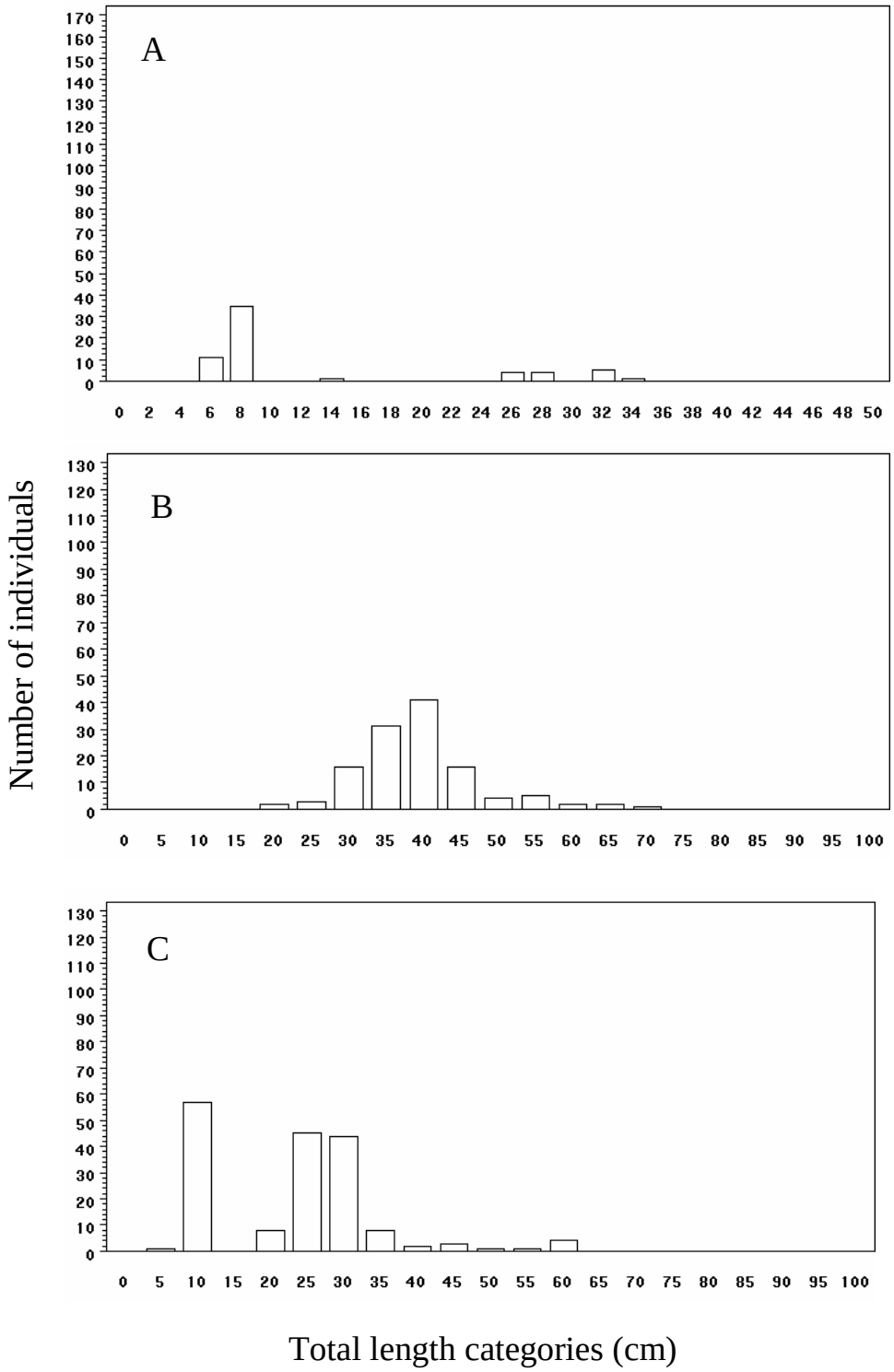

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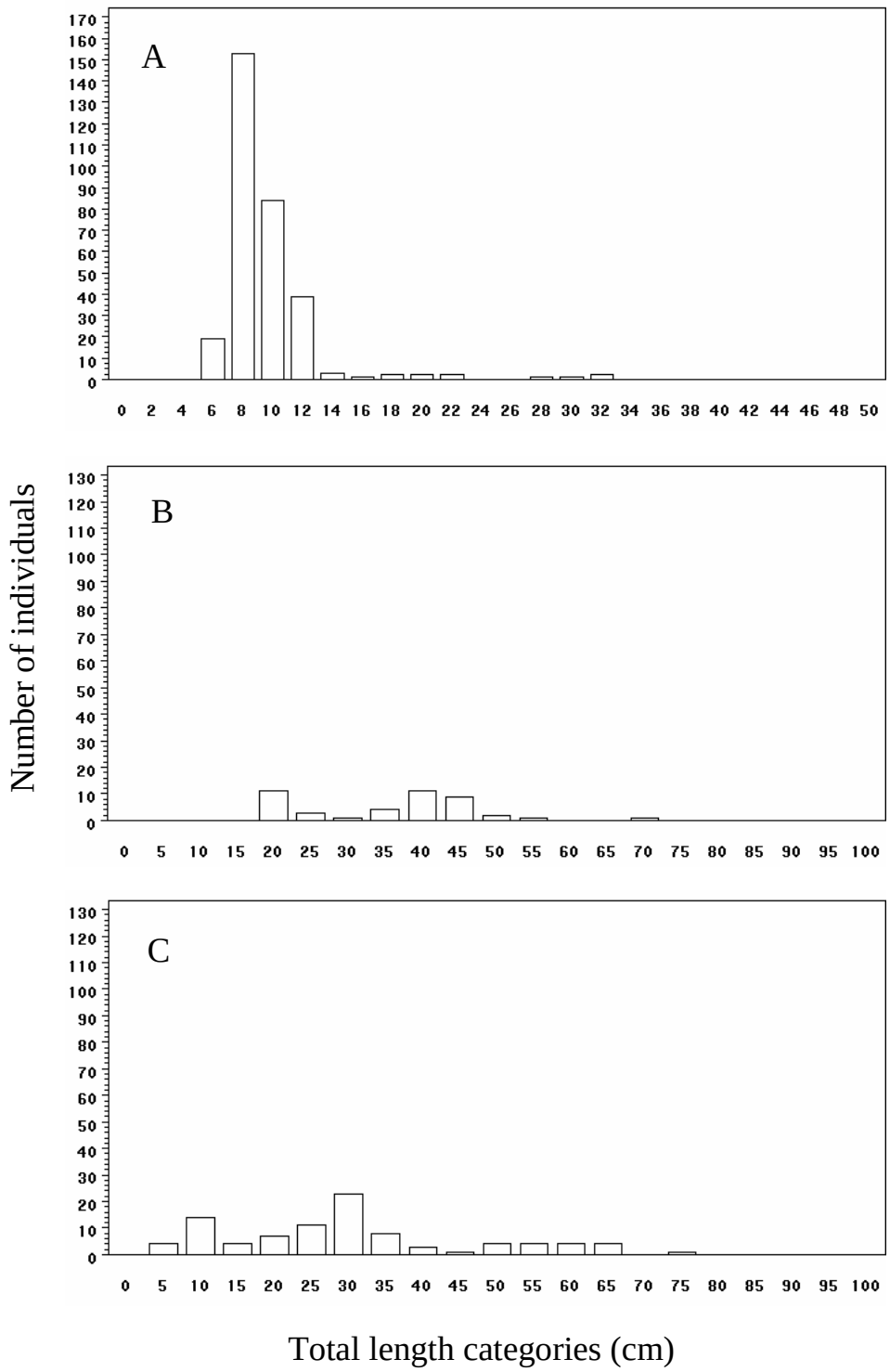

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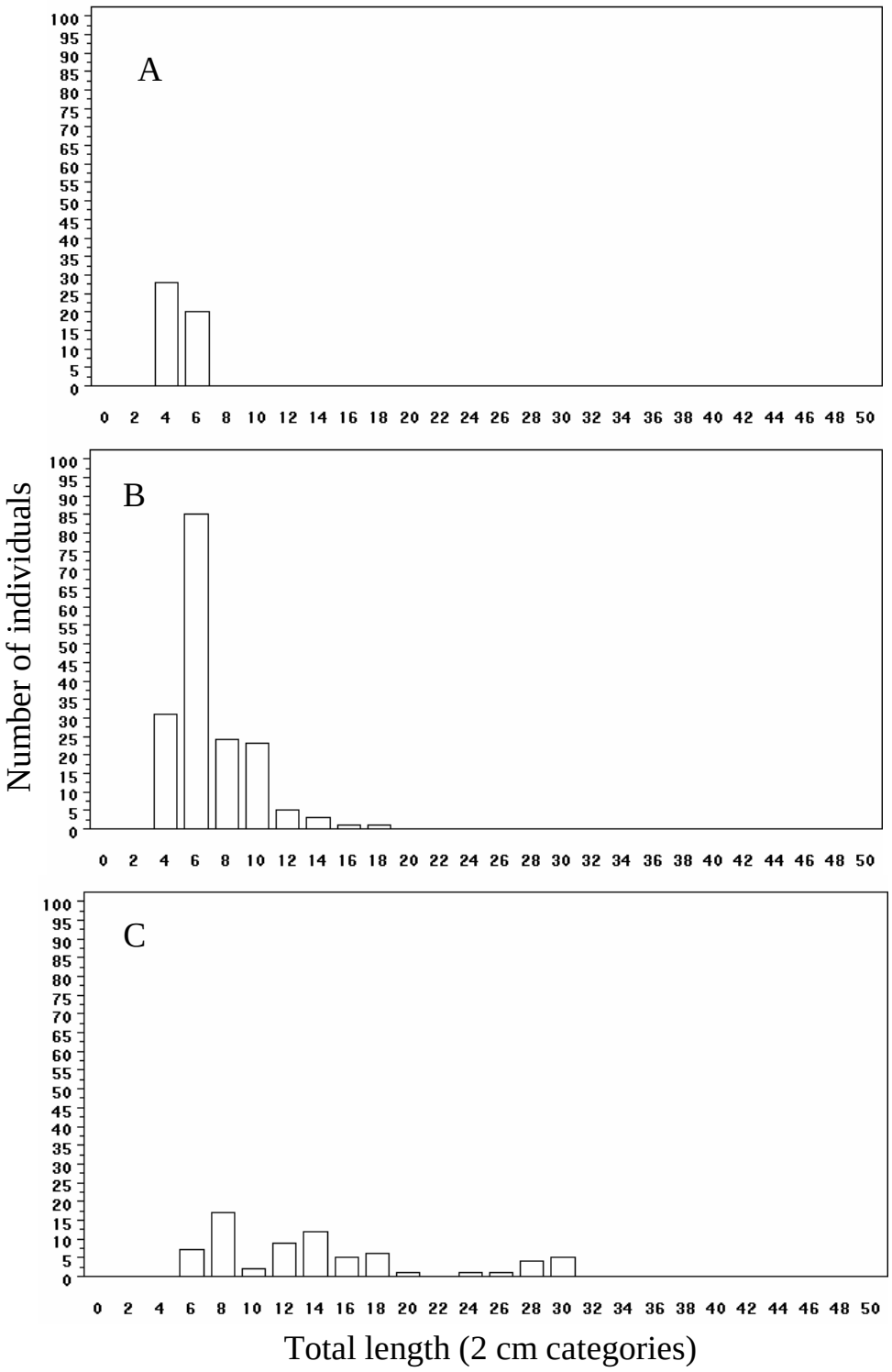

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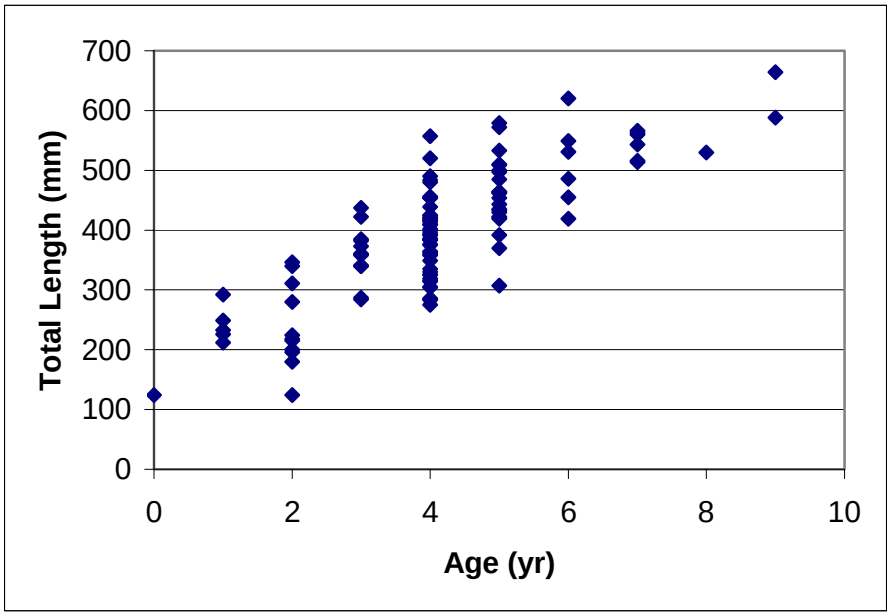

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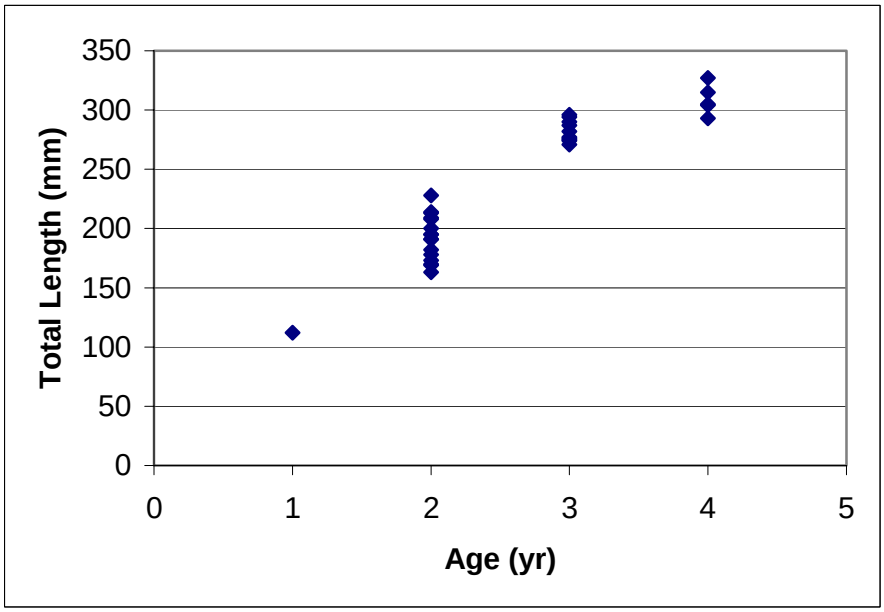

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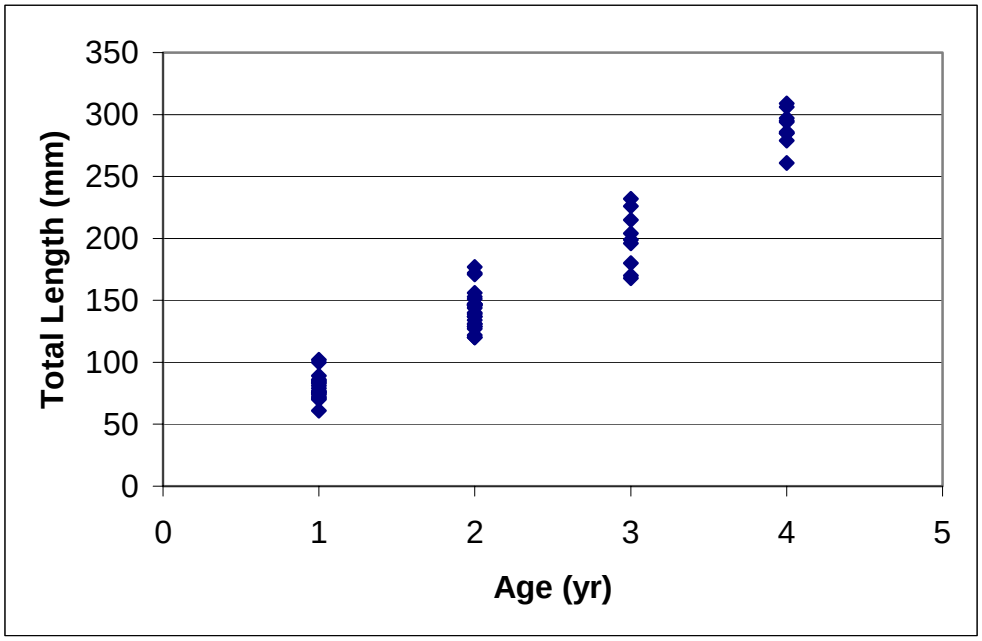

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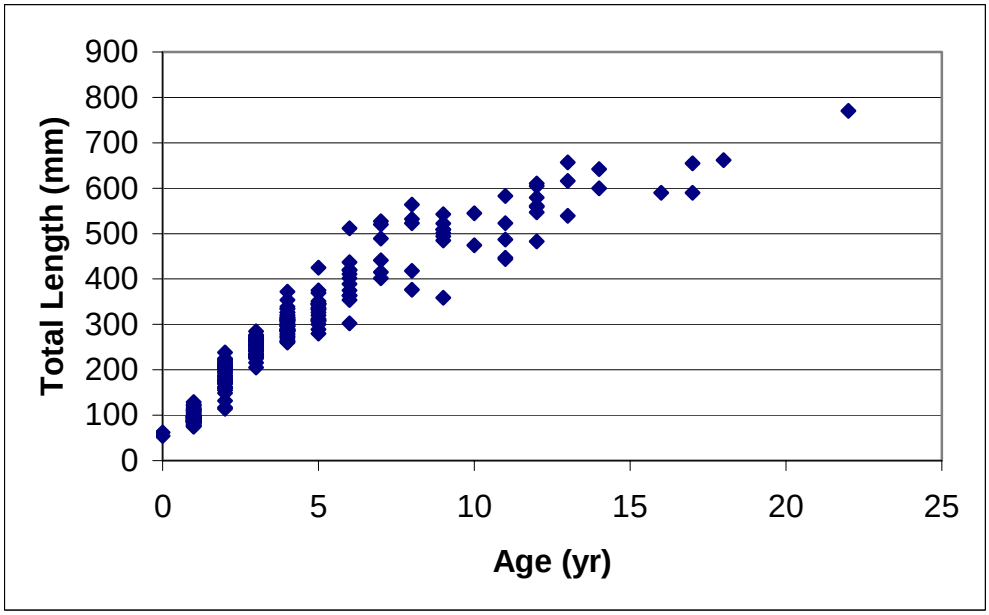

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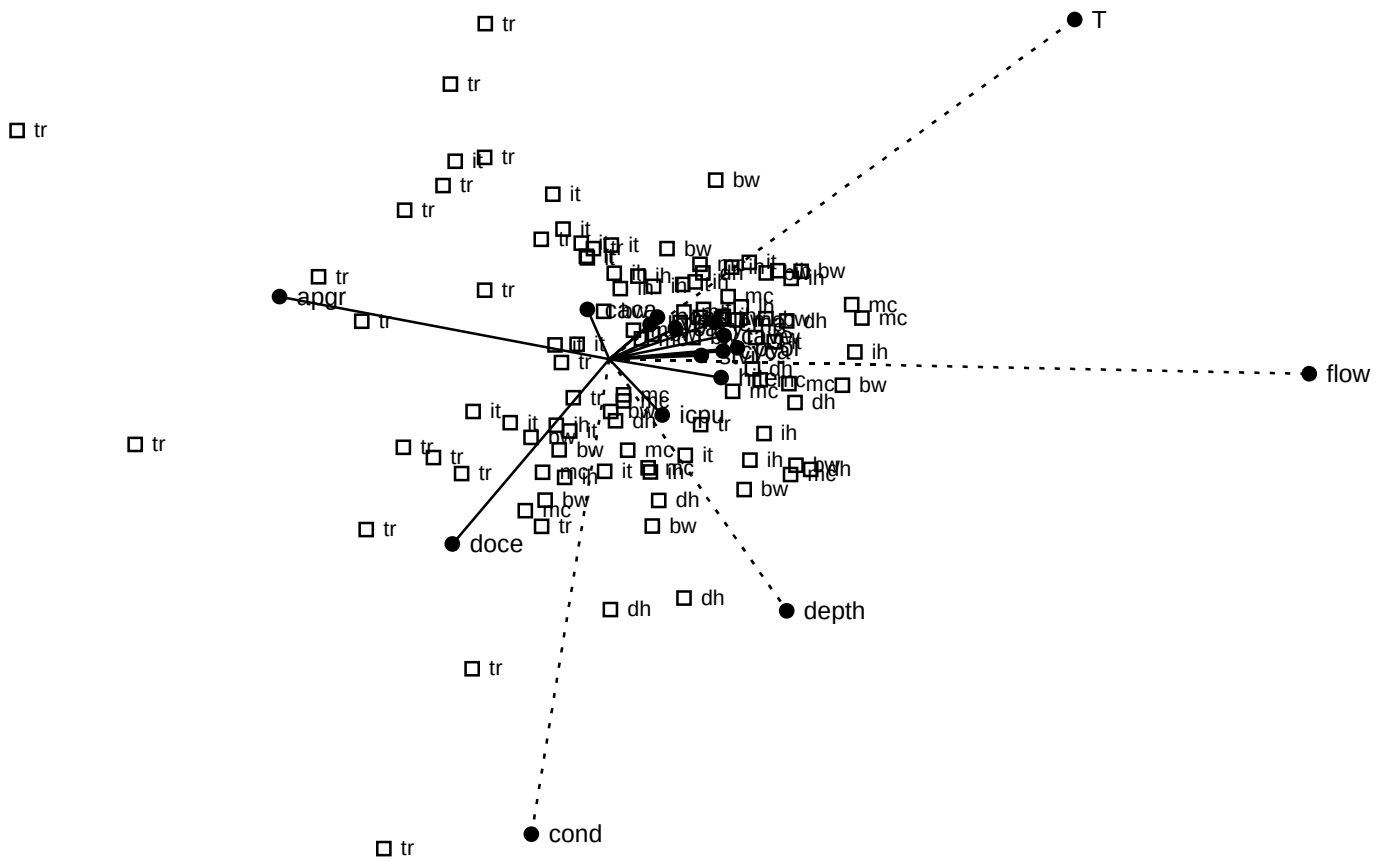

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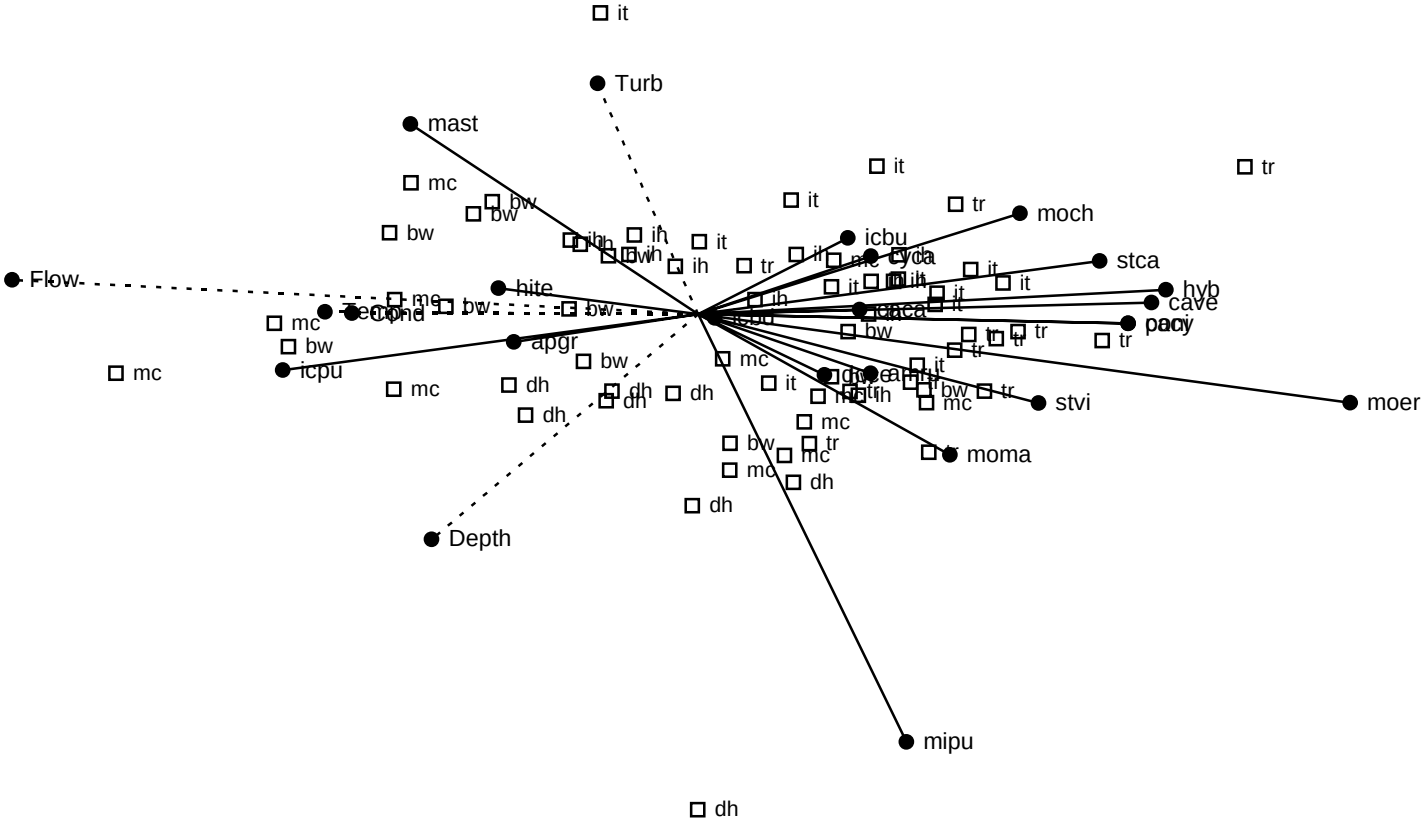

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ACKNOWLEDGMENTS

SIUC thanks the U.S. Army Corps of Engineers and the SIUC Vice Chancellor for Research for funding this project. Assistance from Dean Sherman, Matt Roberts, and Shawn Meyers was instrumental in completing this project. We also thank Les Frankland, Illinois Department of Natural Resources, for his advice and assistance.

WVU gratefully acknowledges the West Virginia Division of Natural Resources and the U.S. Army Corps of Engineers for funding this research effort. Administrative assistance from Dr. Patricia Mazik was critical to our success. Becky Nestor "the Unit Director" provided office support. John Howell provided field and office support. Many individuals provided field help, including Gerry Balmert, Kim Bjorgo, Carmen Lenz, Roy Martin, Chris Nelson, Jon Niles, Liz Osier, Jeremy Webster, and Dave Wellman. We thank Alan Temple for helpful discussions on electrofishing.

APPENDIX I

WINTER HABITAT USE OF FISHES IN THE OHIO RIVER

Benjamin Ernst Lenz

Thesis submitted to the
Davis College of Agriculture, Forestry, and Consumer Science
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Wildlife and Fisheries Resources

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Department of Forestry

Morgantown, West Virginia

2003

Keywords: winter, juvenile, tributary, embayment, channel catfish (*Ictalurus punctatus*), freshwater drum (*Aplodinotus grunniens*), white bass (*Morone chrysops*)

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ABSTRACT

Winter Habitat Use of Fishes in the Ohio River

Benjamin Ernst Lenz

Winter is a critical period during which fishes may suffer increased mortality. To identify the habitats that fishes use in large rivers during winter conditions, we electrofished six habitat types in the Belleville Pool, Ohio River. We collected the greatest diversity and numbers of fishes in low-velocity tributary confluences when water temperatures were > 4 °C. When water temperatures were < 4 °C, certain species were collected in greater abundance in faster-velocity main channel and back channel habitats while other species continued to associate with lower flows in tributary mouths. Differing habitat use between species obscures broad generalizations about when and how fishes use overwintering refuges.

In an additional habitat sampled, an embayment, 85% of all fishes collected were juveniles. Centrarchids, rarely collected in the mainstem portion of the river, were one of the dominant fishes collected in the embayment. Protecting large river embayments may prove important for managing recreational sunfish fisheries.

Channel catfish, *Ictalurus punctatus*, and freshwater drum, *Aplodinotus grunniens*, the most abundant fishes collected in the Belleville Pool, exhibited growth comparable to other populations in temperate large rivers in eastern North America. Conversely, white bass, *Morone chrysops*, growth was slower compared to other populations, possibly explaining why none of the white bass individuals collected were harvestable size. Population growth and the probability of survival of all fishes may

increase by protecting and enhancing tributary and embayment habitats in large rivers during winter.

Dedicated to my wife Carmen

ACKNOWLEDGMENTS

To those of you who helped me during the cold months of the year, John Howell, Kim Bjorgo, Gerry Balmert, Dave Wellman, Liz Osier, Jeremy Webster, Chris Nelson, Roy Martin, Dr. Stuart Welsh, Jon Niles, Elsa Lenz, Carmen Crisostomo-Lenz, and Jen Titus, when most others were warm and cozy, I thank you. To John Howell, whose patience proved worthy in crafting a sturdy vessel, I thank you. To my wife, Carmen, who suffered my absence, I thank you. To my mentors, Dr. Stuart Welsh, Dr. Kyle Hartman, and Dr. Alan Temple, I thank you. To George Seidel and Dr. John Sweka, for their statistical prowess, I thank you. To Dr. Pat Mazik, for her leadership, I thank you. To Becky Nestor, for her administrative help, I thank you. To the West Virginia Department of Natural Resources and the United States Army Corps of Engineers for their financial support of this project, I thank you. Last but not least, to Gary Batton for his ever-present humor and allowing us access to what we needed at the Bass Shack, I thank you.

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Chapter 1. Introduction to Winter Habitat Use of Fishes in Large Rivers, Juvenile Mortality during Winter, and the Use of Age and Growth Information in Assessing the Condition of Sport Fisheries.

Overview

This manuscript attempts to define which habitats large river fishes use to survive during winter. We identify the specific abiotic conditions existing in habitats fishes use during winter in the upper Ohio River. Chapter 2 of this manuscript discusses the results from the winter habitat study of the mainstem portion of the Ohio River. Chapter 3 reveals the use of embayments by juvenile fishes during winter in the upper Ohio River. Lastly, Chapter 4 summarizes the results from the age and growth study of three popular game fishes collected during the winter habitat study.

Winter survival of fishes in large rivers

Winter is a critical period during which freshwater fishes suffer increased mortality (Hubbs and Trautman 1935; Cunjak 1988; Garvey et al. 1998). Young-of-year (YOY) fishes often experience the highest mortality during winter (Toneys and Coble 1979; Ludsin and DeVries 1997; Garvey et al. 1998). Yet, fishes of all ages suffer increased mortality during winter. To increase their probability of survival, fish use certain habitats during winter. Fishes in large rivers are no exception to this rule (Johnson et al. 1998).

In large temperate river systems, extremely low water temperatures during winter coupled with high flows increase mortality rates of fishes (Bodensteiner and Lewis 1992; Lyons 1997). Low levels of dissolved oxygen (D. O.) also increase mortality of fishes, and occur typically during ice-cover of backwater areas (Raibley et al. 1997). Many fishes forage infrequently during cold winter extremes, and select refuges that minimize

energy depletion (Crawshaw 1984; Carlson 1992). Fishes often increase fat-reserves before winter; hence, reducing mortality associated with energy depletion (Fullerton et al. 2000). However, energy reserves may not suffice given long winters or energy expenditures due to disturbance, such as variation in river flows or boat traffic (Nielsen et al. 1986). Past research has shown which abiotic conditions large river fishes prefer to minimize mortality during winter.

Abiotic conditions that limit fish survival during winter

Temperature and flow

During winter, riverine fishes select habitats with relatively high temperatures and low flows. Riverine fishes overwinter in velocity shelters (Logsdon 1993; Bodensteiner and Lewis 1994; Johnson et al. 1998) and areas with warmer temperatures and lower flows than mainstem river sections, such as off-channel coves, marinas, embayments and industrial warm-water outflows (Sheehan et al. 1990; Knights et al. 1995; Gent et al. 1995; Raibley et al. 1997). Also, backwater areas with relatively warmer temperatures and lower flows provide winter habitats (Bodensteiner and Lewis 1992; Raibley et al. 1997; Sheehan and Rasmussen 1999). By occupying favorable habitats during winter, fishes avoid the stresses of variable flow velocity in the main channel portion of large rivers.

Sheehan et al. (1990) examined temperature and flow requirements for several fishes common in the Ohio River, such as gizzard shad, *Dorosoma cepedianum*, channel catfish, *Ictalurus punctatus*, and freshwater drum, *Aplodinotus grunniens*. Gizzard shad, channel catfish, and freshwater drum occupy relatively low velocity areas during winter (Heese and Newcomb 1982; Newcomb 1989; Sheehan et al 1990; Logsdon 1993;

Bodensteiner and Lewis 1994). Gizzard shad are vulnerable to winter die-offs during low water temperatures (Miller 1960). Some fishes experiencing extreme low temperatures suffer cold shock (Cichra et al. 1982). These fish lose their ability to maintain their position in a preferred habitat and can be swept downstream to open channel habitats, reducing their chances of survival (Sheehan et al.1990; Bodensteiner and Lewis 1994). Sheehan et al. (1990) reported temperature preferences of > 4 °C for many species in large rivers, such as green sunfish, *Lepomis cyanellus*, bluegill, *Lepomis macrochirus*, and freshwater drum. Some species, such as channel catfish, black crappie, *Pomoxis nigromaculatus*, and walleye, *Stizostedion vitreum*, can maintain swimming abilities at temperatures < 4 °C (Sheehan et al. 1990). Temperature and flow preferences during winter and swimming abilities during low temperatures are unknown for most riverine fishes.

Dissolved oxygen

Abiotic factors other than water temperature and flow velocity can influence the suitability of winter habitats. Backwater areas can become anoxic and unsuitable as overwintering areas (Bodensteiner and Lewis 1992; Knights et al. 1995; Johnson et al. 1998). Low D. O. levels can result in fish die-offs when backwater areas become isolated from the main channel during low water levels in winter (Raibley et al. 1997). In the West Virginia section of the Ohio River, dissolved oxygen is reduced by water pollution near cities, but normally remains above critical levels (Pearson and Krumholz 1984). In the upper Ohio River, the availability and quality of backwater habitat typical of larger rivers such as the Missouri and Mississippi is limited and largely unavailable for fishes. The steep topography of the riparian zone restricts lateral movement of waters outside of

the main channel. Embayments are the habitat type in the upper Ohio River most similar to lower elevation large river backwaters.

Habitats available to fishes in the upper Ohio River during winter

The abiotic conditions of a particular habitat type may make them unsuitable for use by fishes during winter. As stated above, extreme and varying conditions during winter can increase mortality in fishes. To survive, fishes must choose habitats that offer refuge from the extreme conditions of winter. Habitats available to fishes during winter vary in their physical and chemical characteristics. A combination of physiochemical conditions, such as low-flow velocities and warmer temperatures, may offer the best refuge to overwintering fishes, yet these conditions can vary temporally, forcing fishes to use more than one specific habitat during winter.

Nine habitat types classified as main channel, deep hole, back channel, island head, island tail, tributary, wing dam, embayment, and tailwater are available for sampling in the upper Ohio River. Vallazza et al. (1994) and Cray (1999) discussed similar habitats, and our classification scheme is further described below. Main channel habitats are the open water portion of the river used as commercial navigation routes, and typically have shallow near-shore areas and deeper mid-channel sections. Deep hole habitats are relatively deep areas created by dredging or natural scour within main channel or back channel areas. Back channels, island head, and island tail habitats are associated with islands. Back channel habitats are also open waters, but are not typically used for barge navigation and occur between an island and the mainland. Habitats near the upstream and downstream ends of each island are island head and island tail habitats, respectively. Tributary habitats are located, specifically, where the joining waters form a

confluence with the mainstem of the Ohio River. Wing dams (and other artificial flow barriers) create near-shore habitats with low water velocities. Tailwater habitats are the open often-turbulent water immediately below a dam. Embayment habitats are shallow bay-like areas connected to the main channel by a tributary or artificial channel.

Juvenile survival during winter

Survival probability of fishes during winter often increases with body size (Hubbs and Trautman 1935; Cunjak 1988). Juvenile and YOY (young-of-year) individuals suffer increased mortality during winter compared to larger individuals (Toneys and Coble 1979; Ludsin and Devries 1997; Garvey et al 1998). Due to the higher loss of young individuals, winter is a critical period for recruitment into a population (Oliver et al. 1979; Toneys and Coble 1979; Miranda and Hubbard 1994). Limiting exposure to severe winter conditions allows fishes to persist through winter. Juvenile fishes should occupy habitats that are favorable for increasing the probability of survival during winter.

Embayments

Embayment habitats offer critical overwintering refuge for fishes of all ages in large river systems. Embayments are shallow bay-like areas connected to the main channel by a tributary or artificial channel. Backwaters are similar in morphology and function as embayments, but embayments receive input (water, sediment, and aquatic organisms) from both associated tributaries and the riverine system. Backwaters only receive input from their associated river (Cray 1999). Similar to backwaters, embayments offer relatively high temperatures and low flows during winter. These velocity shelters are favorable for overwintering riverine fishes (Logsdon 1993; Bodensteiner and Lewis 1994; Johnson et al. 1998). The warmer temperatures and lower

flows of embayments are often more benign than mainstem river conditions, offering fishes a refuge to escape the harsh conditions of winter (Sheehan et al. 1990, Knights et al. 1995, Gent et al. 1995; Raibley et al. 1997). These favorable conditions in embayments are optimal for overwintering fishes, especially juveniles, since they are most likely to suffer increased mortality during winter.

Importance of age and growth information about sport fisheries

Fish length-at-age estimates are important information used to assess the status of a fishery. The age of a fish can be determined in many ways. Bony parts of the fish such as otoliths, pectoral spines, and vertebrae can all be sectioned (cut) and, by simply counting the growth rings of the section, the reader can estimate the age of an individual. Regardless of the method used to determine ages of fishes, the information gathered yields important insight into age-related growth rates and the relative numbers of juvenile and mature fish in a population (DeVries and Frie 1996). The average size and size variation at different ages over several years can be used to determine growth patterns of a fish population over time or compare it with other populations. Changes in these measurements can be normal or may reflect unsuitable environmental conditions.

Fishery managers also use length and weight data as another method of assessing population condition. The sizes of individuals in a population also reflect growth rates. Knowing the abundance of certain sizes of fishes is important for evaluating the ability of a recreational fishery to support exploitation (Anderson and Neumann 1996). Harvest of recreational fisheries is often regulated by size limits. If few legal-sized individuals are available for harvest, it may be due to unfavorable conditions, which come in many forms (overharvest, pollution, competition for limited resources, overabundance, and more). If

unhealthy conditions persist, fishery managers implement plans to improve the status of a fishery to make it viable for harvest. Without age and growth information, fishery managers would have difficulty in determining the status of sport fish populations.

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Chapter 2. Winter Habitat Use by Fishes in a Large River

Abstract

Winter is a critical period during which fishes suffer increased mortality. In order to identify the abiotic conditions large river fish communities use during winter, we electrofished six habitat types in the Belleville Pool, Ohio River. We collected the greatest diversity and abundance of fishes in low-velocity tributary confluences. When water temperatures were < 4 °C, certain species were collected in greater abundance in faster-velocity main channel and back channel habitats. The lack of temperatures > 4 °C may have left fishes susceptible to current velocity, carrying them out of tributaries into channel habitats. Not all species responded to decreasing water temperatures in the same manner. CCA (canonical correspondence analysis) results showed some species continued to associate with low-velocity tributaries at low temperatures. Species-specific responses to winter conditions may obscure broad generalizations about when and how riverine fishes use overwintering refuges. We recommend that protection and enhancement of tributary habitats can increase the probability of survival of fishes in large rivers during winter.

Introduction

Physiochemical tolerances of fishes influence range distributions and habitat use. In temperate climates, fishes shift habitats in response to seasonal variations in physiochemical factors. During winter conditions, fishes select refuge habitats where physiochemical factors are unlikely to exceed tolerance limits. In large temperate river systems, extremely low water temperatures during winter coupled with high flows

increase mortality rates of fishes (Bodensteiner and Lewis 1992; Lyons 1997). Low levels of dissolved oxygen also increase mortality of fishes, and occur typically during ice-cover of backwater areas (Bodensteiner and Lewis 1992; Knights et al. 1995; Johnson et al. 1998).

Many fishes forage infrequently during cold winter extremes, and select refuges that minimize energy depletion (Crawshaw 1984; Carlson 1992). Fishes often increase fat-reserves before winter; hence, reducing mortality associated with energy depletion (Fullerton et al. 2000). However, energy reserves may not suffice given long winters or energy expenditures due to disturbance, such as variation in river flows or boat traffic (Nielsen et al. 1986).

During winter, riverine fishes select habitats with relatively high temperatures and low flows that offer velocity shelters (Logsdon 1993; Bodensteiner and Lewis 1994; Johnson et al. 1998). These conditions have been found in areas other than mainstem river sections, such as off-channel coves, marinas, embayments and industrial warm-water outflows (Sheehan et al. 1994; Gent et al. 1995: Knights et al. 1995; Raibley et al. 1997). Also, backwater areas with relatively warmer temperatures and lower flows provide winter refuge habitats (Bodensteiner and Lewis 1992; Raibley et al. 1997; Sheehan and Rasmussen 1999).

Sheehan et al. (1990) examined temperature and flow requirements in the laboratory for several fishes common in the Ohio River, such as gizzard shad, *Dorosoma cepedianum*, channel catfish, *Ictalurus punctatus*, and freshwater drum, *Aplodinotus grunniens*. These three fishes occupy relatively low velocity areas during winter (Heese and Newcomb 1982; Newcomb 1989; Sheehan et al. 1990; Logsdon 1993; Bodensteiner

and Lewis 1994). Gizzard shad are vulnerable to winter die-offs during low water temperatures (Miller 1960). Sheehan et al. (1990) also reported temperature preferences of > 4 °C for many species in large rivers, such as green sunfish, *Lepomis cyanellus*, bluegill, *Lepomis macrochirus*, and freshwater drum. Some species, such as channel catfish, black crappie, *Pomoxis nigromaculatus*, and walleye, *Stizostedion vitreum*, can maintain swimming abilities at temperatures < 4 °C (Sheehan et al. 1990). However, temperature, flow preferences, and swimming abilities during low temperatures are unknown for most riverine fishes.

To quantify winter habitats of fishes in large rivers, we sampled the Belleville Pool of the Ohio River during the winter months of 2002 and 2003. Previous research is primarily limited to *in vitro* analysis of simulated winter abiotic conditions preferred by large river fishes. Our goal was to analyze *in situ* winter habitat use by fishes in large rivers. Thus, our main objective was to determine abiotic habitat characteristics associated with fish habitat use. We attempted to do this by examining species/habitat associations among main channel, tributary mouth, back channel, head of island, tail of island, and deep hole habitats during winter. Through an understanding of overwintering areas, we hope to provide resource managers with knowledge needed to reduce winter mortality of fishes by protecting and enhancing important habitats.

Methods

Study site

The Belleville Pool of the Ohio River, created by Belleville Lock and Dam (rkm 328.1), extends upstream to Willow Island Lock and Dam (rkm 260.2). The 67.9 km pool averages 404.5 m wide, 7.3 m deep, and comprises 2850 ha of surface area

(ORSANCO 1994). The deepest section of the pool (15 m) lies directly upstream of Belleville Lock and Dam. A navigation channel (3.7 m deep) is maintained for commercial barge traffic by the United States Army Corps of Engineers (USACE) (ORSANCO 1994). Two other large rivers, the Muskingum River in Ohio, and the Little Kanawha River in West Virginia are navigable tributaries of the Ohio River within the Belleville Pool. The riparian zone is a mixture of hardwood forests, urban and industrial frameworks, and agricultural settings. Most large floodplains near Belleville Pool are heavily urbanized. The two largest population centers along Belleville Pool are Parkersburg, WV (confluence of the Little Kanawha and Ohio rivers) and Marietta, OH (junction of Muskingum and Ohio rivers).

Habitat classification

For the purpose of defining habitat use by overwintering fishes, we classified six habitat types in the Belleville Pool: main channel, deep hole, back channel, island head, island tail, and tributary confluence (see Vallazza et al. 1994, Cray 1999). Main channel habitats are used as commercial navigation routes, and typically have shallow near-shore areas and deeper mid-channel sections. Deep hole habitats (> 8 m in depth) result from dredging or natural scour within main channel or back channel areas. Back channel, island head, and island tail habitats are associated with islands. Back channel habitats are not typically used for commercial navigation and occur between an island and the mainland. The waters immediately adjacent to the upstream and downstream ends of each island are island head and island tail habitats, respectively. Tributary habitats are located, specifically, where the joining waters form a confluence with the mainstem of the Ohio River.

Habitat selection

To evaluate winter habitat selection by fishes within the Ohio River, we sampled six sites in six habitat categories on six different occasions. Main channel and tributary sites were selected in a constrained random fashion according to their relative abundance in the upper and lower half of the Belleville Pool. We chose six of the seven island habitats located in the Belleville Pool. Island size (measured in length) differed among Blennerhasset (6.4 km), Halfway (1.6 km), Newberry (0.4 km), Marietta (4.8 km), Muskingum (3.2 km), and Neal (2.4 km) Islands, but sample areas within back channel, head, and tail habitats were similar among islands. Depths of main channel and back channel sites ranged from 3 to 8 m, and included near-shore and mid-channel transects. Tributary habitats were 2 to 9 m deep, and included near-shore areas and deeper scour holes. Depths of deep hole habitats ranged from 8 to 14 m, and those of island head and tail habitats ranged from 2 to 6 m.

Data collection

We sampled fish at the habitat sites during six periods (February 16 – 22, 2002, March 9 - 25, 2002, April 4 - 7, 2002, December 12 - 17, 2002, January 10 -19, 2003, and March 1 -17, 2003). At each site, we sampled fishes with a variable-depth AC electrofishing boat for water depths of 2-15 meters (Grunwald 1983, Newcomb 1989). Three weighted electrodes (2 m sections of 1.25 inch diameter corrugated conduit) were lowered to near the river bottom over a boom connected to the bow. The desired output of the Honda 5 kilowatt 3-phase AC generator, monitored by clip-on gauges, was above 7 Irms, and typically 9-10 Irms while collecting fish. One, two, or three transects were

electrofished, (depending on the amount of available habitat at a site), in the downstream direction of the river current lasting up to 10-minutes (peddle time) for each transect. During peddle time, the boat (with bow upstream) drifted with the river current. This maintained electrodes near the river bottom, but caused longer transects during higher flows. In habitats with a wide range of depths such as back and main channel habitats, the three transects represented shallow and intermediate depths near each shore and deep areas in mid-channel. Peddle time and number of transects varied with habitat availability at each site. During and after peddle time, fishes were netted from a chase boat or the electrofishing boat. Collected fishes were identified to species, counted, measured (nearest mm total length, TL), and weighed. Large fishes (over 1 kg) were weighed to the nearest 25 g with a Pesola spring scale (5 kg maximum). Smaller fishes (less than 1 kg) were weighed to the nearest 1g with a Homs spring dial scale (1 kg maximum).

Abiotic conditions were measured at each site to further characterize habitat types. After electrofishing at a site, we measured specific conductivity, dissolved oxygen (DO), pH, and temperature at 1-m depth intervals (YSI 6820 meter or Hydrolab Surveyor 4), and estimated surface flow velocity (Marsh-McBirney Flowmate). We estimated turbidity near surface (secchi disk), and at 1 m depth intervals (YSI 6820 meter) during the second winter sampling (December 2002 to March 2003). We used Tidbit temperature loggers to record water temperature at three back channel and three main channel sites at depths between 1 and 2 m during both winter samples.

Statistical analyses

To characterize the six habitat categories, the abiotic variables were averaged by site and sample period. First, the profile values for each abiotic variable, from surface to near bottom were averaged as a single value for each site (except flow and secchi, which were single values). Second, the six site average values for each abiotic variable were averaged as a single value for each habitat type for each of the six periods (e.g., all average temperature values from tributary sites during December 12-17, 2002 were averaged as a single value). Third, the abiotic values from the three sample periods were averaged as a single value for each habitat category for both of the winter samples (February – April, 2002 and December, 2002 – March, 2003). Finally, standard deviations of the averaged abiotic variables were also calculated.

To determine which habitats particular species of fish used at critical low temperatures, we first calculated the proportion of the total catch for each species collected at average temperature values > 4 °C, 3 < 4 °C, and < 3 °C in each habitat category. These temperature values stem from the laboratory findings of Sheehan et al. (1990) suggesting < 4 °C is the critical water temperature when many riverine fishes lose their swimming ability and are unable to maintain their position in the water column. Second, we calculated the percentage of the total catch at each temperature range for the five most numerous fishes at each temperature range separately. All other less numerous fishes were calculated as a single group. Lastly, we counted the number of species collected in each habitat category.

We used canonical correspondence analysis (CCA) to explore relationships between species and abiotic variables. Canonical correspondence analysis, a constrained

ordination approach, allowed concurrent analysis of species abundance, site, and environmental (abiotic) data (ter Braak 1995). A square root transformation of abundance data minimized affects of a few high abundance values (McGarigal et al. 2000). We conducted CCAs with data from each winter sample separately using an Excel macro (Eric Smith, Virginia Polytechnic Institute and State University). A significant high water event during March 2003 (see Figure 2b) interrupted our data collection and forced us to finish over a much greater length of time than the previous two sample periods. For this reason, the CCA for the second winter sample only represents data collected from December 12, 2002 through January 19, 2003.

Results

Tributary habitats represented important overwintering habitats for large river fishes. Tributary habitats consistently had the lowest average flow velocity (mode of 0.1 m/s) during all sample periods (Table 1). Low flow velocities likely contributed to the relatively high numbers of fishes caught at tributaries. Fifty-eight percent of the total individuals collected during both winter samples were from tributaries. More individuals were collected in tributaries during the warmer first winter sample (87 % of the total individuals from this sample) than the colder second winter sample (Table 1). Thirty-nine percent of the total individuals from the second winter sample were collected in tributaries.

Species presence and abundance in both back and main channel habitats increased during colder water temperatures. Forty-three percent and 14% of all individuals were collected in main channel and back channel habitats, respectively, during the colder winter sample. When sites had an average temperature > 4 °C, more individuals were

collected in tributaries (66 %) than main and back channel sites (30 %) (Figure 1a). At temperatures between 3 and 4 °C, more individuals were still collected at tributaries, but at a reduced proportion compared to main and back channel sites at temperatures > 4 °C (Figure 1b). A shift to a greater proportion of individuals occupying main and back channel sites occurred when water temperatures at all habitat types were < 3 °C (Figure 1c). Sixty-six percent of the individuals were collected at main channel sites, while 31 % were collected at tributary sites at water temperatures < 3 °C.

Freshwater drum was the most abundant species captured, representing 48 % of the total catch from both winter samples. During the warmer first winter, 90% of the freshwater drum individuals were collected from tributaries. Freshwater drum dominated the pattern of shifting from tributary to main channel habitats when water temperatures at all habitat types were < 3 °C (Figure 1). During the colder sample, 37% of the freshwater drum individuals were collected from tributaries, while 50% were collected in main channel sites. Other less numerous species followed a similar pattern.

Channel catfish, the second most abundant species, represented 21% of the total catch from both winter samples. Sixty-three percent of the channel catfish individuals were collected from tributary habitats during the warmer sample. Channel catfish followed a similar yet more pronounced pattern as freshwater drum by shifting to main and back channel habitats when water temperatures at all habitat types were < 4 °C (Figure 1). Fifty-three percent of the channel catfish individuals were collected in tributaries and 43 % in main and back channel habitats at temperatures > 4 °C. At temperatures between 3 and 4 °C, 84 % of the channel catfish individuals were collected

in main and back channel habitats. Likewise, 83 % of all channel catfish individuals were collected in main and back channel sites when temperatures were < 3 °C.

Tributary habitats also had the highest species diversity of all habitat types. A total of 19 species were collected in tributaries, while totals of 14 and 11 species were collected in main channel and back channel habitats, respectively (Figure 3). Even during January 10 –19, 2003, the coldest sampling period (average water temperatures ranged between 2.1 and 3.0 °C; Table 1), tributaries still contained the highest species diversity (N=13). However, most of the species collected in January 2003 were from one site, Bull Creek.

High abundance and species diversity occurred in Bull Creek (a tributary habitat) during both winter samples. During the second winter sample, 75 % of the fish captured in tributaries and 30 % of the total catch from all habitat types were from Bull Creek. Bull Creek had the single greatest total catch of fishes at one site (134 individuals on January 11, 2003) when the water temperature was 3.2 °C (Figure 5 shows a captured sonar image of this event). Interestingly, immediately downstream from Bull Creek, the largest single catch of fishes at a main channel site occurred on the same day.

The CCA results indicate which abiotic conditions correspond with individual species habitat use. The large difference between mean abiotic conditions of the two winter samples, (February 7, 2002 – April 7, 2002 had warmer water temperatures than December 12, 2002 – March 17, 2003; Figure 2 and Table 1), offered a chance to explore individual species differences in habitat use during winter. Because one fish species (freshwater drum) dominated our collections, these exploratory results allowed us to see if other species followed similar patterns of winter habitat use as freshwater drum.

Freshwater drum (# 23 in Figure 4a) corresponded with decreasing flow values and tributary sites during the warmer winter sample. Channel catfish (# 13 in Figure 4a) were weakly linked to increasing water temperatures and the sites that contained them (4 main channel sites and 1 tributary site, Duck Creek on March 24, 2002, when 50 of the 100 fishes collected were channel catfish) during the warmer sample. Only channel catfish weakly correlated with water temperatures during the warmer period, probably due to increased average water temperatures across all habitat types during this time period (Table 1). During the first winter sample, gizzard shad (# 2 in Figure 4a) closely associated with increased conductivity values of some tributary sites. The other species collected during the first sample period corresponded with relatively lower flows and slightly increasing depths. Most of these fishes (9 of the 13 species), however, were collected in negligible abundance from two tributary sites, Bull and Duck Creeks.

Contrary to the warmer sampling period, freshwater drum (# 23 in Figure 4b) corresponded equally (but to a slightly lesser intensity) with channel catfish (# 13 in Figure 4b) to increasing flow velocity, water temperature, and conductivity during the colder sampling period. Mooneye, *Hiodon tergisus*, (#3 in Figure 4b) also closely coincided with increasing values of these same abiotic variables. Main and back channel sites were associated with increasing flow velocity, temperature and conductivity axes. Fourteen of the 20 species were correlated with decreasing values of these three major axes and were associated with tributary sites.

Discussion

Low-velocity tributary habitats contained the highest abundances and diversity of fishes during February 2002 - March 2003 sample sessions. Although other unmeasured

variables may explain fish use of tributary habitats during winter, we believe that low velocity is an important abiotic regulator of winter habitat use. Supporting this conclusion, largemouth bass, *Micropterus salmoides*, in the Hudson River (Carlson 1992), and river carpsucker, *Carpiodes carpio*, and sauger, *Stizostedion canadense*, in the Missouri River (Braaten and Guy 1999) also used tributary confluences during winter. We do not believe that electrofishing sampling efficiency was higher in tributary habitats because ambient conductivities (Reynolds 1996) were similar in all habitats during both years (ranged from 182 – 303 uS/cm) and were close to the standard conductivity of a fish (115 uS/cm) (Miranda and Dolan 2003).

River current velocities may overcome fishes' swimming ability to hold their position in preferred habitats such as tributaries as water temperatures decline below 4 °C. During our coldest sample periods (water temperatures < 4 °C), the catch of several species increased in back channel or main channel habitats, including channel catfish, and freshwater drum (Figure 1). We did not have high catches of fish in back and main channel habitats, except when average water temperatures in low-velocity tributary habitats were < 3 °C. On January 11, 2003, all tributary habitats were < 3 °C, except for Bull Creek (3.2 °C) when the single highest total catch of fishes occurred (Figure 5). It is possible that previous to this sampling date, the high flow conditions and declining water temperatures (Figure 2b) forced fishes to occupy relatively lower-velocity tributary sites like Bull Creek. On January 11, 2003, the declining temperatures may have limited fishes' swimming ability. The minimum amount of flow that existed in Bull Creek on that day may have swept fishes downstream into an eddy current along the main channel shoreline immediately below the mouth of Bull Creek, where they were collected. In the

upper Mississippi River, Bodensteiner and Lewis (1994) documented increased flow velocity coupled with near-freezing water temperature caused freshwater drum to lose equilibrium and become incapacitated, resulting in large numbers of individuals floating downstream with the current.

The lack of sufficiently warmer temperatures may force fishes to occupy main and back channel habitats. Average water temperatures in channel habitats were higher than tributaries during January 2003, yet still below the critical 4 °C (Table 1). Sheehan et al. (1990) reported riverine fishes in laboratory conditions preferred water temperatures > 4 °C. If water temperatures > 4 °C are unavailable, current velocities may overwhelm fishes' swimming ability, sending them downstream where they collect in channel borders. However, the ability to withstand critically low water temperatures may vary between species.

Species-specific responses to winter conditions result in differential habitat use. Physiochemical tolerances vary among fish species (Sheehan et al. 1990), which was evident between our two most abundant species. For example, channel catfish occupied warmer and deeper habitats, while freshwater drum occupied shallower habitats with lower flow velocities during February 16 through April 7, 2002 (Figure 4a). During this time period, freshwater drum appeared less tolerant of higher flow velocities, but used shallower habitats than channel catfish. However, during the coldest months of 2003, freshwater drum occupied warmer and deeper habitats with higher flow velocities, similar to channel catfish (Figure 4b), suggesting a mutual tolerance of physiochemical factors during severe winter conditions. Conversely, other species continued to associate with lower temperatures at low-velocity tributaries (Figure 4b).

Our study was conditional on six habitats, but other overwintering habitats occur in Belleville Pool. We also sampled and found high diversity and abundance of fishes in an embayment, downstream of a wing dam, and within an industrial warm-water outflow, but these habitats (uncommon within Belleville Pool) were not part of our study design. Off-channel coves, marinas, embayments and industrial warm-water outflows have been shown to be valuable overwintering refuges for fishes (Sheehan et al. 1994; Gent et al. 1995; Knights et al. 1995; Raibley et al. 1997). Additional studies of alternative habitats, such as embayments, warm-water outflows, artificial structures, and tailwaters, are needed to further address fish-habitat relationships in large rivers.

In conclusion, our data support tributary confluences as important overwintering sites for fishes in the Belleville Pool, Ohio River. Some fishes, however, shift to main and back channel habitats when temperatures are < 3 °C. If altered or unprotected, the loss of overwintering habitats at tributary mouths could contribute to increased mortality of fishes during winter. Additionally, tributary mouths are susceptible to disturbance from boat and barge traffic, and fishes using these habitats during winter could be displaced. Nielsen (1986) and Sheehan and Rasmussen (1999) suggested detrimental effects of commercial boat traffic on fishes in large rivers. Passage of boats during winter causes turbulence, possibly forcing fish from their overwintering position. Those fishes forced into less suitable conditions may suffer increased mortality. Protecting tributary confluences from further degradation by commercial boat traffic, pollution, sedimentation, and channelization, among others, may increase the probability of survival of fishes in large rivers.

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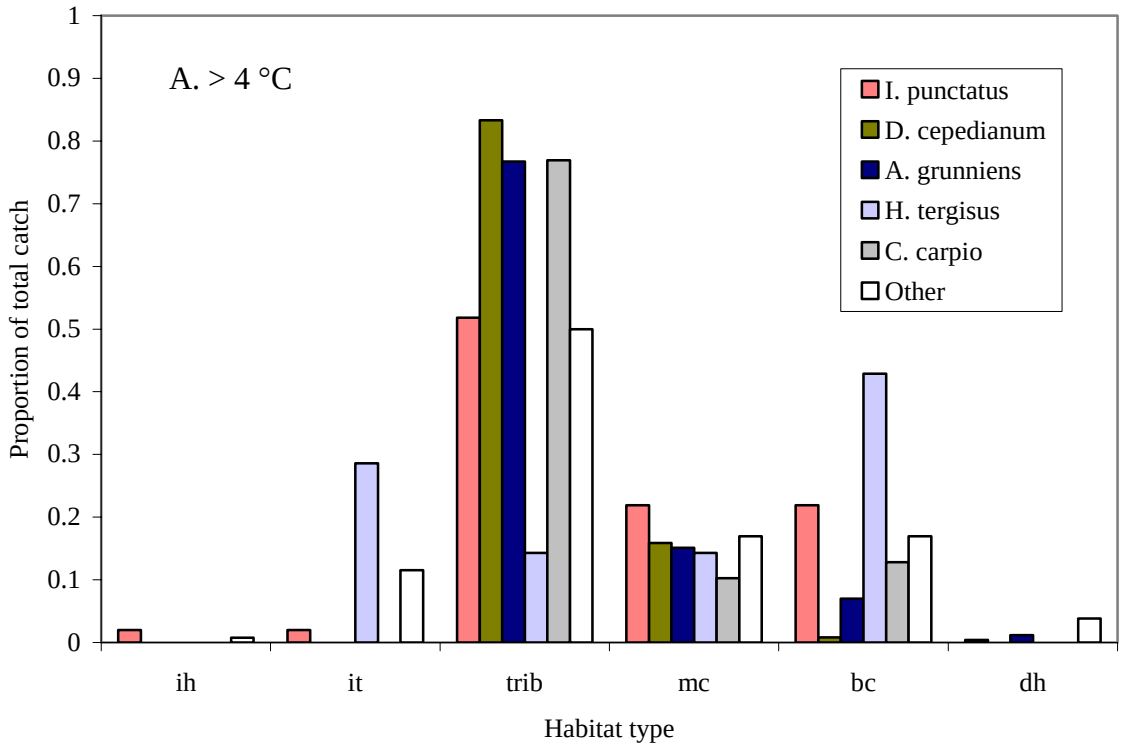
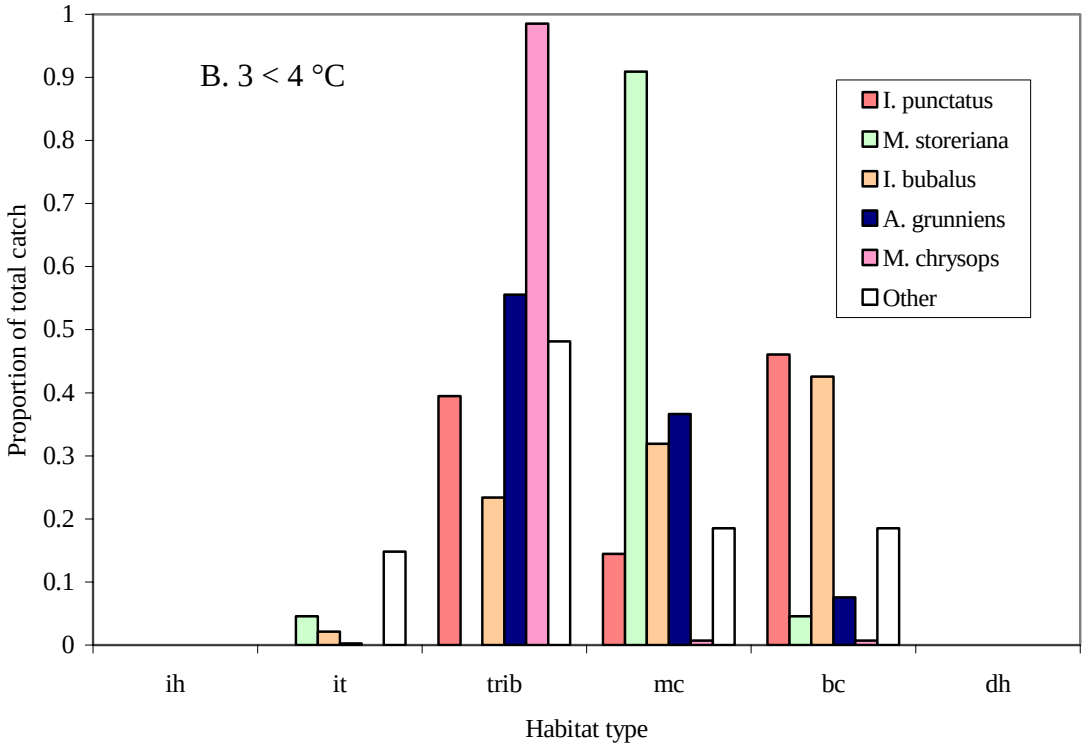
Figure 1. The proportion of the total catch of each species among habitat categories. Data are separated by water temperatures > 4 ˚C (A), 3 < 4 ˚C (B), and < 3 ˚C (C) within the Belleville Pool, Ohio River, during February 17 through April 7, 2002 and December 12, 2002 through March 17, 2003. Sites are abbreviated as bc (back channel), dh (deep hole), ih (island head), it (island tail), mc (main channel), and tr (tributary). Fish species are abbreviated as *D. cepedianum* (gizzard shad), *H. tergisus* (mooneye), *M. storeriana* (silver chub), *C. carpio* (river carpsucker), *I. bubalus* (smallmouth buffalo), *I. punctatus* (channel catfish), *M. chrysops* (white bass), *M. saxatilis x chrysops* (hybrid striped bass), and *A. grunniens* (freshwater drum).




B. 3 < 4 °C
I. punctatus
M. storeriana
I. bubalus
A. grunniens
M. chrysops
Other
Proportion of total catch
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ih
it
trib
mc
bc
dh
Habitat type

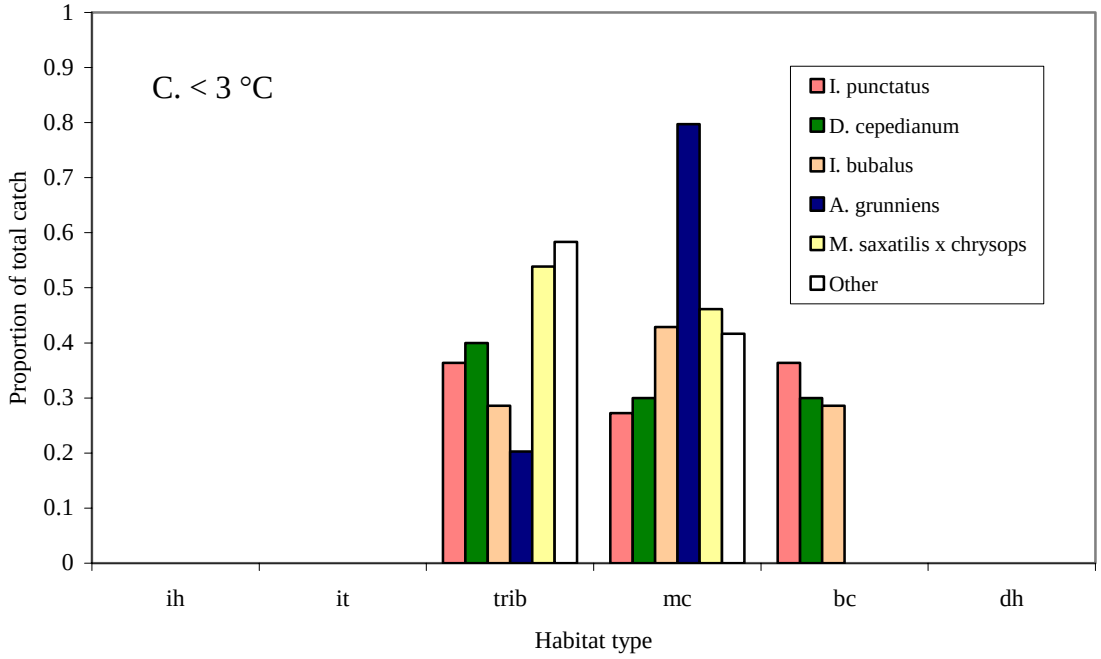
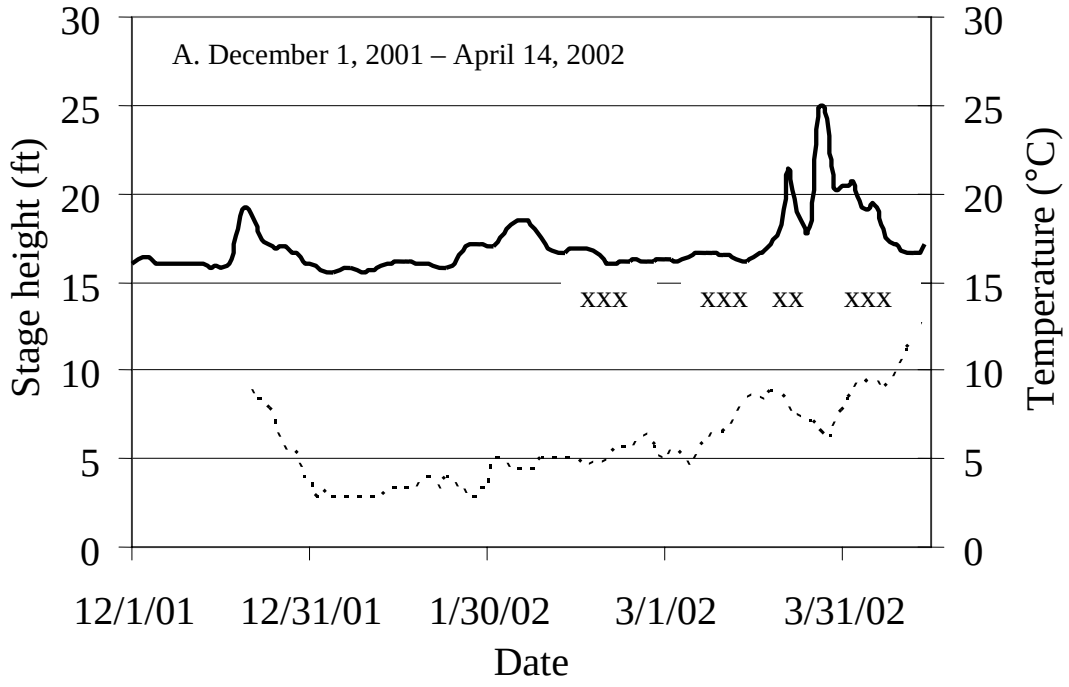

C. < 3 °C
I. punctatus
D. cepedianum
I. bubalus
A. grunniens
M. saxatilis x chrysops
Other
Proportion of total catch
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ih
it
trib
mc
bc
dh
Habitat type

Figure 2. Water temperature (broken line), stage height (solid line), and sampling session dates (x) in Belleville Pool, Ohio River, during December 1, 2001 through April 14, 2002 (A) and December 1, 2002 through April 14, 2003 (B).



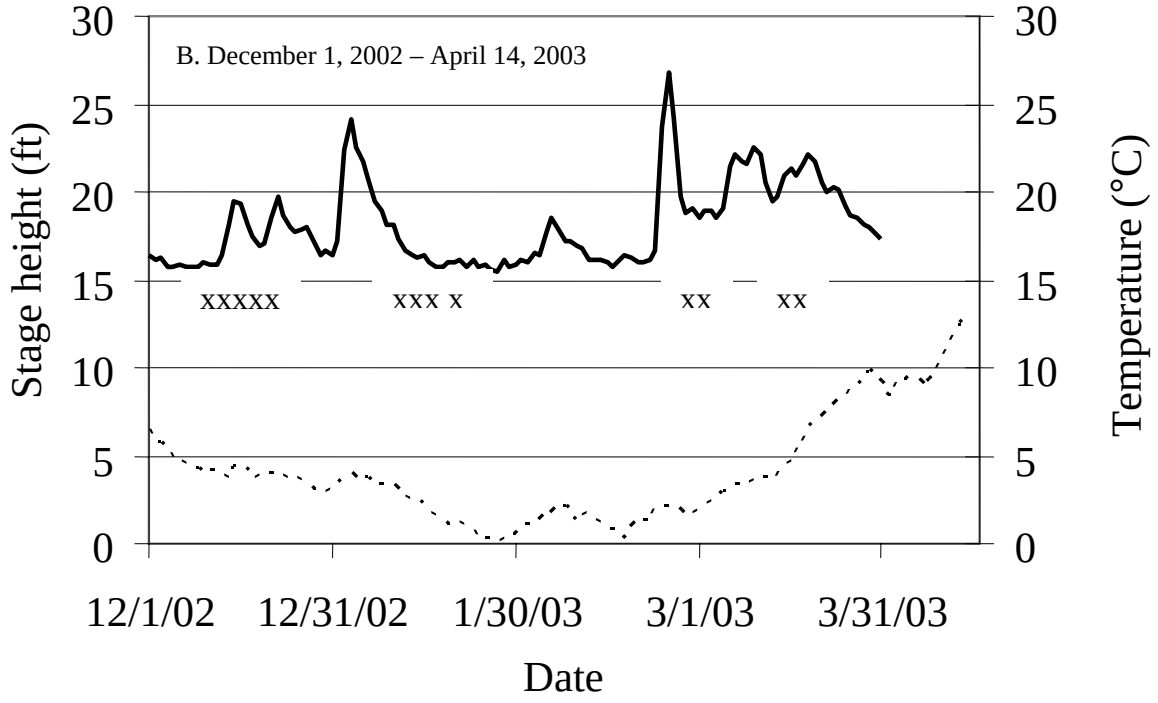

B. December 1, 2002 – April 14, 2003
Stage height (ft)
Temperature (°C)
30
25
20
15
10
5
0
xxxxx
xxx x
xx
xx
12/1/02
12/31/02
1/30/03
3/1/03
3/31/03
Date

Figure 3. The number of species in each habitat category collected in the Belleville Pool during December 1, 2001 through April 14, 2002 and December 1, 2002 through April 14, 2003. Sites are abbreviated as ih (island head), it (island tail), trib (tributary), mc (main channel), bc (back channel), and dh (deep hole).

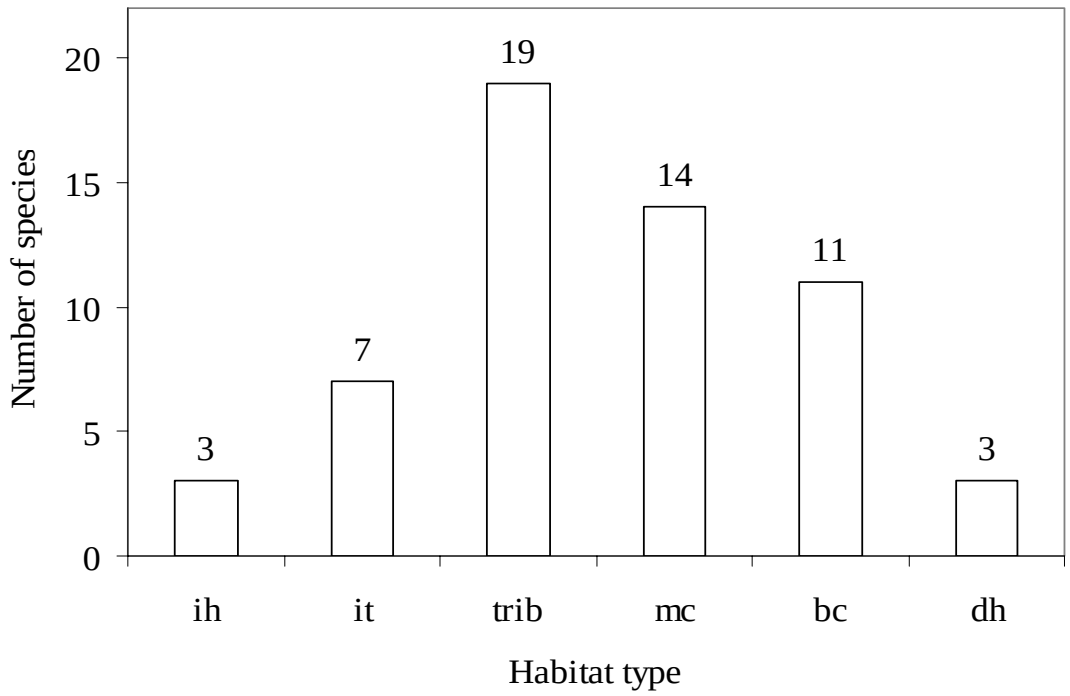
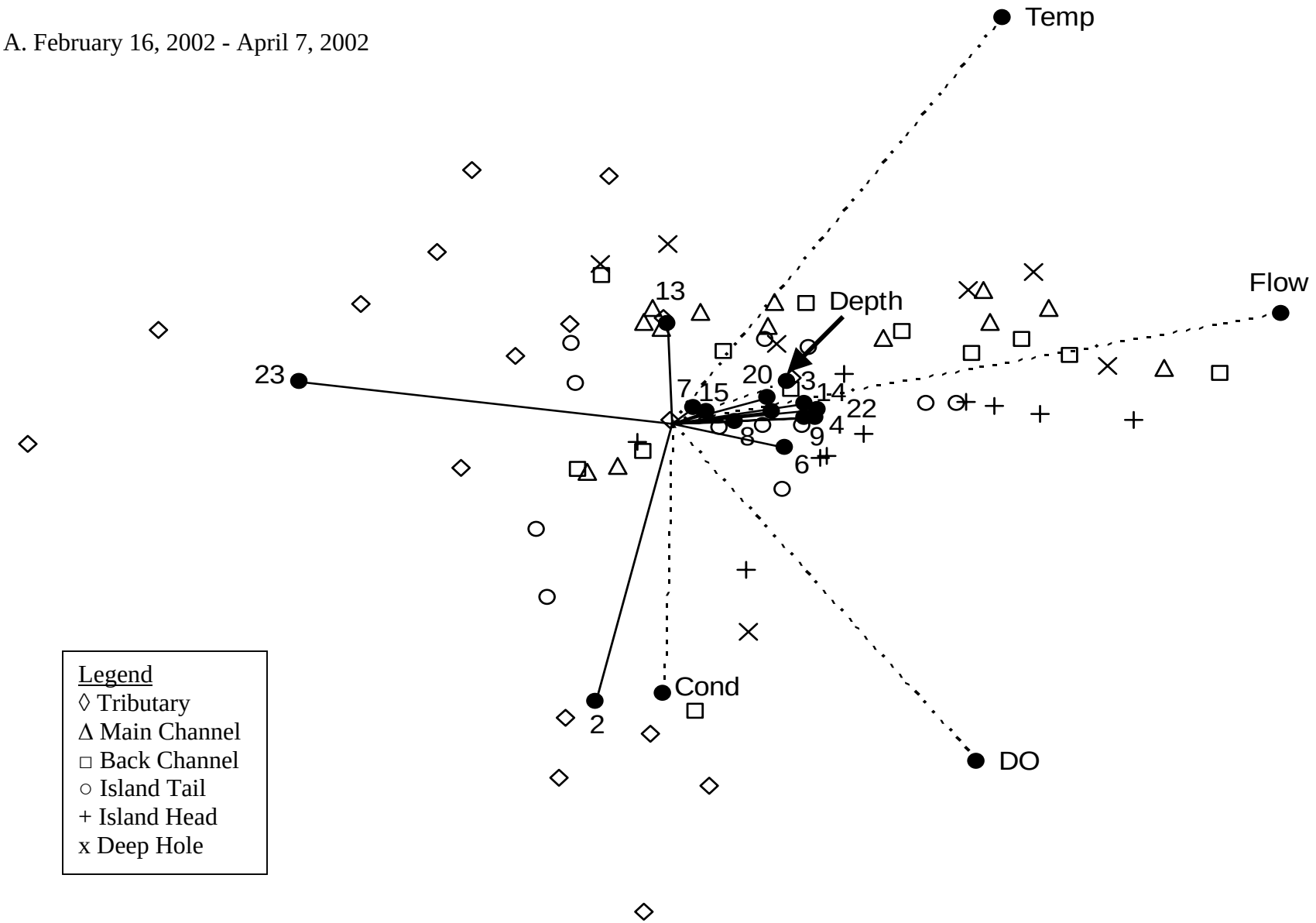


Figure 4. Triplot from canonical correspondence analysis (CCA) of species abundance, sites, and abiotic variables from February 16, 2002 through April 7, 2002 (A) and December 12, 2002 through January 19, 2003 (B) in the Belleville Pool, Ohio River. Sites are symbolized as ◊ (tributary), + (island head), ○ (island tail), □ (back channel), Δ (main channel), and x (deep hole). Abiotic variables are depth, specific conductivity (Cond), temperature (Temp), turbidity (Turb), and water velocity (Flow). Species are numbered as 1) *I. bdellium*, 2) *D. cepedianum*, 3) *H. tergisus*, 4) *Cyprinus carpio*, 5) *M. storeriana*, 6) *N. atherinoides*, 7) *Carpiodes carpio*, 8) *C. cyprinus*, 9) *C. velifer*, 10) *M. erythrurum*, 11) *M. macrolepidotum*, 12) *I. bubalus*, 13) *I. punctatus*, 14) *P. olivaris*, 15) *M. chrysops*, 16) *M. chrysops x saxatilis*, 17) *A. rupestris*, 18) *P. nigromaculatus*, 19) *M. punctatus*, 20) *L. macrochirus*, 21) *S. canadense*, 22) *S. vitreum*, and 23) *A. grunniens*.

A. February 16, 2002 - April 7, 2002



B. December 12, 2002 – January 19, 2003

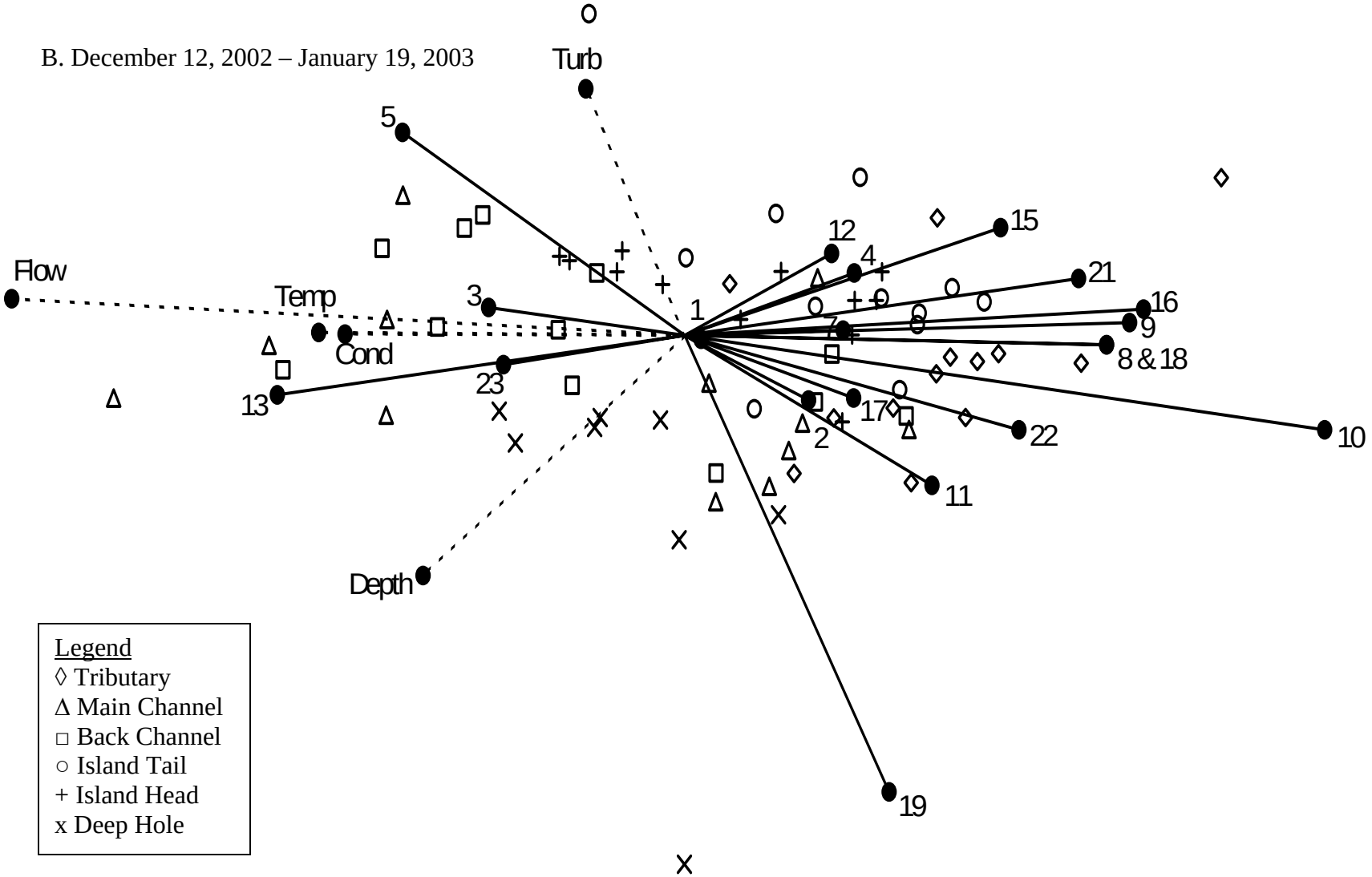


Figure 5. The captured sonar image from Bull Creek on January 11, 2003, when the single highest total catch of fishes occurred. Black streak like blotches are individual fish.

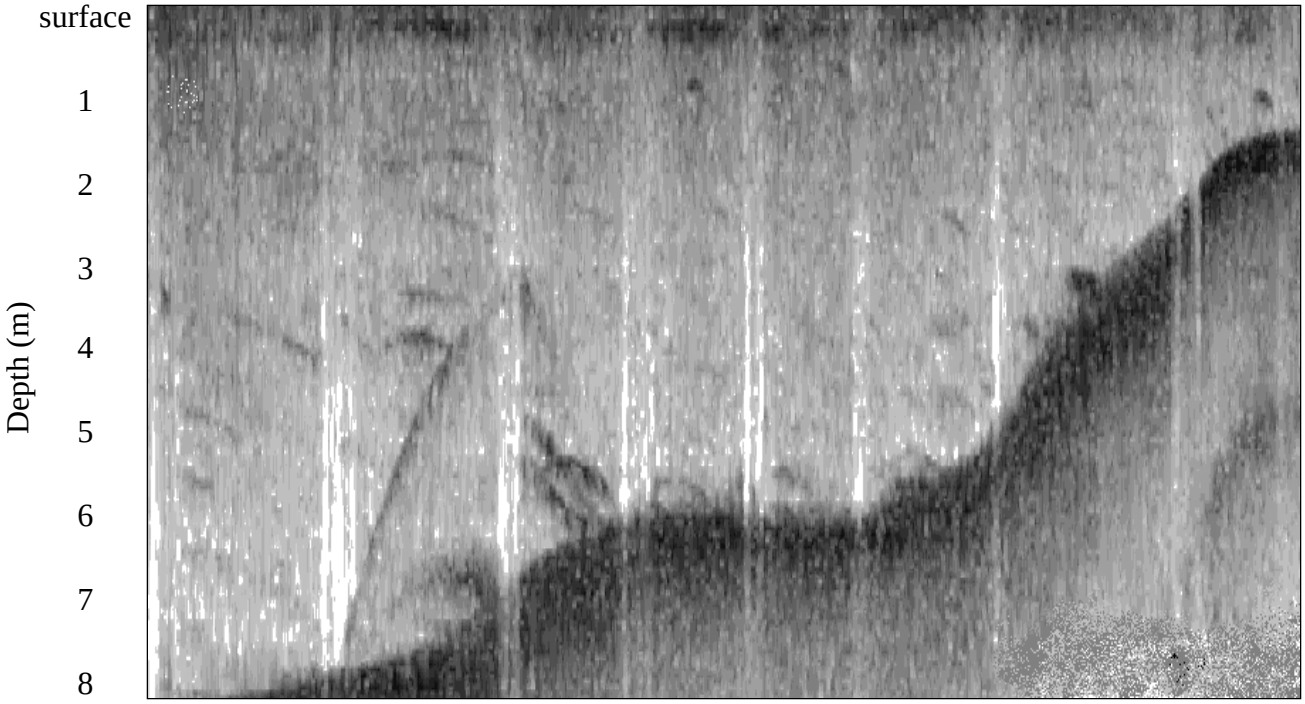


Table 1. Average abiotic conditions of all sites in six habitat types during six different sampling periods between February 16 through April 7, 2002 and December 12, 2002 through March 17, 2003 in the Belleville Pool, Ohio River. Standard deviations are in parentheses. Habitat types and abiotic variables with no values were not sampled during February 16 - 22, 2002 and the deep hole category with no standard deviation values only had one sample site during this period.

Date	Habitat types					
	Island Head	Island Tail	Back channel	Main channel	Tributary	Deep hole
February 16 – 22, 2002						
Temp. (°C)					4.8 (0.35)	5.4 (-)
D. O. (mg/L)					13.3 (0.25)	13.6 (-)
Flow (m/s)					0.1 (0.02)	
Spec. Cond. (uS/cm)					390.1 (87.1)	373.0 (-)
March 9 - 25, 2002						
Temp. (°C)	7.7 (0.54)	7.1 (0.60)	6.9 (1.22)	7.3 (0.07)	6.8 (0.74)	7.3 (0.03)
D. O. (mg/L)	8.3 (0.49)	8.3 (0.53)	8.4 (0.58)	8.5 (0.46)	8.1 (0.49)	8.5 (0.52)
Flow (m/s)	0.5 (0.30)	0.3 (0.20)	0.4 (0.29)	0.4 (0.17)	0.1 (0.13)	0.4 (0.06)
Spec. Cond. (uS/cm)	353.3 (46.7)	354.6 (45.0)	355.6 (40.5)	338.7 (47.1)	316.2 (48.1)	337.9 (53.6)
April 4 - 7, 2002						
Temp. (°C)	9.0 (0.28)	9.0 (0.30)	9.0 (0.37)	8.9 (0.20)	9.4 (0.73)	8.9 (0.09)
D. O. (mg/L)	10.7 (0.67)	10.5 (0.26)	10.5 (0.26)	10.8 (0.85)	9.5 (1.64)	11.0 (1.12)
Flow (m/s)	0.6 (0.24)	0.4 (0.22)	0.7 (0.23)	0.7 (0.24)	0.2 (0.22)	1.0 (0.15)
Spec. Cond. (uS/cm)	265.9 (47.4)	267.0 (46.5)	267.4 (50.7)	261.9 (38.2)	282.2 (103.7)	250.9 (7.00)
February 16 – April 7, 2002						
Temp. (°C)	8.4 (0.80)	8.1 (1.07)	6.9 (1.39)	8.3 (0.84)	7.5 (2.25)	7.7 (1.31)
D. O. (mg/L)	9.6 (1.38)	9.5 (1.19)	9.4 (1.13)	9.9 (1.37)	10.0 (2.24)	10.3 (2.06)
Flow (m/s)	0.6 (0.27)	0.4 (0.21)	0.5 (0.30)	0.6 (0.28)	0.1 (0.17)	0.7 (0.35)
Spec. Cond. (uS/cm)	306.2 (64.0)	307.4 (63.2)	311.5 (63.8)	292.6 (56.1)	319.3 (92.0)	305.6 (61.2)

Table 1. continued.

Date	Habitat types					
	Island Head	Island Tail	Back channel	Main channel	Tributary	Deep hole
December 12 - 17, 2002						
Temp. (°C)	4.0 (0.55)	4.2 (0.56)	4.1 (0.52)	4.0 (0.47)	4.1 (0.74)	4.2 (0.42)
D. O. (mg/L)	7.3 (0.14)	8.5 (1.09)	7.9 (0.67)	7.2 (0.11)	7.1 (0.58)	8.4 (0.00)
Flow (m/s)	0.6 (0.29)	0.2 (0.10)	0.7 (0.21)	0.5 (0.26)	0.1 (0.13)	0.5 (0.15)
Spec. Cond. (uS/cm)	424.5 (80.6)	434.2 (76.3)	423.5 (91.7)	460.3 (60.5)	336.5 (95.3)	405.3 (61.0)
January 10 -19, 2003						
Temp. (°C)	2.3 (1.10)	2.7 (1.07)	2.5 (1.29)	2.5 (0.97)	2.1 (1.05)	3.0 (0.73)
D. O. (mg/L)	13.4 (0.17)	13.3 (0.60)	13.4 (0.23)	13.4 (0.67)	13.7 (0.33)	13.5 (0.49)
Flow (m/s)	0.4 (0.20)	0.1 (0.08)	0.4 (0.25)	0.4 (0.28)	0.1 (0.08)	0.6 (0.23)
Spec. Cond. (uS/cm)	443.0 (41.0)	434.2 (41.5)	446.8 (51.0)	428.4 (32.6)	417.9 (54.0)	404.6 (13.2)
March 1 -17, 2003						
Temp. (°C)	4.1 (1.47)	4.1 (1.44)	4.1 (1.39)	3.8 (1.31)	4.1 (1.96)	2.7 (1.03)
D. O. (mg/L)	13.2 (0.35)	13.0 (0.35)	13.0 (0.37)	12.4 (1.04)	11.8 (0.56)	12.9 (0.29)
Flow (m/s)	0.8 (0.24)	0.4 (0.15)	0.7 (0.14)	0.6 (0.43)	0.1 (0.13)	0.6 (0.21)
Spec. Cond. (uS/cm)	448.6 (69.7)	445.1 (69.4)	439.9 (73.0)	435.4 (66.6)	353.9 (97.7)	383.4 (56.4)
December 12, 2002 - March 17, 2003						
Temp. (°C)	3.1 (1.34)	3.4 (1.23)	3.3 (1.34)	3.3 (1.14)	3.1 (1.59)	3.6 (0.98)
D. O. (mg/L)	10.4 (2.19)	10.9 (2.03)	10.7 (2.00)	10.3 (2.24)	10.4 (2.69)	11.7 (2.19)
Flow (m/s)	0.5 (0.30)	0.2 (0.16)	0.5 (0.25)	0.5 (0.33)	0.1 (0.11)	0.6 (0.19)
Spec. Cond. (uS/cm)	433.8 (62.8)	434.2 (60.5)	435.7 (70.0)	444.4 (53.8)	377.2 (86.6)	415.0 (46.8)

Chapter 3. Juvenile Use of a Large River Embayment during Winter

Abstract

The severity of winter conditions regulates juvenile fish mortality rates. Identifying habitats used by juveniles is essential for understanding where fishes survive during winter. Shallow, low-gradient, off-channel embayments, like Little Sandy Creek adjacent to the Ohio River, are ideal refuges for overwintering juvenile species. Eighty-five percent of all fishes collected in Little Sandy Creek embayment during this study were juveniles. Many of the fishes collected were juvenile sunfish (Centrarchidae). Bluegill, *Lepomis macrochirus*, and white crappie, *Pomoxis annularis*, were the dominant sunfishes collected. Protecting and modifying embayment habitats may reduce juvenile mortality during winter and improve recreational angling opportunities for sunfish in large river systems.

Introduction

Winter, a critical period for juvenile riverine fishes in temperate climates, reduces probabilities of survival (Bodensteiner and Lewis 1992; Lyons 1997) and recruitment (Oliver et al. 1979; Toneys and Coble 1979; Miranda and Hubbard 1994). Fishes enter a torpor-like state during low winter temperatures (Crawshaw 1984) where metabolic rates and consequently, respiration and activity rates are low (Bodensteiner and Lewis 1992; Carlson 1992; Cunjak 1996). Fishes increase fat-reserves before winter; hence, reducing mortality associated with energy depletion (Post and Evans 1989; Cargnelli and Gross 1996). During torpor, however, juvenile fishes are susceptible to predation (Garvey et al. 1998) and adverse physiochemical conditions, such as low dissolved oxygen concentrations and strong current velocities (Cunjak 1996). Consequently, optimal

winter habitats should provide protection from predators as well as amiable abiotic conditions that minimize energy depletion (Crawshaw 1984).

Riverine fishes overwinter in areas of low flow and relatively warm temperatures (Logsdon 1993; Bodensteiner and Lewis 1994; Johnson et al. 1998), such as off-channel coves, backwaters, marinas, embayments and industrial warm-water outflows (Sheehan et al. 1990; Gent et al. 1995; Knights et al. 1995; Raibley et al. 1997; Sheehan and Rasmussen 1999). Although riverine fishes select thermal refuges and areas of relatively low flow during winter, high winter mortality rates of juvenile fishes have been documented (Bodensteiner and Lewis 1992; Lyons 1997). Rates of juvenile survival influence numbers of individuals recruited into future fisheries (Toneys and Coble 1979; Miranda and Hubbard 1994). Given the link between winter temperature and fish mortality, and the importance of juvenile survival to fishery recruitment, fishery managers need to locate and protect winter refuge habitats of juvenile fishes.

In the Ohio River, channelization and impoundment from lock and dams have homogenized habitats, and reduced low-velocity mainstem habitats. However, embayments, shallow off-channel areas, offer low-velocity habitat for fishes during winter. Embayments contain riverine fishes during winter (Sheehan et al. 1990; Gent et al. 1995; Knights et al. 1995; Raibley et al. 1997), but their importance in the Belleville Pool of the Ohio River was undocumented before this study.

Objectives

Our primary objective was to examine species composition and size classes (juveniles vs. adults) of fishes in Little Sandy Creek embayment, Belleville Pool, Ohio River, West Virginia, during winter 2002-2003. A secondary objective was to quantify

age-length relationships of white crappie, *Pomoxis annularis*, a popular sport fish for recreational anglers. This study was part of a larger evaluation of winter habitats used by fishes in main channels, island back channels, island heads and tails, and tributary mouths within Belleville Pool (see Chapter 2).

Study site

Little Sandy Creek drains 26 sq. km and includes a 12.4 ha embayment (39° 13' 57" N, 81° 41'10" W) near its confluence with the Ohio River. The embayment reaches a maximum 2 m channel depth, but is mostly shallow (< 0.5 m) during normal flows. The riparian zone is a mixture of agricultural fields, mixed deciduous forest, and housing developments.

Methods

Data collection

During the winter of 2002-2003, we electrofished (Smith-Root pulsed DC electrofishing boat) Little Sandy Creek embayment on 15 December 2002, and 1 and 17 March 2003. On each sample date, we electrofished two near-shore transects and one mid-channel transect. Transects were sampled for 10 minutes (peddle time). Ice cover prevented sampling during January and February. Fishes were captured, identified to species, measured (nearest mm total length, TL), and weighed. Weights for large fishes (over 1kg) were taken to the nearest 25g with a Pesola spring scale (5 kg maximum). Smaller fishes (less than 1 kg) were weighed to the nearest 1g with a Homs spring dial scale (1kg maximum). After measuring the weights and lengths of 100 individuals of a species collected during a single sample date, the remaining individuals were counted, (except for emerald shiner, *Notropis atherinoides*, due to its extremely small size). When

collected, five white crappie individuals from each 50 mm size class were kept during each sample date for age analysis.

To describe the abiotic conditions of Little Sandy Creek embayment, we measured specific conductivity, dissolved oxygen (D. O.), pH, and temperature with an YSI 6820 during each sample date. Additionally, we estimated turbidity (secchi disk, and NTUs with YSI 6820), and flow velocity (Marsh-McBirney Flowmate 2000).

Length-at-maturity and age analysis

To evaluate the importance of Little Sandy Creek embayment to juvenile fishes, we defined juveniles (except white crappie) based on published length-at-maturity data from Trautman (1981), Mittelbach (1984), Etnier and Starnes (1993), Jenkins and Burkhead (1993), and Johnson and Jennings (1998). We defined white crappie individuals as juveniles or adults based on our age estimates.

We examined age structure of white crappie with otoliths. Otoliths were removed from a subset of the white crappie, sectioned with an Isomet 1000 precision saw with a 12.7 cm x 0.4 mm blade, and viewed with a dissecting scope. Two observers estimated age independently, and a third observer resolved discrepancies. In order to simplify the aging process because these fish were collected in winter, we assumed January 1 as the birth date (DeVries and Frie 1996) and assigned ages as if all individuals were collected on or after January 1.

Statistical analysis

We used length-frequency distributions for the five most abundant species and compiled the information from the sources listed above for the least abundant species to establish juvenile length ranges for all species collected in Little Sandy Creek

embayment. We calculated the proportion of juveniles of each species by sampling dates. To further classify the age-length distribution of white crappie, the length range, mean length, and variance were calculated for each white crappie age class.

Results

Abiotic conditions

Water temperatures rose from 2.95 to 11.24 °C between 1 and 17 March 2003. During the 15 December 2002 sample, the water temperature was 4.08 °C. Dissolved oxygen ranged from 11.16 to 11.75 mg/L. Specific conductivity (uS/cm) values were 257.3, 257, and 350, and pH values were 6.9, 7.3, and 7.7 during the first, second, and third sample dates, respectively. A null flow velocity measurement (0 m/s) was recorded during all three sample dates. Turbidity (NTU) was lowest during the March 1 sample (55) and highest during the March 17 sample (84). Secchi disk readings corresponded with the turbidity measurements, the highest value recorded during March 1 (39 cm) and the lowest during March 17 (25 cm).

Fish species and abundance

Juveniles represented the majority of the individuals collected in the Little Sandy Creek embayment during winter. Eighty-five percent of all fishes collected were juveniles (Table 2). The five most abundant species, gizzard shad, *Dorosoma cepedianum*, bluegill, *Lepomis macrochirus*, emerald shiner, white crappie, and orangespotted sunfish, *Lepomis humilus*, represented 96% of the total catch (Table 2). Of these five most abundant species, juveniles represented 83% of the total individuals. The length frequency distributions for these five species also show that shorter individuals (juveniles) were more numerous than longer individuals (Figure 6). Nearly all (97% and

94%, respectively) of the gizzard shad and orangespotted sunfish individuals were juveniles (Table 2). Of the 305 centrarchid individuals collected, 81% were juvenile. Interestingly, the proportion of the total individuals represented by juveniles decreased during the March 1 and 17, 2003 sample dates (Table 2).

Seventeen species were collected during the three sampling periods (Table 2). Fish numbers differed among sample periods (717 individuals on 15 December, 52 on 1 March, and 121 on 17 March) (Table 2). The most abundant fish, gizzard shad, was only collected in large abundance during a single sample date, December 15. One each of bowfin, *Amia calva*, mosquitofish, *Gambusia affinis*, and smallmouth buffalo, *Ictiobus bubalus*, were collected during all sample periods, none of which were juveniles. Only one fish, white crappie, was consistently collected in relatively equal numbers and abundance (Table 2).

Five different size classes of white crappie were collected representing age classes one through five (Table 3 and Figure 6d). Eighteen age-one (juvenile) white crappie represented 29% of the aged individuals. Age-two white crappies were most abundant, representing 40% of the aged individuals. Age-three, four, and five white crappies consisted of 14.5%, 8%, and 8%, respectively, of the aged individuals.

Discussion

The Little Sandy Creek embayment, a shallow off-channel, low velocity habitat, provides an important winter refuge for juvenile fishes. The upper Ohio River, with steep topography and a restricted channel, lacks the slow-moving isolated sloughs found in other large river systems in temperate North America. Embayments in the upper Ohio River, however, are similar in abiotic characteristics to other large river backwater

habitats that are important overwintering habitats for fishes of all ages (Sheehan et al. 1990; Gent et al. 1995; Knights et al. 1995; Raibley et al. 1997; Sheehan and Rasmussen 1999). Previous to this study, the value of these shallow, low-velocity, off-channel habitats, specifically for overwintering juvenile fishes, was undocumented.

The shallow, low-gradient physical characteristics of embayments make them ideal refuges for overwintering fishes. However, reductions in flow velocities in backwaters and embayments coupled with ice-cover can lead to low D. O. concentrations (Bodensteiner and Lewis 1992; Knights et al. 1995; Johnson et al. 1998). This reduction in D. O. content may either cause mortality in fishes or force them to seek alternative overwintering refuges in other habitat types. We do not know whether or not D. O. levels decreased below sufficient levels for fishes during the ice cover event in January and February 2003, but the measured D. O. concentrations were above critical minimal values before and after ice cover in Little Sandy Creek. Regardless of flow conditions, when temperatures fall below 4 °C, fishes may prefer warmer habitats, if available. In laboratory settings, Sheehan et al. (1990) reported temperature preferences of > 4 °C for many species in large rivers, such as green sunfish, *Lepomis cyanellus*, bluegill, and freshwater drum, *Aplodinotus grunniens*. Our data collected on species residing in the mainstem portions of the Ohio River show that some fishes will select higher-velocity warmer habitats over lower velocity colder habitats during winter (see Chapter 2). Increased mortality of fishes may occur because they cannot survive the low temperatures or dissolved oxygen concentrations in an embayment, forcing them to inhabit suboptimal habitats in the mainstem portions of large rivers. Fishery managers can modify

embayments to better suit the abiotic requirements of overwintering fishes to avoid increased mortalities due to these factors.

Given that centrarchids are popular game fishes, recreational fishery managers may want to consider the importance of embayments as overwintering sites for juvenile centrarchids of all ages, (but especially juveniles since they are the most susceptible to winter mortality), and protect these habitats. In our study, eight of the 17 species were comprised primarily juveniles of bluegill, green sunfish, orangespotted sunfish, pumpkinseed, *Lepomis gibbosus*, warmouth, *Lepomis gulosus*, white crappie, black crappie, and largemouth bass, *Micropterus salmoides*. Juvenile and adult white crappie used Little Sandy Creek embayment during winter, stressing the importance of this habitat for this species. Adult centrarchids use embayments during winter because of the low flow velocities (Oliver et al. 1979; Knights et al. 1995; Johnson et al. 1998; Jackson and Noble 2000). Juvenile centrarchids may use embayment habitats during winter to avoid predation. Santucci and Wahl (2003) reported 75 % to 85 % mortality rates during the first winter of young-of-the-year bluegills due to predation by largemouth bass. We captured few large predatory fishes during our samples, and juveniles were primarily associated with near-shore structure (overhanging vegetation, woody debris, and undercut banks). The use of structure by juveniles to avoid predation is well documented (Mittelbach 1988; Gotceitas 1990; Miranda and Hubbard 1994). The addition of woody debris into embayments would increase the amount of cover offering escape from predation, possibly increasing survival of juveniles.

A reduction of the proportion of juveniles in Little Sandy Creek embayment during the course of this study may have been due to mortality loss from the severely

cold temperatures during the winter of 2002-2003. High winter mortality rates of juvenile freshwater drum in the Mississippi River have been documented when water temperatures approached 0 °C (Bodensteiner and Lewis 1994). We believe water temperatures within Little Sandy Creek embayment approached 0 °C during ice-cover in January and February. Low levels of dissolved oxygen during ice-cover of backwater areas have increased mortality of fishes (Bodensteiner and Lewis 1992; Knights et al. 1995; Johnson et al. 1998). These critically low temperatures (coupled with possible reductions in D. O. concentrations) may have led to increased mortality, which explains the reduction in the numbers of total individuals present in early March, after the embayment thawed.

Increasing flow rates to minimal levels (> 0) in embayments could limit mortality losses due to insufficient dissolved oxygen levels. Knights et al. (1995) showed that overwintering bluegill and black crappie, *Pomoxis nigromaculatus*, required flow velocities > 0 cm/s, but ≤ 1 cm/s to ensure dissolved oxygen concentrations > 2 mg/ L in backwater lakes of the Mississippi River. Increasing flows > 1 cm/s rendered these habitats unsuitable to these centrarchid species (Knights et al. 1995; Johnson et al. 1998). In the Ohio River, reduction in the elevation of the impounded pool of water during freezing temperatures would allow minimal flows in and out of embayments, reducing the probability of hypoxia. Care would need to be taken to avoid releasing water so quickly that flow velocities in the embayments carry fishes (especially juveniles) out of these areas into the main channel of the river. Extended research into the specific flow velocity requirements of fishes during winter would provide more insight into how embayments can be manipulated in order to improve juvenile survival during winter.

In summary, the severity of winter conditions regulates juvenile fish mortality rates (Bodensteiner and Lewis 1994; Post et al. 1998; Wright et al. 1999; Fullerton et al. 2000; Jackson and Noble 2000). Shallow low-velocity embayments offer a refuge for juvenile fishes so as to improve their probability of survival during winter. Protection, creation, and modification of embayment habitats may reduce juvenile mortality and spur increased sunfish production in large river systems by providing critical overwintering habitat. Whether modified or not, those embayment habitats that offer low current velocities (≤1 cm/s), warmer temperatures (≥4 °C), and sufficient dissolved oxygen levels (≥2 mg/L), can be beneficial to overwintering juvenile fishes.

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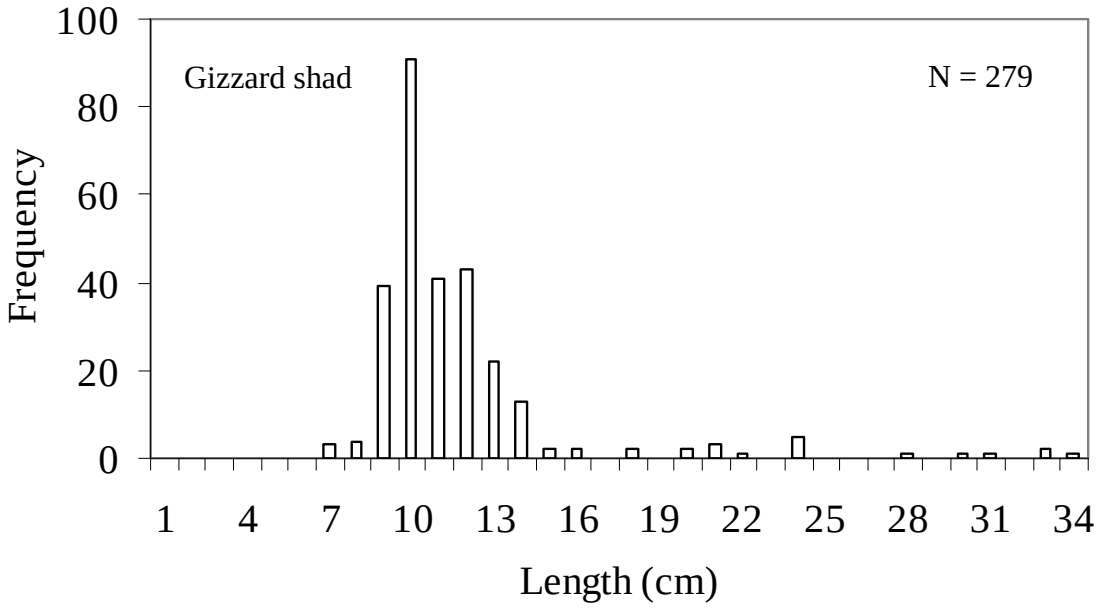
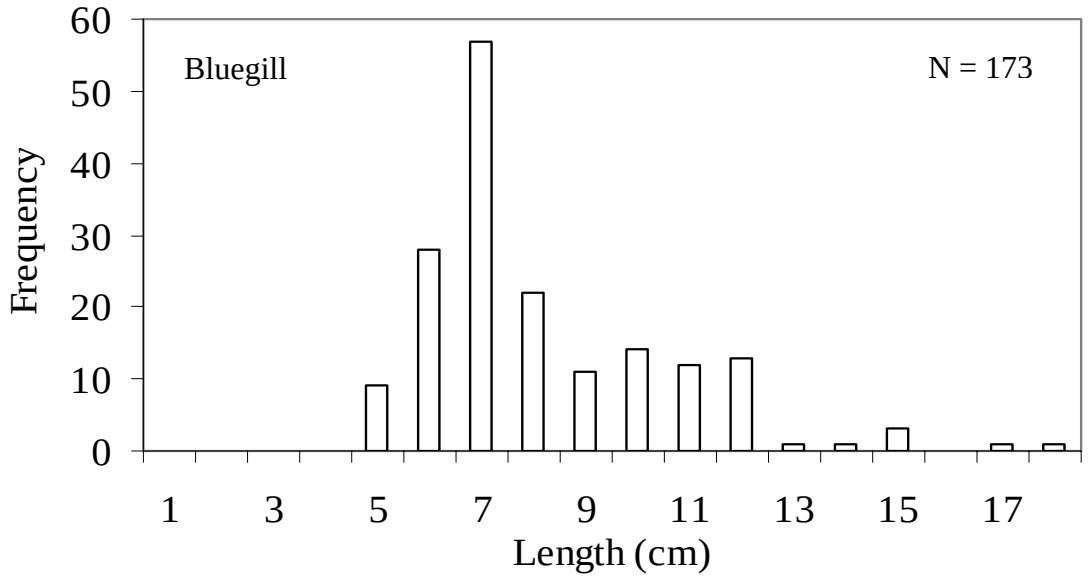
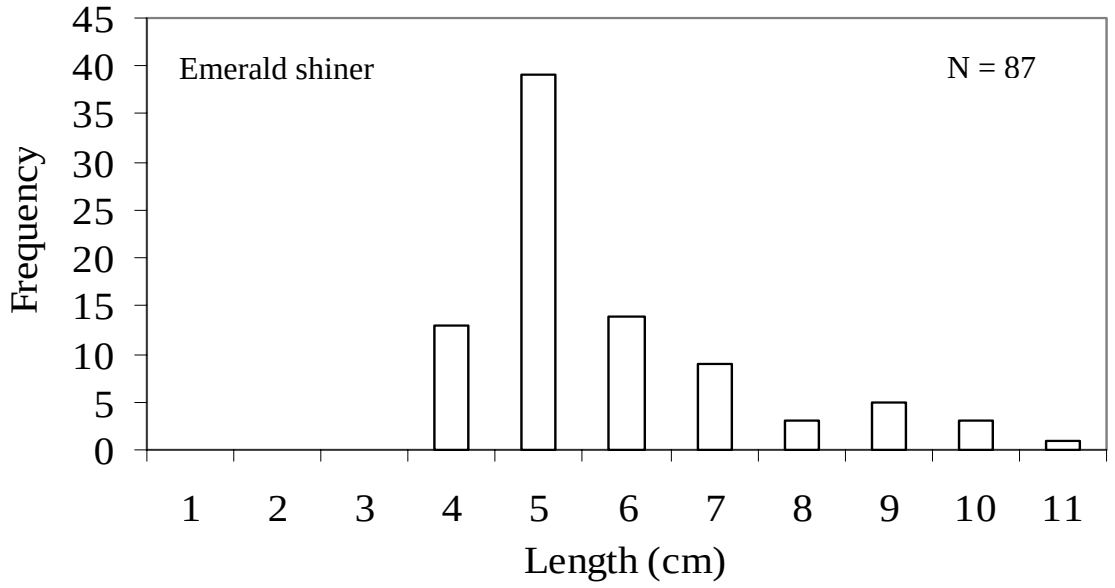
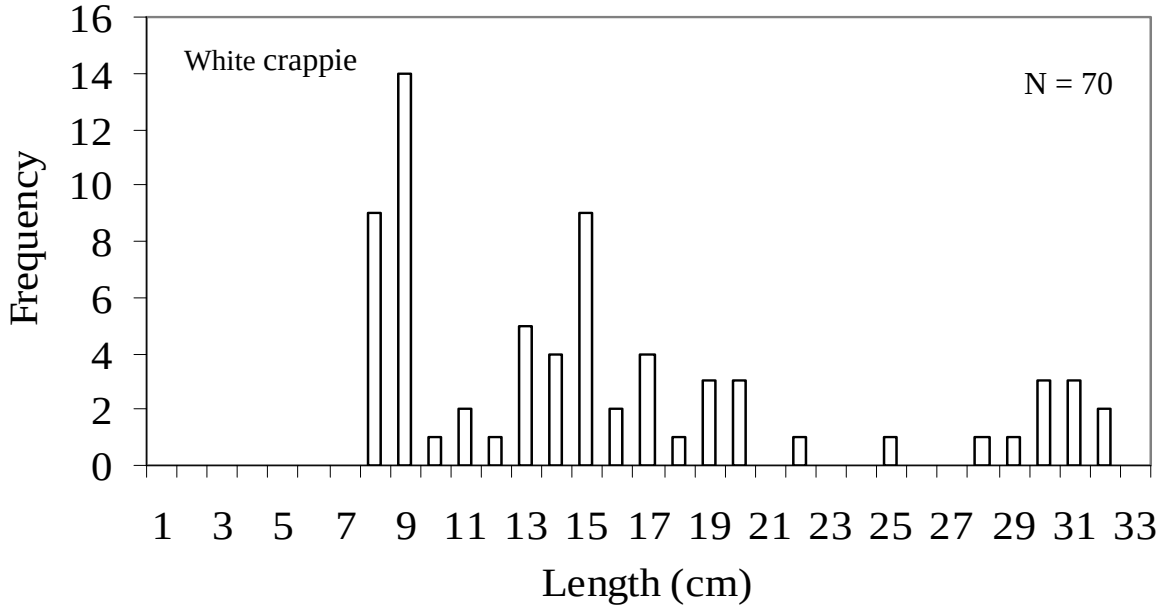
Figure 6. Length-frequencies of gizzard shad, bluegill, emerald shiner, white crappie, and orangespotted sunfish collected by pulsed DC electrofishing in the Little Sandy Creek embayment, West Virginia, during December 15, 2002 through March 17, 2003.






Emerald shiner
N = 87
Frequency
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
Length (cm)


White crappie
N = 70
Frequency
16
14
12
10
8
6
4
2
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33
Length (cm)

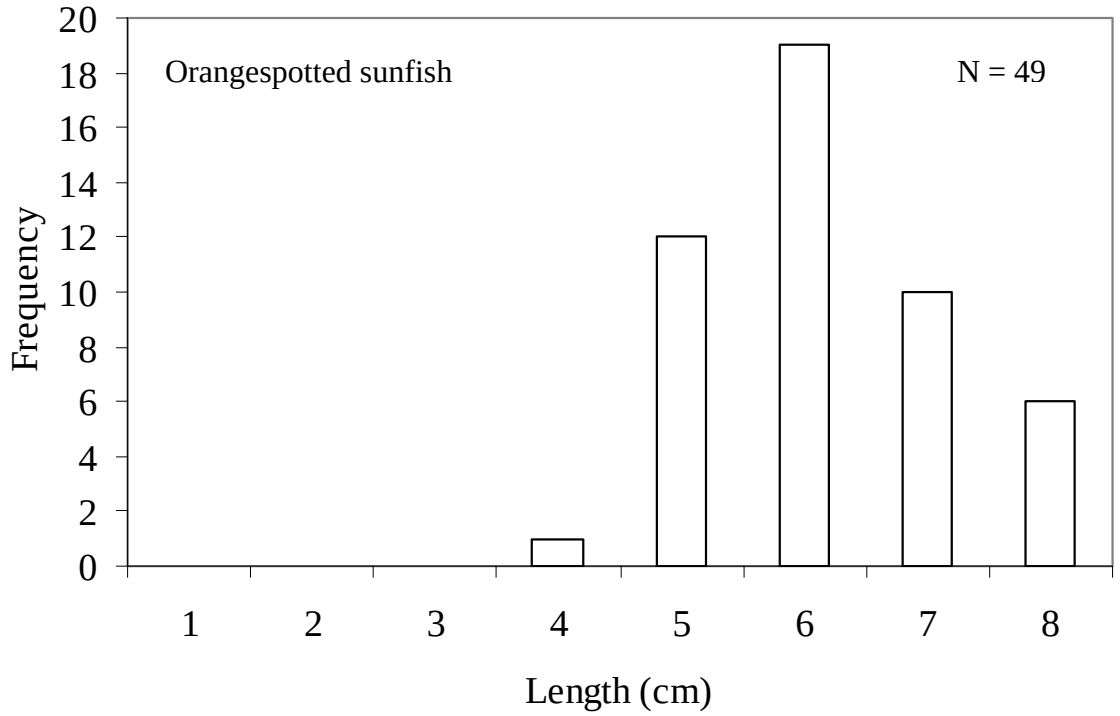

Orangespotted sunfish
N = 49
Frequency
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
Length (cm)

Table 2. Total number of individuals and juvenile proportion of the total for each fish species collected by pulsed DC electrofishing in the Little Sandy Creek embayment, West Virginia, during December 15, 2002 through March 17, 2003. Values in parentheses are the proportion of the total individuals represented by juveniles for that sampling date.

Taxon	Number collected 15-Dec-02	1-Mar-03	17-Mar-03	Total	Juvenile proportion
Black crappie *Pomoxis nigromaculatus*	1	0	1	2	1
Bluegill *Lepomis macrochirus*	113	10	41	164	0.85
Bowfin *Amia calva*	0	0	1	1	0
Common carp *Cyprinus carpio*	0	0	3	3	0
Emerald shiner *Notropis atherinoides*	120	1	16	137	0.68
Freshwater Drum *Aplodinotus grunniens*	4	0	2	6	0.5
Gizzard shad *Dorosoma cepedianum*	404	5	21	430	0.97
Green sunfish *Lepomis cyanellus*	3	1	3	7	0.29
Largemouth bass *Micropterus salmoides*	0	2	1	3	0.33
Mosquitofish *Gambusia affinis*	1	0	0	1	0
Orangespotted sunfish *Lepomis humilis*	35	6	8	49	0.94
Pumpkinseed *Lepomis gibbosus*	0	3	2	5	0.2
River carpsucker *Carpiodes carpio*	0	0	4	4	1
Smallmouth buffalo *Ictiobus bubalus*	0	0	1	1	0
Spotted sucker *Minytrema melanops*	1	1	0	2	0
Warmouth *Lepomis gulosus*	2	2	1	5	0.2
White crappie *Pomoxis annularis*	33	21	16	70	0.79
Total	717 (0.92)	52 (0.65)	121 (0.44)	890	0.83

Table 3. The length range, mean length, and variance at age for white crappies collected by pulsed DC electrofishing in the Little Sandy Creek embayment, West Virginia, during December 15, 2002 through March 17, 2003.

Age	Length range (cm)	Mean length (cm)	Variance (cm)	Number collected
1	6.1 – 10.2	7.6	1.1	18
2	12 – 17.2	13.8	2.4	25
3	16.8 – 23.2	19.4	5.3	9
4	26.1 – 28.6	27.4	0.8	5
5	29.4 – 30.9	29.4	0.3	5

Chapter 4. Growth Assessment of three Sport Fishes of the Ohio River

Abstract

Channel catfish, *Ictalurus punctatus*, freshwater drum, *Aplodinotus grunniens*, and white bass, *Morone chrysops*, are popular sport fishes in the Ohio River. Standard age and growth statistics were computed to assess the population growth and condition of these fishes. Channel catfish reached larger mean-lengths at all ages compared to specimens collected over 30 years ago in the Ohio River. Numerous older and larger freshwater drum individuals were collected, suggesting plentiful trophy-sized individuals exist in the Ohio River. None of the white bass collected were harvestable size, suggesting larger individuals may use different habitats than smaller individuals or that environmental conditions are unsuitable for appreciable growth of this species in the Ohio River. Although the population status appears satisfactory for channel catfish and freshwater drum, more information is needed to better assess the condition of white bass in the Ohio River.

Introduction

Channel catfish, *Ictalurus punctatus*, freshwater drum, *Aplodinotus grunniens*, and white bass, *Morone chrysops*, are popular gamefishes of the Ohio River, West Virginia. Currently, harvest regulations for the Ohio River, West Virginia, do not restrict lengths or numbers of channel catfish and freshwater drum, but impose a daily creel limit of four white bass > 38 cm. Little published information exists on the population dynamics of these three fishes in West Virginia waters of the Ohio River. An

understanding of age, length, and weight relationships of these important fishes is needed to manage and maintain viable recreational fisheries (Anderson and Neumann 1996).

Channel catfish live to a maximum age of 24 years and can attain weights of 34 kg (Etnier and Starnes 1993). In 1973, Schoumacher reported a maximum mean length of 43 cm at age eight for Ohio River specimens. Quist and Guy (1998) also reported a maximum age of eight for channel catfish specimens from the Kansas River, but the mean length at age eight was a greater 59 cm. Maximum ages and mean lengths reported for freshwater drum differ, however, a maximum age of 10 to 11 years and a mean length of 69 cm generalizes Goeman et al. (1984), Etnier and Starnes (1993), and Braaten and Guy (2002). The maximum age of white bass from Tennessee is 8 (Etnier and Starnes 1993), while Colvin (2002) recorded age-7 white bass specimens from the Missouri River.

Objectives

The objective of this study was to document growth relationships of channel catfish, freshwater drum, and white bass from Belleville Pool, Ohio River, West Virginia. Age-frequency distributions, the von Bertalanffy growth equation (Ricker 1975) and the allometric growth equation are used in this analysis in order to assess the population condition, structure, and growth of these three commonly occurring sport fishes in the Ohio River.

Study site

The Belleville Pool of the Ohio River, created by Belleville Lock and Dam (rkm 328.1), extends upstream to Willow Island Lock and Dam (rkm 260.2). The 67.9 km pool averages 404.5 m wide, 7.3 m deep, and comprises 2850 ha of surface area

(ORSANCO 1994). The deepest section of the pool (15 m) lies directly upstream of Belleville Lock and Dam. A navigation channel (3.7 m deep) is maintained for commercial barge traffic by the United States Army Corps of Engineers (USACE) (ORSANCO 1994). The riparian zone is a mixture of hardwood forests, urban and industrial frameworks, and agricultural settings. Most large floodplains near Belleville Pool are heavily urbanized, including cities of Parkersburg, WV (confluence of the Little Kanawha and Ohio rivers) and Marietta, OH (junction of Muskingum and Ohio rivers).

Methods

Data collection

We sampled the Belleville Pool during two periods (February 2002 – April 2002, and December 2002 to March 2002) with a variable-depth AC electrofishing boat for water depths of 2-15 meters (Grunwald 1983, Newcomb 1989). Fishes were identified to species, measured (nearest mm total length, TL), and weighed. Large fishes (over 1 kg) were weighed to the nearest 25 g with a Pesola spring scale (5 kg maximum). Smaller fishes (less than 1 kg) were weighed to the nearest 1g with a Homs spring dial scale (1 kg maximum). When collected, five individuals from each 50 mm size class of channel catfish, freshwater drum, and white bass were frozen for age analysis.

Age analysis

Sagittal otoliths were extracted from freshwater drum and white bass and sectioned with an Isomet 1000 precision saw with a 12.7 cm x 0.4 mm blade (DeVries and Frie 1996). Transverse otolith sections (approximately 1 mm thickness) were stained with iodine. When illuminated, most small otoliths (age classes 0-2, especially in freshwater drum) were aged without sectioning. Pectoral spines of channel catfish were

removed and softened in 4% nitric acid solution (HNO_3) (K. Hartman pers. comm.). Each spine was sectioned at the distal end of the basal groove (Sneed 1951) with a single-edge razor blade. Annuli of otolith and pectoral spine sections were counted under magnification (2-4 X). Two observers estimated age independently, and a third observer resolved discrepancies. In order to simplify the aging process because these fish were collected in winter, we assumed January 1 as the birth date (DeVries and Frie 1996) and assigned ages as if all individuals were collected on or after January 1.

Mean length for each age class and the variance of these values were calculated for all species. The frequency of each age class for all species was also calculated. We used the von Bertalanffy (Ricker 1975) equation $L_t = L_\infty * (1 - e^{(-K * t_0)})$ to describe the relationship of age and length of these three species. This equation calculated L_t (length at a specific age) values for channel catfish, freshwater drum, and white bass by estimating the asymptotic length (L_∞ (cm)), growth coefficient (K), and t_0 (theoretical age in years when length = 0). Standard errors of these three parameters were also calculated. We also used the allometric growth equation $W = aL^b$, where W = weight (g), a = y-intercept, and b = slope, and L = length (mm), to describe the length-weight relationship of the three species. Standard errors of the slope and y-intercept were also calculated.

Results

Younger age classes represented the greatest proportion of individuals of white bass and freshwater drum (Figure 7). The greatest number of individuals was age-4 for channel catfish, age-1 for freshwater drum, and age-2 for white bass (Figure 7). Freshwater drum were represented by the oldest age class (22), while the oldest age classes of channel catfish and white bass were 9 and 4, respectively (Table 4). The

longest freshwater drum individual was 77 cm, 62 cm for channel catfish, and approximately 30 cm for white bass (Table 4). Surprisingly, no white bass individuals collected were longer than the harvest minimum size limit of > 38 cm. High variances of mean-length-at-age values occurred due to low sample sizes for older age classes of freshwater drum and most age classes of channel catfish (Table 4).

The growth parameters calculated by the von Bertalanffy and allometric growth equations varied between the three species. The von Bertalanffy growth parameter estimates are as follows: for channel catfish, the L_∞ = 113 cm (SE = 1.34), K = 0.077 (SE = 0.056), and t_0 = 1.71 (SE = 0.46) (Figure 8a); for freshwater drum, the L_∞ = 118 cm (SE = 6.82), K = 0.051 (SE = 0.013), and t_0 = 1.47 (SE = 0.38) (Figure 8b); for white bass, the L_∞ = 48 cm (SE = 3.36), K = 0.248 (SE = 0.32), and t_0 = 1.16 (SE = 0.21) (Figure 8c). The allometric growth parameter estimates are as follows: for channel catfish, the slope = 3.35 (SE = 0.268), and y-intercept = 1.0×10^{-6} (SE = 2.35×10^{-7}) (Figure 9a); for freshwater drum, the slope = 3.39 (SE = 0.179), and y-intercept = 1.0×10^{-6} (SE = 1.12×10^{-7}) (Figure 9b); for white bass, the slope = 3.13 (SE = 0.492), and y-intercept = 1.7×10^{-6} (SE = 4.61×10^{-7}) (Figure 9c).

Discussion

White bass growth appears to be deficient for angling harvest in the upper Ohio River. It is possible that we failed to locate larger white bass individuals in the habitats we sampled, but none of the individuals collected were greater than the minimum size limit set for harvest, > 38 cm, by the West Virginia Department of Natural Resources (Table 4). Even though the von Bertalanffy maximum length (L_∞) value was 48 cm and the growth coefficient (K) was highest of all species, collected white bass individuals did

not approach harvestable size. Our L_∞ value for white bass agrees with Colvin's Missouri River specimens (2002), while our K value is considerably lower, denoting that Ohio River white bass may attain relatively equal maximum sizes but at a slower rate. White bass specimens from the Roach Lake, Ohio had mean lengths (cm) of 14.0, 26.9, and 36.6 for ages 1, 2, and 3, respectively (Carlander 1997), substantially larger sizes than our Ohio River specimens (Table 4). Our mean-length-at-age estimates for the four white bass age classes measured were considerably less than those from Tennessee (Etnier and Starnes 1993), further suggesting that white bass growth in the Ohio River is limited.

Channel catfish growth is extremely variable across spatial and temporal boundaries (Etnier and Starnes 1993). Our low von Bertalanffy K value suggests channel catfish are not growing quickly in the upper Ohio River. However, our mean-length-at-age estimates for channel catfish were higher for all age classes than Schoumacher's (1973) Ohio River specimens (also taken from the Belleville Pool). Mississippi River specimens were reported as having mean lengths (cm) of 15.0, 21.1, and 25.4 for ages 2, 3, and 4, respectively (Carlander 1969), also significantly less than our Ohio River specimens. However, our maximum mean length agrees with the mean-length-at-age 8 (Table 4) from Tennessee (Etnier and Starnes 1993) and Kansas River specimens (Quist and Guy 1998). This suggests that channel catfish in the upper Ohio River may be growing at a higher rate and attaining larger sizes faster than in the past.

Freshwater drum reach considerable sizes in the Belleville Pool, Ohio River. The maximum age estimate for our freshwater drum specimens (Table 4) is greater than most published information. The oldest freshwater drum individual collected in the Belleville Pool was estimated to be 22 years of age, measured 77 cm in length, and weighed 7.4 kg.

In Lake Erie, Cunningham (1989) recorded a 33-yr old freshwater drum and numerous individuals older than 10 years. A relatively large number of freshwater drum individuals collected were of older age classes (> 10) (Figure 7b and Table 4), suggesting that conditions in the upper Ohio River are favorable for long life expectancy of freshwater drum.

In summary, the age and growth information presented here is useful in assessing the population growth and condition of these three popular sport fishes in the Ohio River. None of the white bass collected were harvestable size, possibly indicating larger white bass either use different habitats than smaller individuals or sub optimal environmental conditions exist in the Belleville Pool for this species. Channel catfish appear to be growing at faster rates than in the past, suggesting environmental conditions have improved for this species over time. The impressive sizes that freshwater drum reach in the Belleville Pool should delight any angler seeking trophy-sized individuals of this species. Hopefully, this information proves useful for fishery managers seeking to improve conditions or assess past management actions for these three sport fisheries in the Ohio River.

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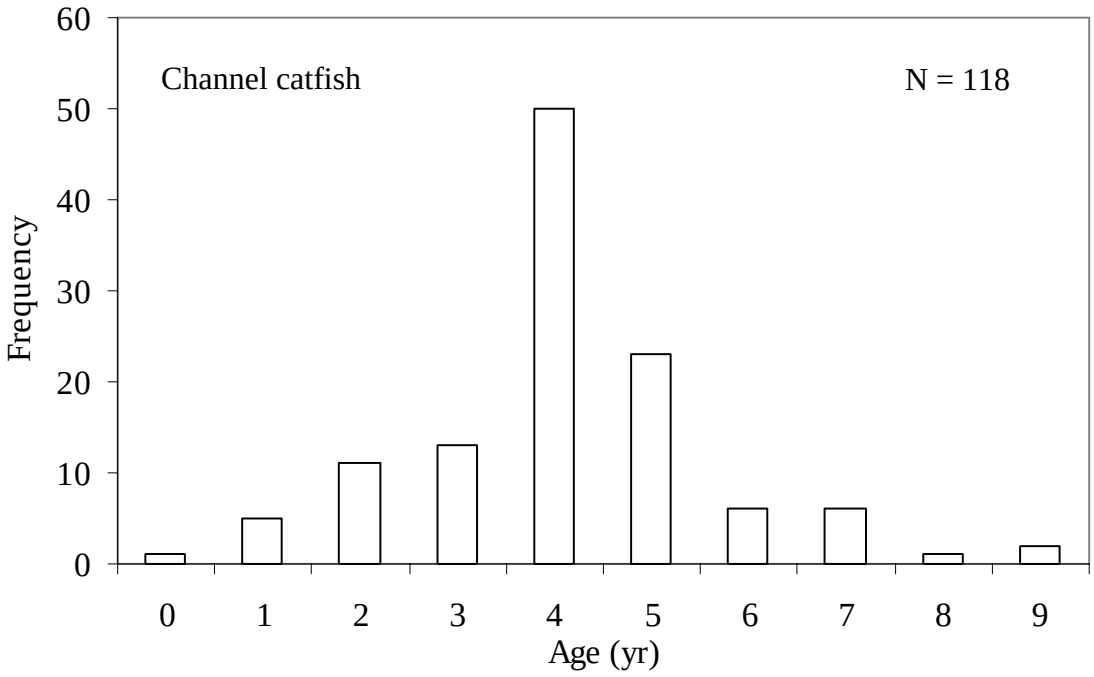
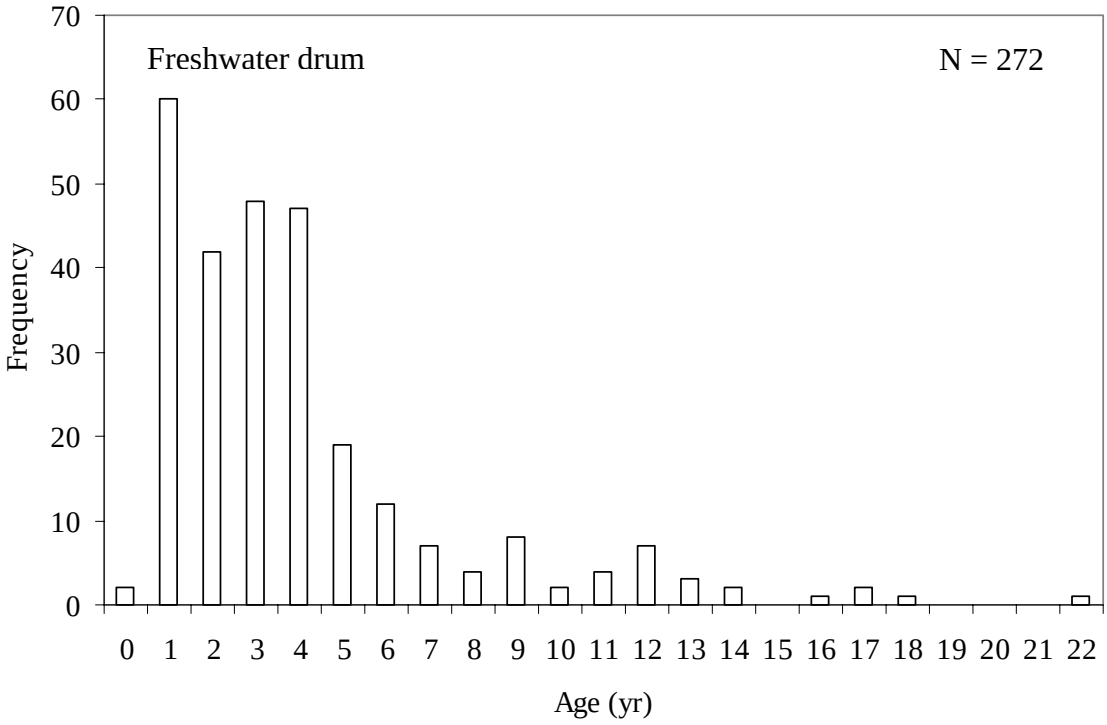
Figure 7. The age frequencies of channel catfish, freshwater drum, and white bass collected in the Belleville Pool, Ohio River during February 17 through April 7, 2002 and December 12, 2002 through March 17, 2003.




Freshwater drum
N = 272
Frequency
0
10
20
30
40
50
60
70
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Age (yr)

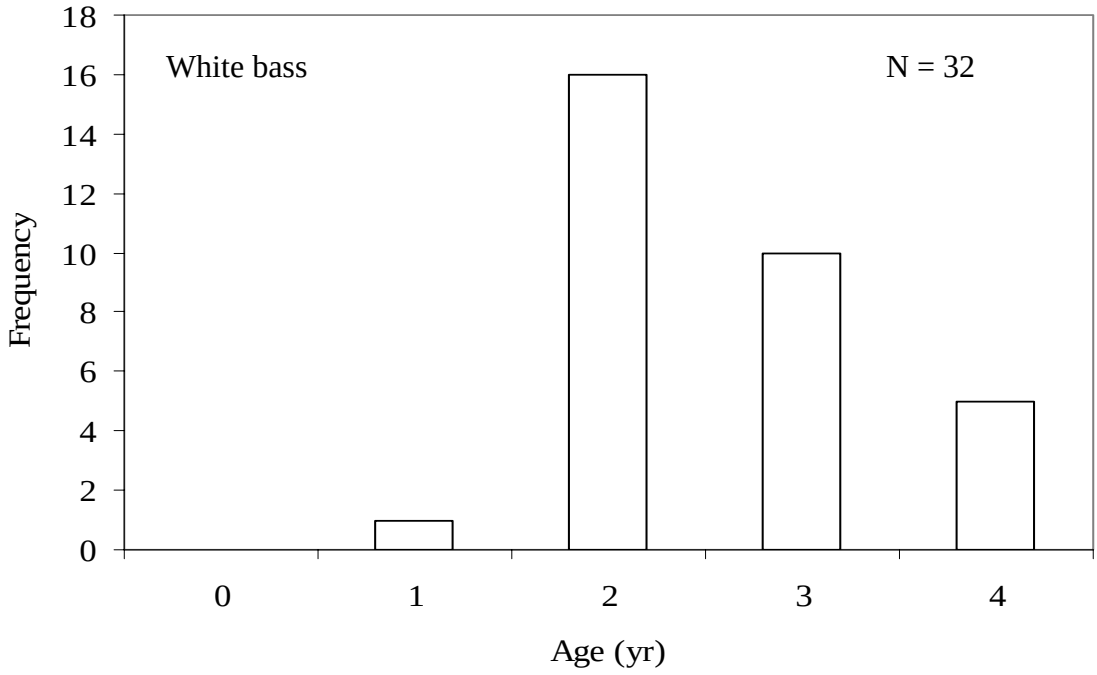
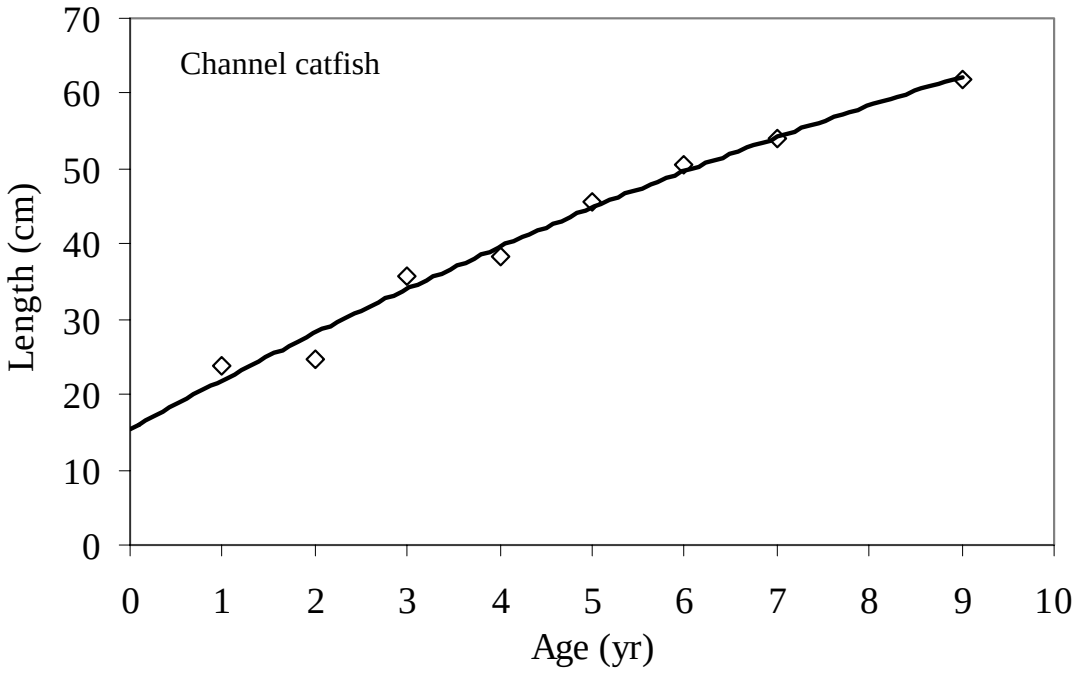
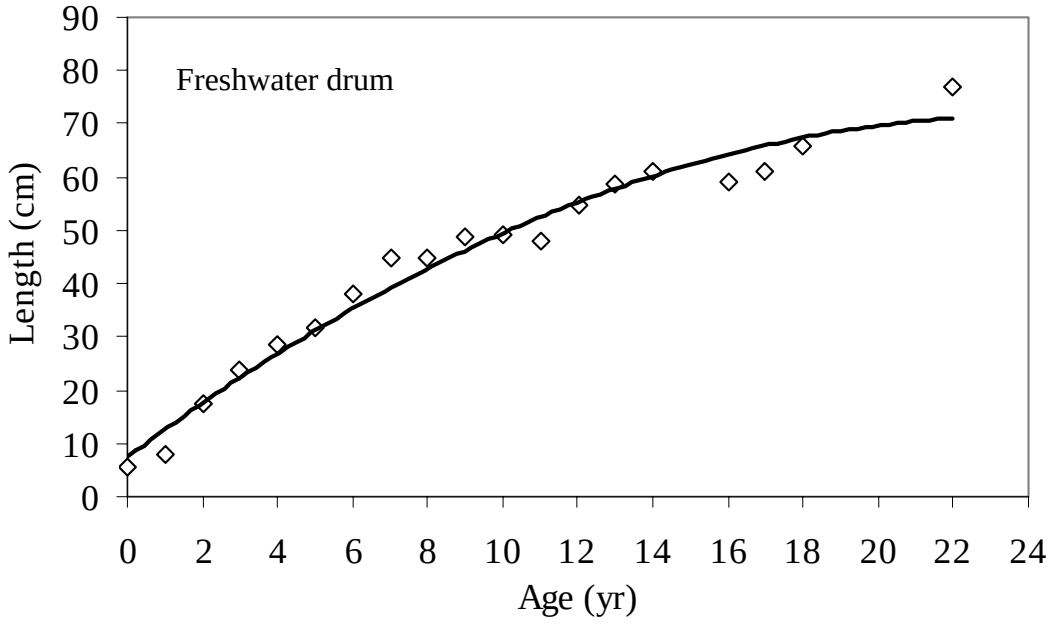

White bass
N = 32
Frequency
0
2
4
6
8
10
12
14
16
18
0 1 2 3 4
Age (yr)

Figure 8. The von Bertalanffy growth curves of channel catfish, freshwater drum, and white bass collected in the Belleville Pool, Ohio River.




Freshwater drum
Length (cm)
Age (yr)
0
10
20
30
40
50
60
70
80
90
0
2
4
6
8
10
12
14
16
18
20
22
24

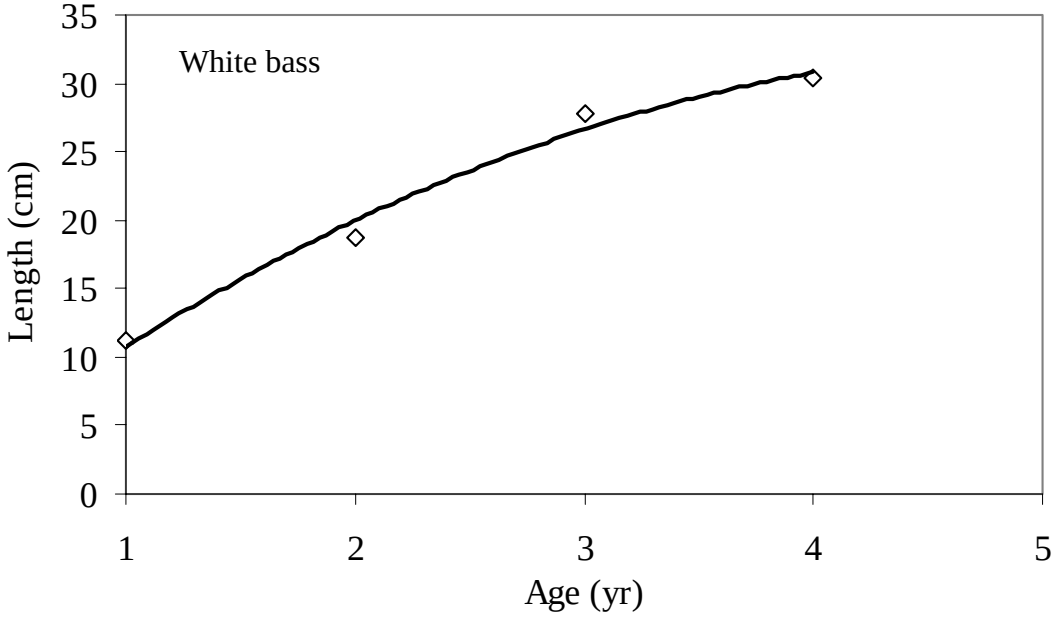
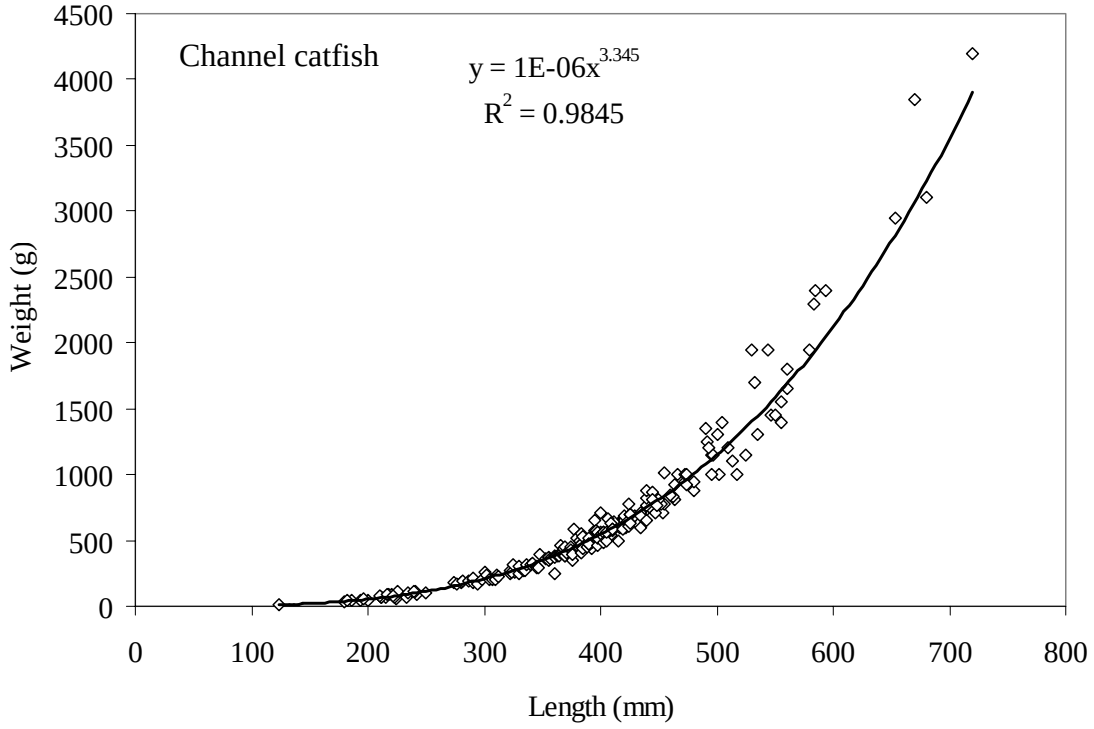
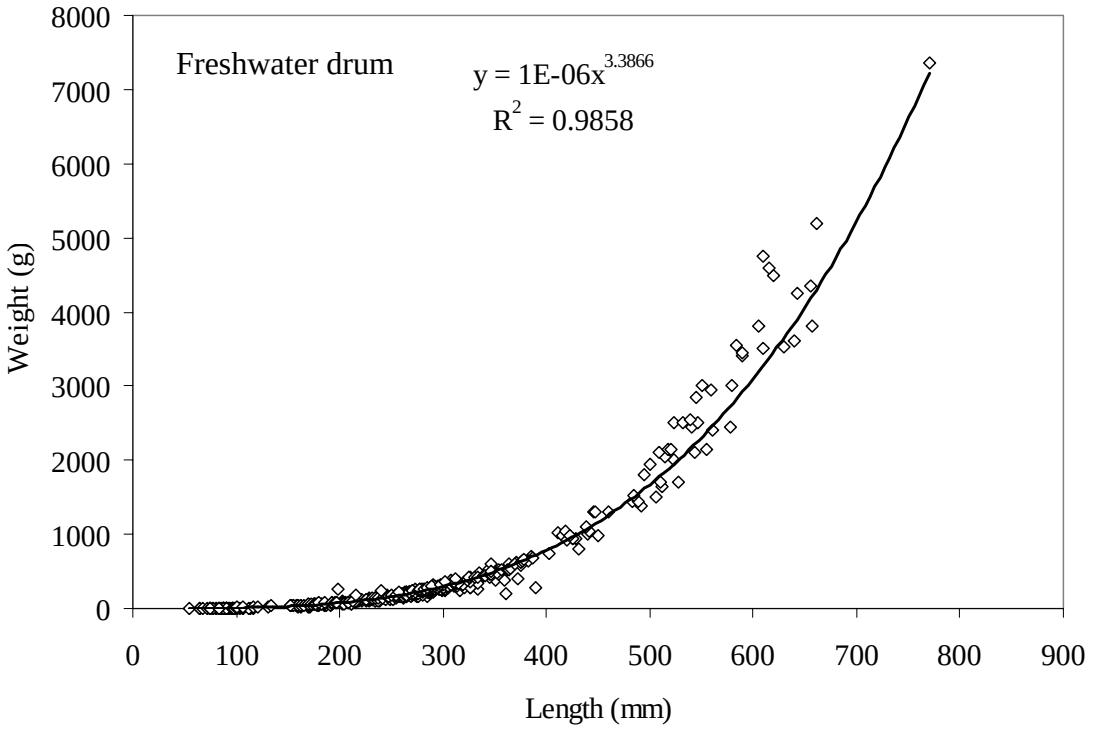

White bass
Length (cm)
Age (yr)
0
5
10
15
20
25
30
35
1
2
3
4
5

Figure 9. The allometric growth of channel catfish, freshwater drum, and white bass collected in the Belleville Pool, Ohio River.




Freshwater drum
y = 1E-06x^3.3866
R^2 = 0.9858
Weight (g)
Length (mm)
0
1000
2000
3000
4000
5000
6000
7000
8000
0
100
200
300
400
500
600
700
800
900

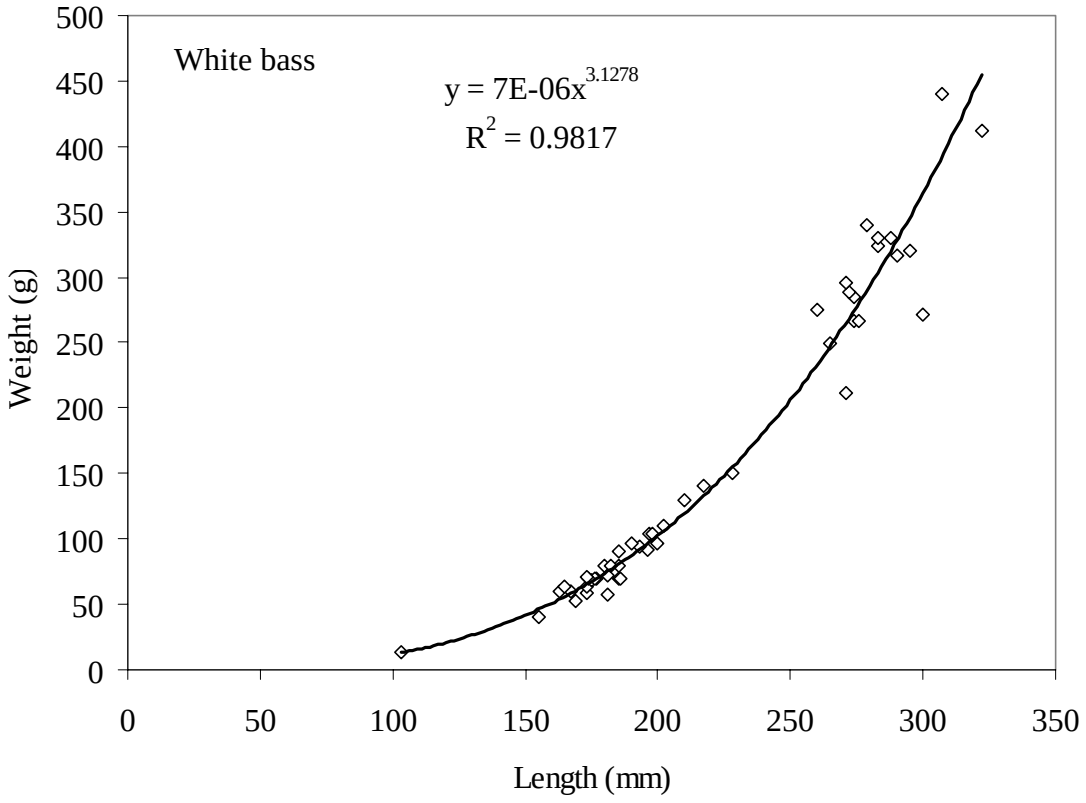

White bass
y = 7E-06x^3.1278
R^2 = 0.9817
Weight (g)
Length (mm)
0
50
100
150
200
250
300
350
400
450
500
0
50
100
150
200
250
300
350

Table 4. Mean length-at-age of channel catfish, freshwater drum, and white bass collected in the Belleville Pool, Ohio River during February 17 through April 7, 2002 and December 12, 2002 through March 17, 2003. Variances are in parentheses; no values indicate only one individual for that age group was collected.

	Mean length (cm)					
Age	Channel catfish		Freshwater drum		White bass	
0	23.8	(9.7)	5.5	(0.5)		
1	24.8	(39.7)	8.0	(1.6)	11.2	
2	35.6	(19.4)	17.3	(8.2)	18.8	(3.4)
3	38.4	(40.7)	23.8	(2.5)	27.8	(0.8)
4	45.6	(37.8)	28.6	(5.6)	30.4	(1.3)
5	50.5	(55.5)	31.6	(5.4)		
6	54.0	(53.2)	37.9	(8.1)		
7	56.8	(46.8)	45.0	(27.6)		
8	59.2		44.8	(63.6)		
9	62.0	(32.0)	48.7	(5.9)		
10			49.0	(32.0)		
11			48.0	(36.0)		
12			54.7	(21.2)		
13			58.7	(37.3)		
14			61.0	(8.0)		
16			59.0			
17			61.0	(18.0)		
18			66.0			
22			77.0			

SUMMARY

Winter is a critical period during which fishes suffer increased mortality. During winter conditions, fishes select refuge habitats where physiochemical factors are unlikely to exceed tolerance limits. In large temperate river systems, such as the Ohio River, extremely low water temperatures during winter coupled with high flows could be expected to increase mortality rates of fishes. Juvenile fishes are most susceptible to winter mortality due to their small size and lack of energy reserves. The greatest diversity and abundance of fishes were collected by electrofishing in the Belleville Pool, Ohio River, in low-velocity tributary confluences and an embayment at temperatures > 3 - 4 °C. When water temperatures were < 3 °C, more individuals of certain species were collected in faster-velocity main channel and back channel habitats. Other species collected at temperatures < 3 °C continued to associate with the lower flows in tributaries. The lack of water temperatures > 4 °C in tributaries may have left some fishes susceptible to current velocity, which carried them into channel habitats.

Species- and age-specific responses to winter conditions may obscure broad generalizations about when and how certain species use overwintering refuges. For example, in the Little Sandy Creek embayment, adjacent to the Belleville Pool, 85% of all fishes collected were juveniles. Centrarchids, popular sport fishes, while collected in low numbers in the mainstem portion of the river, were one of the dominant fishes collected in the embayment. Protecting and modifying embayment habitats may reduce juvenile mortality during winter and improve recreational angling opportunities for sunfish in large river systems

Populations of channel catfish, *Ictalurus punctatus*, and freshwater drum, *Aplodinotus grunniens*, the most abundant fishes collected in the Belleville Pool, exhibit satisfactory population growth and condition. Channel catfish reach larger mean-lengths at all ages compared to specimens collected over 30 years ago in the Belleville Pool. Numerous older and larger freshwater drum individuals were collected, suggesting plentiful trophy-sized individuals exist in the Ohio River. Conversely, none of the white bass, *Morone chrysops*, individuals collected were harvestable size. Fishery managers can use this information to assess the population growth and condition of these three species and make management decisions according to their goals for each species. Possibly, the population growth and the probability of survival of fishes of all ages may increase by protecting and enhancing tributary and embayment habitats in large rivers during winter.

APPENDIX A

Fish caught per hour (CPUE) within each habitat type in the Belleville Pool, Ohio River. No values indicate habitat not sampled.

February 2002 session

Species	Habitat types: Island Head	Island Tail	Back channel	Main channel	Trib	Deep hole	Total
Emerald Shiner			0		1.6	0	1.0
Freshwater Drum			0		6.5	0	4.2
Gizzard Shad			0		68.5	0	43.6
River Carpsucker			0		1.6	0	1.0
Total			0		78.3	0	49.8

March 2002 session

Species	Habitat types: Island Head	Island Tail	Back channel	Main channel	Trib	Deep hole	Total
Channel Catfish	4.4	0	3.2	1.1	65.4	0	11.1
Common Carp	0	0	0	0	3.9	0	0.6
Emerald Shiner	0	0	0	0	2.9	0	0.4
Freshwater Drum	0	0	0.8	2.8	129.8	0	20.8
Gizzard Shad	0	0	0	0	12.7	0	1.9
Hybrid Striped Bass	0	0	0	0	3.9	0	0.6
Mooneye	0	3.0	0	0	2.0	0	0.7
Quillback	0	0	0	0	2.0	0	0.3
River Carpsucker	0	0	0	0	3.9	0	0.6
Walleye	0	0	0	0	2.0	0	0.3
Total	4.4	3.0	4.0	3.9	228.3	0	37.3

Early April 2002 session

Species	Habitat types: Island Head	Island Tail	Back channel	Main channel	Trib	Deep hole	Total
Channel Catfish	0	1.7	5.6	2.9	0	0	2.9
Emerald Shiner	0	0	0	0	1.5	0	0.1
Flathead Catfish	0	0	0	0.3	0	0	0.1
Freshwater Drum	0	0	0.6	0.3	21.4	0	2.2
Gizzard Shad	0	0	0	0	3.1	0	0.3
Highfin Carpsucker	0	0	0	0	3.1	0	0.3
Mooneye	0	0	0.6	0	0	0	0.1
River Carpsucker	0	0	0	0	6.1	0	0.6
Total	0	1.7	6.7	3.5	35.2	0	6.7

Mid-April 2002 Session

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	channel	channel	Trib	hole	Total
Bluegill	0	0	0	0	1.7	0	0.2
Channel Catfish	7.1	1.8	2.1	2.2	13.1	0	3.6
Emerald Shiner	0	0	0	0	4.9	0	0.5
Freshwater Drum	5.3	3.5	1.4	0.4	14.8	0	2.8
Gizzard Shad	0	0	0	0.4	0	0	0.2
Mooneye	0	0	0	0.4	0	0	0.2
Orangespotted Sunfish	0	0	0	0	1.6	0	0.2
River Carpsucker	0	0	0	0	9.8	0	1.0
Total	12.4	5.3	3.5	3.3	46.0	0	8.5

February - April 2002 sessions total

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	channel	channel	Trib	hole	Total
Bluegill	0	0	0	0	0.3	0	0.1
Channel catfish	4.1	1.9	3.8	2.1	25.8	0	5.8
Common carp	0	0	0	0	1.4	0	0.2
Emerald shiner	0	0	0	0	2.8	0	0.4
Flathead catfish	0	0	0	0.1	0	0	0.1
Freshwater drum	2.0	0.9	0.9	1.1	55.1	0	8.6
Gizzard shad	0	0	0	0.1	19.6	0	2.8
Highfin carpsucker	0	0	0	0	0.7	0	0.1
Hybrid striped bass	0	0	0	0	1.4	0	0.2
Mooneye	0	1.4	0.2	0.1	0.7	0	0.3
Orangespotted Sunfish	0	0	0	0	0.3	0	0.1
Quillback	0	0	0	0	0.7	0	0.1
River carpsucker	0	0	0	0	5.2	0	0.7
Walleye	0	0	0	0	1.0	0	0.1
Total	6.1	4.2	4.9	3.6	114.7	0	19.6

December 2002 session

	Habitat types							
	Island		Back	Main		Deep	Embay-	
Species	Head	Tail	channel	channel	Trib	hole	ment	Total
Black Crappie	0	0	0	0	0	0	1.8	0.1
Bluegill	0	0	0	0	0	0	198.3	13.1
Channel Catfish	0	0	2.6	7.0	0	2.7	0	3.2
Common Carp	0	0	0.4	0	0	0	0	0.1
Emerald Shiner	0	0	0	0	0	0	210.5	13.9
Freshwater Drum	0	1.0	5.6	10.4	0	8.2	7.0	6.1
Gizzard Shad	0	0	0	0.4	0	0	708.8	46.9
Green Sunfish	0	0	0	0	0	0	5.3	0.4
Mooneye	0	1.9	1.5	0	0	0	0	0.7
Mosquitofish	0	0	0	0	0	0	1.8	0.1
Ohio Lamprey	0	0	0.4	0	0	0	0	0.1
Orangespotted Sunfish	0	0	0	0	0	0	61.4	4.1
River Carpsucker	0	0	0	0.4	0	0	0	0.1
Sauger	0	1.0	0	0	0	0	0	0.1
Silver Chub	0	6.7	0.4	1.7	0	0	0	1.2
Smallmouth Buffalo	0	1.0	0.7	0.4	0	0	0	0.5
Spotted Bass	0	0	0	0	0	5.5	0	0.2
Spotted Sucker	0	0	0	0	0	0	1.8	0.1
Warmouth	0	0	0	0	0	0	3.5	0.2
White Bass	0	0	0.4	0	0	0	0	0.1
White Crappie	0	0	0	0	0	0	57.9	3.7
Total	0	11.4	11.9	20.2	0	16.4	1257.9	95.0

January 2003 session

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	channel	channel	Trib	hole	Total
Black Buffalo	0	0	0	0	0	0	0.1
Black Crappie	0	0	0	0	0.9	0	0.1
Channel Catfish	0	0	1.1	1.3	6.4	0	1.6
Common Carp	0	1.4	0.7	0	1.8	0	0.7
Emerald Shiner	0	0	0	0	0	0	0.2
Freshwater Drum	0	0	1.8	3.0	50.9	0	8.7
Gizzard Shad	0	0	0.4	0	0.9	0	0.3
Golden Redhorse	0	0	0	0	0.9	0	0.1
Highfin Carpsucker	0	0	0	0	1.8	0	0.2
Hybrid Striped Bass	0	0	0	0	3.0	0	0.3
Mooneye	0	0	0	0.7	0	0	0.2
Quillback	0	0	0	0	0.9	0	0.1
River Carpsucker	0	0	0	0	3.6	0	0.6
Rock Bass	0	0	0.4	0	0	0	0.1
Sauger	0	0	0	0	0.9	0	0.1
Shorthead Redhorse	0	0	0	0.3	0	0	0.2
Silver Chub	0	0	0.4	0	0	0	0.1
Smallmouth Buffalo	0	0	1.4	1.0	24.5	0	5.2
White Bass	0	0	0	0.3	30.9	0	4.1
Total	0	1.4	6.0	6.7	127.3	0	23.1

March 2003 session

	Habitat types							
	Island		Back	Main		Deep	Embay-	
Species	Head	Tail	channel	channel	Trib	hole	ment	Total
Black Crappie	0	0	0	0	0	0	1.1	0.1
Bluegill	0	0	0	0	0	0	56.9	5.5
Bowfin	0	0	0	0	0	0	1.1	0.1
Channel Catfish	0	0	6.7	4.5	4.5	0	0.0	3.9
Common Carp	0	0	0	0.6	0	0	3.4	0.5
Emerald Shiner	0	0	0	0	0	0	19.0	1.8
Freshwater Drum	0	0	0.8	34.1	40.3	0	2.2	17.6
Gizzard Shad	0	0	0.4	3.5	1.5	0	29.0	4.3
Green Sunfish	0	0	0	0	0	0	4.5	0.4
Hybrid Striped Bass	0	0	0	1.9	5.2	0	0	1.4
Largemouth Bass	0	0	0	0	0	0	3.4	0.3
Mooneye	0	0	0.8	0.3	0	0	0	0.3
Orangespotted Sunfish	0	0	0	0	0	0	15.6	1.5
Pumpkinseed	0	0	0	0	0	0	5.6	0.5
Quillback	0	0	0	0	0.8	0	0	0.1
River Carpsucker	0	0	0.8	0.3	1.5	0	4.5	1.0
Sauger	0	0	0	0	0.8	0	0	0.1
Silver Chub	0	0	0.4	0.3	0	0	0	0.2
Smallmouth Buffalo	0	1.5	1.7	2.3	2.2	0	1.1	1.7
Spotted Sucker	0	0	0	0	0	0	1.1	0.1
Walleye	0	0	0	0	0.8	0	0	0.1
Warmouth	0	0	0	0	0	0	3.4	0.3
White Bass	1.6	0	0.8	1.0	2.2	0	0	1.0
White Crappie	0	0	0	0.3	0	0	41.3	4.1
Total	1.6	1.5	12.6	49.2	59.6	0	193.1	46.9

December 2002-March 2003 sessions total

	Habitat types								
	Island		Back	Main		Deep	Wing	Embay-	
Species	Head	Tail	channel	channel	Trib	hole	dam	ment	Total
Black Buffalo	0	0	0	0	0	0	7.5	0	0.04
Black Crappie	0	0	0	0	0.3	0	0	1.4	0.1
Bluegill	0	0	0	0	0	0	0	111.9	6.1
Bowfin	0	0	0	0	0	0	0	0.7	0.04
Channel Catfish	0	0	3.3	4.8	4.1	0.9	0	0	3.1
Common Carp	0	0.5	0.4	0.2	0.6	0	7.5	2.1	0.5
Emerald Shiner	0	0	0	0	0	0	15.0	93.5	5.2
Freshwater Drum	0	0.5	2.8	16.3	34.8	2.6	52.6	4.1	11.0
Gizzard Shad	0	0	0.3	1.3	1.0	0	7.5	293.3	16.7
Golden Redhorse	0	0	0	0	0.3	0	0	0	0.04
Green Sunfish	0	0	0	0	0	0	0	4.8	0.3
Highfin Carpsucker	0	0	0	0	0.6	0	0	0	0.1
Hybrid Striped Bass	0	0	0	0.7	3.2	0	0	0	0.6
Largemouth Bass	0	0	0	0.1	0	0	0	2.1	0.2
Mooneye	0	0.9	0.8	0.3	0	0	0	0	0.4
Mosquitofish	0	0	0	0	0	0	0	0.7	0.04
Ohio Lamprey	0	0	0.1	0	0	0	0	0	0.04
Orangespotted Sunfish	0	0	0	0	0	0	0	33.4	1.8
Pumpkinseed	0	0	0	0	0	0	0	3.4	0.2
Quillback	0	0	0	0	0.6	0	0	0	0.1
River Carpsucker	0	0	0.3	0.2	1.9	0	7.5	2.7	0.6
Rock Bass	0	0	0.1	0	0	0	0	0	0.04
Sauger	0	0.5	0	0	0.6	0	0	0	0.1
Shorthead Redhorse	0	0	0	0.1	0	0	7.5	0	0.1
Silver Chub	0	1.8	0.5	0.7	0	0	0	0	0.5
Smallmouth Buffalo	0	0.9	1.3	1.3	9.5	0	90.2	0.7	2.5
Spotted Bass	0	0	0	0	0	1.7	0	0	0.1
Spotted Sucker	0	0	0	0	0	0	0	1.4	0.1
Walleye	0	0	0	0	0.3	0	0	0	0.04
Warmouth	0	0	0	0	0	0	0	3.4	0.2
White Bass	0.5	0	0.4	0.4	11.7	0	7.5	0	1.7
White Crappie	0	0	0	0.1	0	0	0	47.8	2.6
Total	0.5	5.0	10.1	26.6	69.6	5.2	203.0	607.1	54.9

VITA

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PRESENTATIONS

Lenz, B., S. Welsh, K. Hartman. Winter habitats of fishes in the Ohio River. Presented at the American Fisheries Society annual meeting, Quebec City, Canada, 12 August 2003.

Lenz, B., S. Welsh, K. Hartman. Winter habitats of fishes in the Belleville Pool, Ohio River. Presented at the West Virginia Cooperative Fish and Wildlife Unit annual meeting, Morgantown, WV, 24 April 2003.

Lenz, B., S. Welsh, K. Hartman. Winter habitats of channel catfish and freshwater drum in the Belleville Pool, Ohio River. Presented at the Wildlife Society annual meeting, Morgantown, WV, 6 March 2003.

Lenz, B., S. Welsh, K. Hartman. Winter habitats of channel catfish and freshwater drum in the Belleville Pool, Ohio River. Presented at the Tri-State (Kentucky, Virginia and West Virginia) annual meeting, Ashland, KY, 5 March 2003.

Lenz, B., S. Welsh, K. Hartman. Winter habitats of channel catfish and freshwater drum in the Belleville Pool, Ohio River. Presented at the Southern Division of the American Fisheries Society annual meeting, Wilmington, NC, 16 February 2003.

FIELDS OF STUDY

Major Field: Zoology

Specialization: Aquatic Ecology

Final Report

Ohio River Mainstem System Study

(ORMSS)

Fish Passage Issues Associated with Ohio River High-Lift Dams

Submitted To:

U.S. Army Corps of Engineers
Huntington District
Huntington, West Virginia

Submitted By:

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April 2004

Study Abstract

The Ohio River and its major tributaries have played a key role in the development of North America by European settlers. From its origins in the northern Appalachian Mountains to its confluence with the Mississippi River, the river has and continues to provide both habitat for diverse aquatic life, as well as resources for the human inhabitants. Since its initial canalization in the early 1880s to the completion of high-lift locks and dam complexes in the late 1990s, the river has been altered from a dynamic lotic ecosystem to more controlled series of navigational pools. Recently, all river users associated with both environmental and navigational issues have expressed concern over the river's condition.

To address these diverse issues, the Ohio River Mainstem System Study (ORMSS) was proposed with an overall goal to determine the optimum investment strategy for major navigation improvements along the entire length of the Ohio River. Since its inception, the ORMSS has evolved to address both economic and environmental concerns associated with navigation and improvements. The findings reported herein are concerned with these environmental issues associated with fish passage.

Several collaborative studies were conducted over a three-year period to determine the influence of high-lift dams on fish passage.

Major findings were:

a. Migratory fish species do congregate seasonally downstream of locks and dam complexes,
b. If river conditions are suitable, Ohio River fish do move through locks and dam complexes,
c. Distinct sub-populations exist between both downstream and upstream reaches, and
d. Minimal interactions between upper and lower river fish occur.

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Chapter 1

Ohio River Mainstem System Study (ORMSS)

Project Overview and Synthesis of Results

Introduction

The Ohio River is one of the great rivers of North America. From its origins in the northern Appalachian Mountains of New York, Pennsylvania, and West Virginia to its confluence with the Mississippi River, the Ohio River provides a diverse ecosystem for both humans and aquatic life. Native Americans utilized the Ohio River for transportation via bark and dugout canoes, as well as sources of fish and game for food. Europeans first visited the Ohio in the 1540s with the overland expedition by DeSoto from Florida through the Tennessee and Cumberland rivers sub-basins and into the lower Ohio River system. In the late 1600s, notable explorers such as LaSalle and Arnout Viele descended the Ohio River via its major tributary, the Allegheny River. Abraham Wood between 1654 and 1664 explored the north-flowing major tributaries such as the New and Kanawha rivers. With the initiation of conflicts between Great Britain and France over North American superiority, the Ohio River became a key area of contention. French forts at current day Pittsburgh near the confluence of the Allegheny and Monongahela rivers were seen by the British as an encroachment to their sovereignty resulting in a force lead by Major George Washington of Virginia to attack French installations. This battle won by the French precipitated the French and Indian War leading to the temporary dominance of North America by the British.

The Ohio River also played a key role during the American Revolution. General George Rogers Clark successfully directed a force into the lower Ohio River sub-basin that lead to the American claims of ownership of the Northwest Terrorist. Following the American Revolutionary War, thousand of settlers floated down the Ohio River from Pittsburgh and Wheeling, as well as Oleans on the Allegheny River and Kelly's Station on the Kanawha River. River cities like Marietta, Cincinnati, and Louisville soon were formed leading to the admission of Kentucky (1792) and Ohio (1803) into Union. In 1803, Meriwether Lewis and William Clark set out from present day Pittsburgh and floated down the Ohio River to Camp Wood at the mouth of the Missouri River to set our on their historic Corps of Discovery.

The influx of settlers into the Ohio River basin resulted in this region becoming a dominant center for industry and enterprise. Boat building, and mining for coal and iron ore provided an infant steel and iron industry to flourish. Glassmaking also become established by the start of the 1800s. With this expanding industrial economy, the need for transportation was evident. Early river transportation was primarily through the use of flatboats, keelboats, and barges that moved cargo downstream. Keelboats also provided regular passenger service between Louisville, Cincinnati, and Pittsburgh. In 1811, the first steamboat, the *New Orleans*, was first to navigate the Ohio River marking the inception of modern day travel. Steamboats were the primary mode of river-based transportation of both cargo and passengers until the advent of diesel powered towboats.

The emergence of the Ohio River as a vital route of commerce resulted in the need for navigational-associated improvements. In a retrospective description of the Ohio River by the Chief of Engineers in 1934, the system was considered obstructed

throughout its entire length by snags, rocks, and gravel and sand bars. Channel width and depth was variable with depths at a minimum of 1-foot over shallow shoals. This resulted in the impedance of commercial navigation. Flooding also was considered a hazard to commercial navigation. In 1824 with the passage of the Inland Waterways Improvement Act, the U.S. Army Corps of Engineers (USACOE) was directed to determine the best method with coping with sandbars and snags. Soon after, the USACOE initiated a process to tame the river that continues to the present day.

Early attempts to improve navigation were concentrated on the removal of snags and other obstructions, as well as the use of cutoff dams to concentrate flow in the main channel. Construction of the first cutoff dam began in 1825, and the first removal of rocks was begun in 1830. These activities continued until the 1870s when activities were initiated to build lock and dam complexes. In 1875, it was recommended that 13 locks and removable dams be constructed on the Ohio River between Pittsburgh and Wheeling. The first of these complexes was the Davis Island Dam near Pittsburgh that was completed in 1885. The construction of 51 removable dams and associated locks resulting in the canalization of the Ohio River was completed with four complexes by 1929 in the lower reaches of the river. These dams provided commercial navigation a continuous 9-foot channel along the 981-mile length of the Ohio River.

The replacement of these removable dams with fixed high-lift structures was initiated in 1932 with the construction of the Montgomery Locks and Dam complex downstream of Pittsburgh. These high-lift structures included a dam across the entire river with vertical-lift gated spillways, and a main and auxiliary lock chamber. A navigation pool upstream of the locks and dam complex resulted in the alteration of the

Ohio River from a lotic to lenthic system. Only those reaches just downstream of these high-lift dams remained in a lotic state.

Since 1932, 17 additional high-lift locks and dam complexes have been constructed replacing 49 of the 51 removable dams. Two removable dams are still in operation in the lower reach of the system. Consequently, the 981-mile long Ohio River is primarily a series of navigation pools with free-flowing tailwaters downstream for a few miles of these high-lift dams. Most large tributaries have been changed with the construction of flood control dams and/or navigational locks and dams further altering the hydrology of this 204,000 square-mile basin. This has resulted in a very different Ohio River basin as what was first discovered by early European explorers.

The advent of modern navigation on the Ohio River presents many potential influences on aquatic life. Modern towboat propellers cause immediate alterations in hydraulic patterns and increased turbulence as they pass through the water column (Maynord 1990). Cada (1990) reported that fish eggs and larvae experience stress after passage through water currents induced by propellers. Fish at early life stages are more susceptible to propeller impacts because of their delicate condition and lack of avoidance mechanism (Pearson et al. 1989). Elevated mortality of eggs and larvae may result in decreased adult recruitment especially for pelagic species inhabiting main channel reaches (Holland and Sylvester 1983). Mortality of ichthyoplankton related to propeller type turbine passage has been reported as low as 5 percent (Cada 1990). Minimal mortality also has been reported in control studies investigating pressure changes and rapid acceleration (Payne et al. 1990). Sheer forces along a barge hull have been reported sufficient to kill larval fishes (Morgan et al. 1976) and sheer forces associated with

propellers are substantially greater than that associated with barge hulls. Kilgore et al. (2001) did report larval fish mortality approaching 75% associated with propeller based sheer forces for several Mississippi River species.

Another aspect is the passage of migratory fish species through locks and dam complexes. With the construction and operation of the 18 high-lift structures and the proposed replacement of the last two removable dams with a high-lift structure, concern was expressed as to the impact of these structures on fish passage within the Ohio River sub-basin. Truly great river species such as paddlefish and shovelnose sturgeon inhabit the Ohio River main channel as well as species such as sauger, walleye, white bass, and several species of clupeids that exhibit migratory behavior (Etnier and Starnes 1993). In addition, several unionid species depend on species of migratory fish species to serve as host in the reproduction process. Consequently, fish passage through large navigational lock and dam complexes was proposed as a concern within the Ohio River sub-basin (USACOE 2000). A major direction of the study described herein was related with fish passage issues.

Lotic reaches downstream of high-lift dams are the last vestiges of the once free following Ohio River. At most high-lift dams, tailwaters exist downstream for a 2-5 mile reach providing both aquatic biota and humans a fairly unique lotic environment. These tailwaters are often used by fish as spawning areas and many species congregate in these tailwaters during the late winter and spring. Unionid species also are more abundant in these tailwaters resulting in the potential for host relationships with fish species. Lastly, anglers seek many migratory fish species in the winter and spring, as well as catfish species in the summer in these oxygen-rich reaches.

USACOE (2000) outlined needs and goals of the Ohio River Mainstem System Study (ORMSS). Initially, the ORMSS was an overall system study to determine the optimum investment strategy for major navigation improvements along the entire length of the Ohio River. Since its inception, the ORMSS has evolved to address both economic and environmental concerns associated with navigation and improvements. This study is part of the ORMSS process in addressing recreational use by anglers of tailwater reaches and fish passage issues. A complimentary study was conducted addressing winter habitat use by fish in two Ohio River navigational pools.

***The goals of this study were*:**

1. To assess recreational angling activities at high-use tailwater reaches created by these locks and dam complexes,
2. To determine host relationships between unionids and fish species, and
3. To provide insight into fish passage concerns of selected species.

More detailed discussions of each component are provided in associated chapters. This project overview was designed to provide a synopsis of the study components.

Recreational Angling Use:

Ohio River angling opportunities are diverse both in species sought and habitat available. Major recreational fisheries exist for sauger, walleye, white bass, hybrid striped bass, as well as the catfishes and the black basses. Open river sections, embayments and backwaters, as well as tailwaters provide habitat for both anglers and fishes. Schell et al. (1996) reported that tailwaters comprise only 1% of available angling habitat in the Ohio River, but generated more than 66% of the total catch.

To assess angling-based recreation, surveys were conducted at eight tailwaters for a minimum of 12 months. A modified bus-stop method was employed at most tailwaters

were more than one access site was present (Jones and Robson 1991). Surveys were conducted either on foot at access sites or via boat where access was limited. Boat surveys were conducted primarily at the J.T. Myers and New Cumberland tailwaters. Surveys were conducted three days per week (1 weekend period and 2 weekday periods) to determine angler directed effort, catch, harvest, and effort. The ORFMT state agencies developed survey forms that were consistent with past investigations (Schell et al. 1996; Pierce et al. 1983). Count times were randomly assigned at four 15-minute intervals per day. These data were used to estimate total angling effort in hours.

Data were recorded on paper copy, entered using a standard data entry format, and subjected to a QA/QC procedure. Once approved, data were analyzed by the Ohio Division of Wildlife Inland Fisheries Research Group using a SAS-based analytical package with the methods described in Pollock et el. (1994). Results were reported as catch rate (no./hr), effort (hours), and directed effort (%), and length of harvested individuals (mm; total length except for paddlefish which was recorded as eye-fork length).

Interviews were conducted on over 8,500 angler-trips at the eight tailwaters. Anglers resided primarily within the bordering states adjacent to the tailwaters. The predominance of resident anglers usually was a function of better access in these tailwaters.

Directed effort groups were dominated by any species (33%) and percids (24%) river-wide. Catfish (17%), *Morone* species (16%), paddlefish (10%), and black bass (1%) were represented. The any species group and percid group dominated most upstream tailwaters, and catfish were of greater importance in downstream tailwaters. Paddlefish

were of greatest importance at the Markland tailwater with 43% of the effort being expended on this group. The Greenup tailwater fishery was dominated by *Morone*-seeking anglers (44%).

Angling effort peaked in the June-August period (catfish-associated angling) for all tailwaters. A second peak was evident in the late-fall and was most likely associated with the percid and *Morone* fishery. Tailwaters comparisons were made only for the February 2002 through September 2002 period. The McAlpine and Willow Island tailwaters had the greatest angling effort during this period with hours of 19,969 and 15,917 respectively. Angling hours also exceeded 10,000 for the Greenup, Markland, J.T. Myers, and R.C. Byrd tailwaters. Proximity to more urban areas and improved availability of access may have be a factor in increased effort.

Catch rates by directed species group were determined for sauger, all percids (sauger, saugeye, walleye), hybrid striped bass, white bass, and channel catfish by tailwaters. Sauger catch rates ranged from 1.86/hr for the Pike Island tailwater to 0.22/hr for the Markland tailwater. Total percid catch rates ranged from 1.89/hr for the Pike Island tailwater to 0.22/hr for the Markland tailwater. In the Markland, McAlpine, and J.T. Myers tailwaters, the percid fishery was dominated (>98%) by sauger. Hybrid striped bass catch rates were greatest at the Greenup tailwater (1.64/hr) and least at the R.C. Byrd tailwater (0.19/hr). White bass catch rates were dissimilar with catch rates exceeding 0.75/hr at the Pike Island tailwater (1.28/hr), R.C. Byrd tailwater (0.88/hr), and Willow Island tailwater (0.79/hr). Channel catfish catch rates were greatest at the J.T. Myers tailwater (0.68/hr) and lowest at the Willow Island tailwater (0.04/hr). Paddlefish were only caught at the J.T. Myers and Markland tailwaters in adequate numbers to determine

catch rates. Paddlefish catch rate at the Markland tailwater was 0.20 and 0.19/hr. at the J.T. Myers tailwater. Harvest of paddlefish is prohibited from reaches of the Ohio River bordering the states of West Virginia and Ohio.

Sauger, hybrid striped bass, and white bass were the dominant species caught with over 20,000 caught river-wide. An estimated 2,064 paddlefish were caught at all Ohio River tailwaters of which 92% of the paddlefish caught were harvested. The majority of paddlefish were caught at the Markland tailwater (867-99% harvested) and J.T. Myers tailwater (967-99% harvested). Percent harvested ranged from 92% for paddlefish to 3% for hybrid striped bass. River-wide 34% of sauger, 13% of white bass, 31% of channel catfish and 77% of blue catfish were harvested.

Ohio River tailwater-anglers sought primarily those species related to tailwater habitats. Geographic differences of directed effort were evident with the upstream tailwater fisheries dominated by any species and percid groups, the Greenup tailwater by the *Morone* sp. group, and the J.T. Myers tailwater dominated by catfish group. Interest in these fisheries may be a factor of culture, abundance of a given fish species, and the presence or perception of a consumption advisory or health risk. Catfish angling is of greater importance in mid-west and southern states (USFWS 2003, Burlingame and Guy 1999, TVA 1998). Both blue and channel catfish are present in downstream Ohio River tailwaters, and are often extremely abundant. Consumption advisories have and continue to be present in the upper Ohio River (WVDNR 2004). The importance of percids and *Morone* species in upstream tailwaters is partially the result of the abundance of these species, the hydrologic conditions at locks and dam complexes that congregate these species, and the overall cultural importance of angling and the seasonal trends of these

fisheries. Paddlefish were only sought at the J.T. Myers and Markland tailwaters. Directed paddlefish angling is prohibited in the Ohio-West Virginia reach of the Ohio River (WVDNR 2004). The Markland tailwater historically has been popular for paddlefish angling, and hydrologic conditions at this locks and dam complex congregate this species (Henley et al. 2002).

Channel catfish catch rates were greatest at the J.T. Myers tailwater (0.68/hr) and lowest at the Willow Island tailwater (0.04/hr). Catch rates reported from the Missouri River (0.13.hr) and the Tennessee River-Watts Bar tailwater 0.02/hr) were within this range (Stanovick 1999; TVA 1998). Ohio River tailwater catch rates exceeded that found from the Tennessee River-Watts Bar tailwater for all major sport fish species.

Percent of fish harvested was lowest in upstream Ohio River tailwaters. Sauger, walleye, largemouth bass, white bass, hybrid striped bass, catfish species, freshwater drum, and common carp all have consumption advisories in the West Virginia-Ohio reach of the Ohio River (WVDNR 2004).

Present study angling effort was greatly reduced as compared to previous surveys Pierce et al. (1983), Schell et al. (1996), and ORFMT (2001). A reduction of over 50% was estimated for the New Cumberland, Pike Island, Willow Island, Greenup, and Markland tailwaters, as well as 90% at the Greenup tailwater. Water levels were considerably higher in 2002 than 2000 resulting in loss of angling days. Homeland security issues following the September 11, 2001 events resulted in the temporary closure of several access points at Ohio River locks and dam complexes. In addition, a popular access area in the Greenup tailwater was closed from September 2001 through May 2002.

Access appeared to be one factor contributing to angler use and angler residence. Better access is afforded on the Ohio bank at the Pike Island and New Cumberland tailwaters, resulting in a greater percentage of Ohio residing anglers. In contrast, angler access is easier on the West Virginia bank at the Willow Island tailwater, consequently a higher percent of West Virginia anglers fished this tailwater. At tailwaters where easy access is on both banks, angler use by residence was similar. Tailwaters with better or more reliable access were used to a greater degree by anglers than those tailwaters with poor access.

Recreational angling in the Ohio River is of great importance. Over 5.5 million anglers within the six Ohio River bordering states fished in 2001 spending over $ 15.00 per trip (USFWS 2003). Tailwaters created by USACOE high-lift dams are of particular importance with over 65% of the angling effort being expended in these limited reaches Schell et al. (1996). Although several natural and stochastic factors may and will continue to influence angling effort and therefore economic impact of this important activity, increased and improved access to these reaches is one issue that can be addressed. Access by both boat and shore anglers will provide greater angling opportunities resulting in both citizen enjoyment and awareness of the Ohio River, as well as economic benefits to local communities.

Presence of Glochidial Infestation on Ohio River Fish Species:

Freshwater mussels exhibit a highly specialized life history. Modified larvae, glochidia, experience a period as an obligate parasite on the gills, fins, and potentially other external structures of fish. Released glochidia must encounter a suitable fish host, become encysted for a period of time while metamorphosing into juvenile mussels, and

finally release from the fish host. If suitable fish hosts are not encountered, glochidia will be rejected (Kat 1984). Knowledge of fish host and infestation rates is essential in the conservation of North American mussel fauna (Haag and Warren 1997).

The decline of the North American freshwater mussel fauna is well-documented (Williams et al. 1993). Dams, through altering flow regimes, have caused the extirpation of 30%-60% of the native mussel species in selected United States rivers (Williams et al. 1992). Competition from expanding non-endemic mollusks populations has also lead to the decline in native mussel fauna. These range extensions have often been linked to commercial navigation uses.

Concern for native freshwater mussel populations in the Ohio River sub-basin and the potential influence of commercial navigation and locks and dam complexes lead to the investigation of infestation of potential fish hosts, and the problems associated with fish passage.

Fish were collected from 10 different locations within the Ohio River. The J.T. Myers tailwater (ORM 850) represented the most downstream location and the most upstream location was the New Cumberland tailwater (ORM 55). Most collections were made in tailwater reaches because of the potential presence of freshwater mussels in these free-flowing sections, and the congregation of fish species just downstream of the locks and dam complexes. One collection in the Belleville Pool was at the vicinity at a known historic unionid bed.

Thirty-one fish species were collected representing a wide range of behavioral and habitat guilds. Common large river species included the gizzard shad, freshwater drum, redhorses, sauger, and white bass. Non-endemic species included the grass carp,

common carp, saugeye, and hybrid striped bass. Uncommon species included the blue sucker and goldeye. One-thousand and sixty-seven individuals were processed (identified, measured, and dissected). Of these, 536 were examined for the presence of glochidia. All samples taken in the winter and spring were examined, as were 64% of the summer samples, and 42% of the fall samples. Only gizzard shad (84 of 307, 27%) were examined at a less than the 40% criteria of common species.

Four fish (<1%) were found to be infested with glochidia. These included three individuals from the R.C. Byrd tailwater collection in June 2002 and one individual from the J.T. Myers tailwater collection in October 2002. Longnose gar, gizzard shad, and skipjack herring from the R.C. Byrd tailwater collection, as well as a spotted bass from the J.T. Myers tailwater were infested.

The low infestation rates were similar to those found in several river systems including the Green River, a major tributary to the Ohio River (Weiss and Layzer 1995). Glochidia were found in both the spring (June) and fall (October). Several investigators have reported the presence of glochidia infested on fish during all seasons, as well as the presence of glochidia in the water column (Jansen 1991, Weiss and Layzer 1995, Neeves and Widlak 1988). In addition, the fish species found to be infested in this study have been found to serve as hosts (Haag and Warren 1997). Longnose gar, gizzard shad, skipjack herring, and spotted bass also have been reported to serve as host for species of Ohio River mussels (OSU Division of Mollusks-Host Database).

The presence of glochidia in free ranging fishes is problematic because of the natural low rate of infestation. If fish passage issues do exist in relation to glochidia infestation and leading to the decline of unionid populations, it is suggested that a more

informative approach may be the modeling of potential fish hosts and their association with high-lift dams and passage mechanisms.

Fish Movement and Passage through High Lift Dams:

Fish passage issues related to locks and dam complexes are well documented for salmonid fish species (Bergkamp et al. 2000), but impacts to warmwater species are not as well documented. Pearson and Pearson (1989) stated that the elimination of Alabama shad in the Ohio River sub-basin was partially attributed to impaired movement due to high lift dams. Pallid and shovelnose sturgeon populations have been impacted in part by habitat alterations associated with navigation (Keenlyne 1987). Atlantic shad populations also have been adversely affected in rivers impaired by dams (Rulifson 1994), but attempts to pass this species via locking have been fairly successful (Bailey et al. 2004). Other studies suggest that passage may be related to retention time in the proximity to a passage facility (Barry and Kynard 1986), and/or the time spent in a tailwater reach (Pegg et al. 1997). Consequently, factors influencing the passage of most fish species are not well understood and potentially could be a factor in a species decline.

To better understand fish passage in the Ohio River, three complimentary studies were conducted. First, a tagging study of percids, white bass, and paddlefish was conducted throughout the sub-basin. Sauger, saugeye, walleye, and white bass were collected using pulsed DC boat-mounted electrofishing gear during the Fall 2001, as well as Winter, Spring, Fall 2002 and Winter 2003; and tagged with color-coded, uniquely numbered T-Bar anchor tags. Paddlefish were collected by ORFMT biologists and project staff, as well as commercial fishers using variable size (length x width) gill nets consisting of a single panel of 127mm square-bar mesh, as well as pulsed DC boat-

mounted electrofishing gear. Sampling was conducted during the Fall (2001 and 2002), Winter (2002 and 2003), and Spring (2002 and 2003). Paddlefish were checked for the presence of a coded-wire tag (CWT), jaw tag, or elastomer mark. Individuals were then measured (eye-fork length) and inserted with a metal jaw tags prior to release. Jaw tags were uniquely numbered and information concerning mailing address and rewards were present.

Anglers reported the capture of tagged percid and white bass via mail, telephone, or e-mail. Paddlefish tag returns were primarily acquired from commercial fishers, and rewards were provided by the Kentucky Department of Fish and Wildlife (KDFW). An additional effort to collect paddlefish information was conducted through a creel survey conducted by the KDFW in the lower open section of the river, as well as in the lower Tennessee River downstream of Kentucky dam. Project creel surveys also collected tags form all species.

Movement was ascertained for all recaptured fish if information was available. Movement was determined by location (i.e. pool tagged) and direction was noted as either upstream, downstream, or no movement (recaptured within the tagging pool). The number of locks and dam complexes traversed was determined. Gage stage and discharge information were acquired from USGS database (USGS 2003). Water levels at specific locks and dam complexes were acquired from the U.S. Army Corps of Engineers District offices and elevations between upstream and downstream points (head differential) at locks and dam complexes were ascertained by subtracting the downstream elevation from the upstream elevation.

A second approach was to intensively study several species of fish over a limited time period. An investigation at the Winfield Locks and Dam complex (Kanawha River KRM 31.1) was conducted to determine if the fish community inhabiting lock chambers were representative of tailwater reaches. A second phase was to determine short-term movement patterns of targeted species at this complex. Intensive fish sampling tasks were conducted from 19 May 2003 through 29 July 2003. Six fish species were selected to represent large river fishes occupying different behavior and habitat guilds. These species were collected using a variety of techniques and either tagged (t-bar) or marked (elastomer) for future identification.

A final study was conducted using fatty acid composition analysis. Samples from sauger, white bass, and paddlefish were collected from the following pools: Hannibal, Belleville, Greenup, Meldahl, Cannelton, and Smithland. Data for thirteen fatty acids and for total percent lipids were measured. Lipids were extracted from the white muscle tissue. Fatty acids were analyzed by gas chromatography and flame ionization detection with confirmation by gas chromatography—mass spectrometry.

Sauger (5,554), saugeye (53), walleye (432), and white bass (595) were tagged at nine tailwater locations within the Ohio River sub-basin. Anglers recaptured 559 (10%) sauger, 9 (17%) saugeye, 52 (12%) walleye and 52 (9%) white bass. In addition, 51 tagged-sauger and 3 tagged-walleye were recovered during scientific-based surveys.

Ninety percent (90%) of the sauger was recovered within the Ohio River proper with the remaining being recovered within Ohio River tributaries. No sauger were reported from outside the Ohio River sub-basin. River-wide, 53% of the tagged sauger reported by anglers from the Ohio River proper displayed no movement (recovered

within the tagged-pool), 1% displayed a downstream movement, and 46% displayed upstream movement. Saugeye and walleye displayed a greater affinity not to move (78% of saugeye and 74% of walleye), and neither species were reported from downstream pools. Sauger moved into a few larger tributaries including the Wabash, Kentucky, Kanawha, and Allegheny rivers, but most sauger captured within a tributary river did display an affinity for an adjacent river either entering the tagged-pool of a tributary entering a pool just upstream of the tagged-pool. Geographically, sauger moved in a greater proportion to the tagged population from the Smithland Pool (through J.T. Myers Locks and Dam complex) and Greenup Pool (through R.C. Byrd Locks and Dam complex). Most upstream tagged sauger showed minimal affinity to move outside of the tagged pool.

Sixty-five percent of the recovered white bass displayed no movement, 2% displaying a downstream movement pattern, and 33% displaying an upstream pattern. White bass moved in a greater proportion to the tagged population from the Smithland Pool(through the J.T. Myers Locks and Dam complex) and Greenup Pool (through the R.C. Byrd Locks and Dam complex).

Downstream-tagged sauger and white bass (J.T. Myers to McAlpine complexes) moved between pools at greater rate than upstream-tagged (upstream of Racine complex) fish suggesting river conditions differed. Sauger were recovered within 20 days following tagging upstream of downstream locks and dam complexes in contrast to upstream-tagged sauger. For these individuals the first sauger reported upstream of a locks and dam complex was at 60 days following tagging and only after a high flow event which resulted in a head differential of less than 5-feet. This suggested that sauger

although having the opportunity to move through a lock, did not readily use this avenue. The J.T. Myers Locks and Dam complex does afford an auxiliary avenue with a canal open for fish movement when river stage is at least attainable throughout the year.

An evaluation of head differential at the Willow Island Locks and Dam complex provided some insight into the operational opportunities for fish passage. During the study period the upper Ohio River sub-basin experienced greater than average precipitation resulting in above average river stages. Consequently, on several occasions, head differential approached equilibrium at upstream high-lift dams. During one period (December 2001 through March 2002,) fish were tagged during typical river stages (December 16-20, 2001) and recovered by anglers soon afterwards. Interestingly, fish were not recovered upstream of the Willow Island complex until an atypical event resulted in head differential approaching equilibrium. In December 2002 through March 2003 similar conditions were evident and the tagging schemes provided similar results.

The influence of river stage and movement patterns was evident. All species moved through the R.C. Byrd Lock and Dam complex at a greater rate (63%) as compared to other mid-Ohio River lock and dam complexes (Belleville=22% and Willow Island=30%). River stage equilibrium (5-foot differential) was achieved 9.4% of the time at the R.C. Byrd Lock and Dam complex during the study period as compared to 1.4 % for the Belleville Lock and Dam complex and 1.6% for the Willow Island Lock and Dam complex.

Paddlefish were collected primarily in the more downstream reaches of the Ohio River because of the greater abundance of the species in this section. No paddlefish were collected upstream of the Willow Island Locks and Dam complex, although considerable

effort was expended in this reach. ORFMT and project biologists handled 1,579 paddlefish during the 29-month study period. An additional 6,430 were examined by a complimentary study conducted by the KDFW.

Six percent of the paddlefish handled by biologists had been inserted with CWTs, and less than 1% (24 of 6,430) handled by KDFW creel clerks. Jaw tags were inserted into 1,488 paddlefish during the project period. Jaw tags were recovered from 61 paddlefish (1%) of biologists collected paddlefish. Project clerks at the J.T. Myers, McAlpine, Markland, and Greenup tailwaters recovered no jaw-tagged paddlefish, although over 300 paddlefish were examined.

Movement patterns of recovered paddlefish were provided for 210 of 227 individuals. Paddlefish recovered from the Ohio River proper displayed no affinity for either downstream, upstream or no inter-pool movement. Fifty percent were recaptured within their tagging pool, 22% moved downstream, and 28% moved upstream. Downstream movement was slightly biased because more paddlefish were tagged in the extreme downstream pools. Paddlefish tagged in upstream pools (Greenup, Racine, and Belleville pools) displayed no inter-pool movement, as did extremely small (less than 400mm). Paddlefish were recovered from the Green, Tennessee, and Wabash river systems. These major Ohio River tributaries were adjacent to pools in which these paddlefish were tagged. Eight paddlefish tagged within the Ohio River sub-basin were recovered from outside of the sub-basin. One fish was recovered from the Illinois River, one from the Missouri River, and six from the Mississippi River.

Fish species composition was determined from the tailwater reach and the lock chamber at the Winfield Locks and Dam complex. Common species to both habitats were

gizzard shad, the minnows and shiners (ghost shiner, emerald shiner, and channel shiner), and freshwater drum. Species more common in tailwater habitats were white bass, skipjack herring, and sauger. Channel catfish, the sunfishes (*Lepomis* and *Pomoxis*), as well as hybrid striped bass were more common in lock chamber habitats. Species such as some of the catostomids and centrarchids were fairly uncommon in both types of habitats.

More migratory species appeared to occupy both habitat types, but to a differing abundance. Abundant migratory species in the lock chamber habitat included hybrid striped bass and gizzard shad. White bass, sauger, and gizzard shad, all migratory species, were more common in the tailwater sections.

Hybrid striped bass, sauger, smallmouth buffalo, skipjack, freshwater drum, and channel catfish were selected as study species on based abundance and migratory behavior. One-hundred and thirty-eight hybrid striped bass were tagged with T-bar anchor tags on six occasions within 15-days. The majority of these fish were tagged and released on 20 May, 22 May, 27 May, and 28 May. Investigators recovered 4 (3%) tagged individuals within the first 15 days following tagging, but no fish were recovered using electrofishing techniques after 4 June, nor were any fish recovered from outside of the Winfield Tailwater. Anglers caught 15 (11%) of the tagged hybrid striped bass. Twelve recaptured hybrid striped bass were caught from either the R.C. Byrd Pool (Winfield Tailwater, Kanawha River, or the Racine Tailwater, two from the Racine Pool (Belleville Tailwater), and no recapture location was reported for one individual. No hybrid striped bass displayed an upstream movement pattern through the Winfield Locks and Dam complex. Two 20 May tagged-fish were reported captured within 5-days of

tagging. Both individuals were caught in the Winfield Tailwater adjacent to the hydropower unit discharge.

Sauger, channel catfish, smallmouth buffalo, and freshwater drum were inserted with either yellow, red, or green elastomer in either the caudal, pelvic, or pectoral fins. Seventy-nine sauger, 81 smallmouth buffalo, 120 skipjack herring, 150 freshwater drum, and 120 channel catfish were inserted during May-June 2003. Recovery tasks were conducted for a period through 29 July 2003.

No marked skipjack herring were recovered during the study period. Twelve sauger (15%) were recovered from the Winfield Tailwater within 10 days of marking. No sauger were recovered after 2 June or from locations outside of the Winfield Tailwater. Channel catfish (15 of 120-12%), smallmouth buffalo (3 of 81-4%), and freshwater drum (9 of 150-6%) were recovered only from the Winfield Tailwater within 10 days of marking.

Paddlefish, white bass, and sauger were analyzed for lipid and fatty acid composition to assess population differentiation as a potential result of locks and dams. One hundred and twenty-one individuals were initially collected and analyzed from throughout the Ohio River proper. Data for thirteen fatty acids and for total percent lipids were measured.

There was no significant difference ($\alpha = 0.05$) among the mean percent lipids for sauger among the pools sampled. For white bass, percent lipids for the Meldahl Pool were significantly higher than for the Belleville or Greenup pools, with the data for Hannibal, Cannelton, and Smithland pools occurring intermediately.

The profiles for 13 fatty acids were compared between species and among locations. The mass balances for weight percent of fatty acids for Belleville data were determined to be unacceptable relative to all other locations. The data indicated that co-extracted interferences were found in the chemical results for Belleville for both sauger and white bass. In order to overcome this obstacle to data analysis, and produce data for Belleville Pool that could reasonably be compared to the other locations, the data for 11 selected fatty acids was reprocessed to assess the relative contribution of each identified fatty acid while excluding the interferences.

Using statistical procedures for analysis of variance and principal component analysis, the reprocessed data for fish collected in October was used to demonstrate (a) that fish species were separately identifiable within location using the fatty acid profile and (b) that as a biological marker the fatty acid profile indicated the existence of two distinct sub-populations, roughly separated into the upper and lower Ohio River reaches, for both sauger and white bass. These data strongly suggest that an effect of high-lift dam structure on fish movement was evident in the Ohio River.

Results from the three studies concerned with fish passage, as well as the recreational angling survey, suggest that although fish do pass through locks and dam complexes several factors may be inhibiting their movement. Tagging data of recovered percids and white bass indicated that greater than 55% of recovered fish displayed no movement through locks and dam complexes. Movement through these complexes was greater at downstream complexes, as compared to upstream complexes. Inter-pool movement also was primarily in an upstream direction with less than 5% displaying inter-pool movement in a downstream direction. When inter-pool movement was evident at

upstream complexes, it was in conjunction with extremely high river levels resulting in a near equilibrium in head differential at a given high-lift dam. Tag recovery data of paddlefish also suggest that this great river species displayed some inter-pool movement (approximately 50% of tagged-fish). Inter-pool movement in upstream and downstream directions was similar, but this was only evident in lower river pools. No paddlefish tagged and/or recovered in upper river pools displayed inter-pool movement. Data derived from fatty acid composition analysis suggested that two distinct sub-populations of sauger and white bass exist in the Ohio River that can be separated as a downstream and upstream cohort. Lastly, anglers sought and caught migratory species (i.e. sauger, walleye, paddlefish, and hybrid striped bass) at tailwaters reaches adjacent to locks and dam complexes during peak migratory periods.

Consequently, results from these collaborative studies suggest that:

e. Migratory fish species do congregate seasonally downstream of locks and dam complexes,
f. If river conditions are appropriate, Ohio River fish do move through locks and dam complexes,
g. Distinct sub-populations exist between both downstream and upstream reaches, and
h. Minimal interactions between upper and lower river fish occur.

Factors that may be inhibiting fish movement through locks and dam complexes are both ecological and human associated. Biochemical studies of walleye populations in the Ohio River suggest that a distinct sub-population of these percids exist in upstream reaches (White et al. 2004). Other distinct populations of walleye have been identified from Ohio River tributaries such as the Cumberland River sub-basin Rockcastle River (Billington and Sloss 1998), the New River (Palmer and Hallerman 2000), and possible the Big Sandy River (White per. comm.). White et al. (2004) suggested an origin for the

Ohio River haplotype in the Teays River (Flint 1971). Palmer and Hallerman (2000) also suggested a Teays River origin for walleye from the New River and the Rockcastle River. These results suggest that upper Ohio River fish species may have been historically segregated from downstream populations. Fish species community structure also suggest that differences do exist between upstream and downstream composition (ORSANCO 2002).

Behavioral characteristics of sauger in large river systems are fairly well-known (St. John 1990, TVA 1991, Pitlo 1992, Pegg et al. 1997). In the late fall and early winter, sauger migrate upstream to below high-lift dams and concentrate in these tailwater reaches. Initiation of migration appears to be a factor of water temperature and increased flow. As water temperature rises in the early spring, male sauger move to spawning shoals and may remain for weeks until spawning is complete. In contrast, female sauger may remain on spawning shoals for a period of only days. Once spawning has been completed, both sexes disperse from spawning eras. Several investigators have reported movements in excess of 100 miles.

Movement through locks in an upstream direction has been documented by TVA (1991) and Pegg et al. (1997). TVA (1991) suggested that the locations of the discharge structures associated with locks are important in the upstream passage of sauger. Discharges ports in close proximity to river flow were hypothesized as a positive factor in fish passage. Locks with discharge ports in close proximity to river flow allowed upwards to 25% of sauger to pass during peak peaks. In contrast, no sauger passed at locks with discharge ports at greater distance from river flow. Pegg et al. (1997) reported that 4 of 35 (11%) sauger moved through the Pickwick Locks and Dam

Complex on the Tennessee River while the remaining 31 sauger remained within 31km of the complex until the conclusion of the spawning period. TVA (1991) classified the Pickwick lock as one highly compatible to fish passage.

Retention time in close proximity to a fish barrier has been suggested as an additional factor in promoting fish passage (Barry and Kynard 1986). Large variations for migratory species such as blueback herring (Chapplear and Cooke 1994) and sauger (Pegg et al. 1997) have been reported. Pegg et al. (1997) reported that sauger remain in close proximity to a navigational locks and dam complex for a period of months in contrast to clupeid species which may only remain for a period of days (Bailey et al. (2004). Zigler et al. (2003) reported that paddlefish remained in tailwater areas for considerable time periods during the winter, summer, and fall, but moved downstream during the spring period.

Results from the present study indicated that although sauger and white bass moved primarily upstream through locks and dam complexes, two distinct patterns were evident. At lower river complexes, these species moved soon after tagging with no evidence of river conditions affecting migration. In contrast, inter-pool movement at upper river complexes was linked to high flow river conditions and approaching equilibrium of head differential at each locks and dam complex. Consequently, it appeared that although given the opportunity for a period of several weeks during peak migratory seasons, sauger did not migrate through locks in the upper reaches of the Ohio River. Rather, sauger seemed to migrate upstream through gate openings in the dam.

Sauger, as well as all fish species, were afforded an avenue for moving through a canal around the J.T. Myers Locks and Dam complexes during most periods. Paddlefish

movement in the downstream reaches of the river also was noted. Movement through locks have been reported for paddlefish by Zigler et al. (2003) in the upper Mississippi River, as well as during periods of high flow and equal head differential at locks and dam complexes.

The locks in the upper reaches of the Ohio River are similar to those reported by TVA (1991) as not conducive to fish passage. Discharge ports are at distances from the river flow for all complexes, and especially at those that have hydropower facilities. In addition, most gates are either operated to provide a more even flow throughout the river channel or along the opposite shore from the lock chambers. Consequently, fish are either not positively attracted to the lock chamber or ports. TVA (1991) suggested that most fish enter the lock chambers through the ports. Knights et al. (2002) also suggested that fish passage at upstream high-lift dams is not likely because of non-conducive flow patterns.

Ohio River dams are fairly unique in that under extremely high river stages, an open-river condition exist. Knights et al. (2002) postulated that during these open water conditions fish are afforded the greatest opportunity to pass through Ohio River locks and dam complexes. This was especially evident in more upstream complexes where lock chamber and dam operations did not promote passage except during high flow events. Open-river conditions occurred less than 5% of the years for all complexes upstream of the Racine Locks and Dam Complex. In contrast, this condition was achieved for 50% of the years at the J.T. Myers and Newburgh complex (Knights et al. 2002). Inter-pool movement from this study were greatest at these two complexes. Therefore, it is unlikely that fish pass the upstream complexes readily in a normal or low flow year.

River conditions were dissimilar during the study period as compared to historic records (USGS 2004). River stages were extremely high in upstream reaches resulting in open water conditions for 1-5 day periods on at least several occasions. On two of these occasions, sauger that had been tagged prior to open-river conditions were recovered in greater than expected numbers upstream of the complex following open-river conditions. This result suggest that sauger moved upstream through these complexes during open-river conditions and not during normal conditions when the only avenue would be through lock chambers. These results are in concert with Knights et al. (2002).

Inter-pool fish movement in the Ohio River appears to be of two distinct patterns. Fish downstream of Markland Locks and Dam complex appear to move inter-pool more readily, especially at the most downstream locations. Fish upstream of the Markland Locks and Dam complex appear to have more restrictive inter-pool movement patterns and movement is linked to open-river conditions. Minimal fish passage through the Markland Locks and Dam complex was evident suggesting that this complex may be a hindrance to fish exchange within the Ohio River system. Knights et al. (2002) suggested that the Markland Locks and Dam complex is more like those in upstream reaches. Recreational and commercial paddlefish data also suggest that this species has a tendency to concentrate downstream of this complex (Henley et al. 2002).

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Chapter 2

Ohio River Mainstem System Study (ORMSS)

Fish Tagging and Fatty Acid Composition Tasks

Introduction

Fish passage through large navigational lock and dam complexes has been proposed as problematic within the Ohio River sub-basin (USACOE 2000). These complexes serve an important role in promoting navigation in the sub-basin by maintaining a nine-foot navigational channel throughout the year. In contrast, prior to large-scale river alterations the Ohio River was characterized by large fluctuations in water levels during the wetter seasons and a great reduction in river flow resulting in river channels at times of less than 5 feet during the summer (Cannon and Hoffman 1937). Navigation–based alterations to the Ohio River was initiated in the early 1800s with the clearing of woody debris and the construction of a wing dam at Henderson Bar in 1825. These efforts were continued and by 1929 complete canalization of the Ohio River was accomplished through a series of 52 lock and dam complexes (USACOE 1979). The completion of 20 "high-lift" dams began in the 1930s and will culminate with the construction of the Olmstead Lock and Dam complex. The high lift dams provide greater stability to river hydrologic dynamics.

Fish passage problems related to locks and dam complexes are well documented for salmonid fish species (Bergkamp et al. 2000). In contrast, impacts to warmwater species have not been as well documented, but some evidence does suggest that potential impacts may be problematic. Pearson and Pearson (1989) stated that the elimination of

Alabama shad in the Ohio River sub-basin was partially attributed to impaired movement due to high lift dams. Other reviews of tagging and distributional data suggest that movement of large river species such as paddlefish and shovelnose sturgeon may be reduced leading to a reduction in range expansion (Henley et al. 2002; ORSANCO 2002). This is especially critical with water quality improvements in the middle and upper Ohio River leading to increased habitat for large river fish species.

Impaired fish movement has also been suggested as one factor in the demise of several freshwater mussel species, which require a fish host for reproduction (Neeves 1999). Two species, the ebony shell and elephant ear mussel, have declined partially due to the impairment of skipjack herring movement in the upper Mississippi River (Becker 1983).

The suggestions that fish passage may be impaired in the Ohio River sub-basin was a concern expressed by several federal and state biologists. In response to these concerns, the study reported herein was proposed and funded to provide insight into fish passage of three highly migratory species. Sauger and white bass were selected because of their migratory behavior, potential for serving as freshwater mussel hosts, and their selection by recreational anglers, which promoted the reporting of tagged individuals (Pegg et al. 1997). In addition, walleye were included because of importance in the upper Ohio River fish community, the presence of a unique haplotype in this reach of the river, and their migratory behavior (White et al. 2004). Saugeye were also included because of their migratory behavior.

Paddlefish were selected because of their migratory behavior, importance as a commercial fish, and the potential to collaborate with several long-term studies. It was

believed that these three species represented behavioral patterns of many migratory species inhabiting the Ohio River; consequently, these species would serve as a model for future discussions.

Specific objectives were:

1. To determine short-term movement patterns of target species,
2. To ascertain hydrologic conditions which may promote the passage of the target species, and
3. To determine interpool cohort differences using fatty acid techniques.

Approach

Fish Tagging Activities:

Sauger, saugeye, walleye, and white bass were collected using pulsed DC boat-mounted electrofishing gear during the Fall 2001; Winter, Spring, and Fall 2002; and Winter 2003 by four ORFMT state agencies at nine tailwaters within the Ohio River sub-basin (Table 1). Initially, target species were to be tagged within the Greenup tailwater (Meldahl Pool), but because of Homeland Security concerns tagging activities from this location were discontinued. To replace the Greenup tailwater location, targeted species were tagged at the Racine (R.C. Byrd Pool) and Belleville (Racine Pool) tailwaters in 2002 and 2003. Each individual fish was separately measured and tagged with a color-coded, uniquely numbered T-Bar anchor tag. A mailing address number and a reward announcement was printed on each tag. Prior to release, each individual fish was retained for a minimum of 10-minutes to insure recovery and fish that appeared stressed were not released.

To inform anglers of the study, posters were placed at local boat docks and ramps, as well as area sporting good stores, and several news releases were issued throughout the region. In all media, anglers were encouraged to return tags with information about

capture location, and date of capture. In addition, project funded clerks at selected tailwaters informed anglers about the program and encouraged them to report tagged fish.

Upon tagging completion, crew leaders submitted data forms to the WVDNR-Parkersburg Office for processing. Data were entered and reviewed to insure quality. Data sets were maintained using Microsoft Excel. Information on tag number, tagging location and date, and size at tagging were linked to each individual fish. Anglers reported the capture of tagged fish via mail, telephone, or e-mail. Information on recapture date and location, as well as if the fish was harvested or released were recorded. If anglers did not report all recapture information, a self-addressed stamped postcard was sent requesting information. All anglers reporting the recapture of a tagged fish were sent a hat.

Movement was ascertained for all recaptured fish if information was available. Significant differences in length frequencies (sauger, walleye, and white bass) among fish tagged, recovered, and creeled (collected by project funded creel clerks) were determined based on the Kolmogorov-Smirnov test (Sokal and Rohlf 1995). Movement was determined both by time period (Fall 2001 Tagged Individuals, etc) and by location (i.e. pool tagged). Direction was noted as either upstream, downstream, or no movement (recaptured within the tagging pool), and the number of locks and dam complexes traversed were determined. Because exact locations of recapture frequently were not provided by anglers, extent and direction of movement was determined in this manner.

Water level and discharge information were acquired from USGS database (USGS 2003) and linked to specific time periods. Water levels at specific locks and dam complexes was acquired from the U.S. Army Corps of Engineers District offices and

elevations between upstream and downstream points at locks and dam complexes were ascertained by subtracting the downstream elevation from the upstream elevation.

Tag loss and total tagging-related mortality (tagging and handling) were estimated from (O'Bara et al. 1999) since the author provided training to all tagging crews. Non-reporting was determined by distributing 50 postcards per tailwater as tag surrogates (O'Bara et al. 1999) and rewards were provided for each returned postcard. Previous studies had estimated nonreporting as low as 7% for black crappie (Elder 1990) to 73% for sauger (Maciena et al. 1998). Annual angler exploitation was defined as a percent of tags returned by anglers (non-adjusted) during a 12-month period after tagging, adjusted for percent of released fish, tag loss, tagging-related mortality, and non-reporting (Jagielo 1991). Annual angler catch also was determined and defined as the percent of tags returned corrected for tag loss, tagging-related mortality, and non-reporting by anglers. Confidence limits (95%) were determined using a binomial distribution for annual angler exploitation and catch, and unless otherwise indicated were the measurement of variance. Annual exploitation and catch was determined for sauger, all percids (sauger, saugeye, and walleye), and white bass.

Paddlefish were collected by ORFMT biologists and project staff, as well as commercial fishers. ORFMT biologists used variable size (length x width) gill nets consisting of a single panel of 127mm square-bar mesh, as well as pulsed DC boat-mounted electrofishing gear to collect paddlefish. Sampling was conducted during the fall (2001 and 2002), winter (2002 and 2003), and spring (2002 and 2003). In addition, project staff (observers) traveled with commercial fishers to both recover and tag paddlefish in the Cannelton and McAlpine pools. Upon collection, paddlefish were

checked with the use of a magnetic wand for the presence of a coded-wire tag (CWT), and visually inspected for the presence of a jaw tag or elastomer mark. CWTs had been inserted during a previous MICRA-associated study, jaw tags had been attached to wild paddlefish by ORFMT biologists, and elastomer marks used by WVDNR biologists to identify hatchery-reared fish. Individuals were measured (eye-fork length) and inserted with a metal jaw tags prior to release. Jaw tags were uniquely numbered and information concerning mailing address and rewards were present. Rewards were handled by the Kentucky Department of Fish and Wildlife (KDFWR) because most jaw tags returns were thought to come from commercial fishers. An additional effort to collect paddlefish information was conducted through a creel survey conducted by the KDFWR in the lower open section of the river, as well as in the Tennessee River.

Movement was ascertained for all recaptured fish if information was available. Significant differences in length frequencies between tagged and recovered paddlefish were based on the Kolmogorov-Smirnov test (Sokal and Rohlf 1995). Movement was determined by location (i.e. pool tagged) and direction was noted as either upstream, downstream, or no movement (recaptured within the tagging pool). The number of locks and dam complexes traversed also was determined. The duration a paddlefish was at-large was not considered because of incomplete recapture date data provided by commercial fishers.

Fatty Acid Composition Activities:

A more detailed discussion of activities concerned with fatty acid composition tasks is outlined in Wells (2004). This report was submitted as a separate document, but was funded with project funds.

Three fish species: paddlefish, white bass, and sauger were analyzed for lipid and fatty acid composition in order to study the impact of locks and dams upon the lipid and fatty acid composition of these specimens and interpret variation in these profiles. Tissue samples were taken from fish collected by other project personnel using boat-mounted electrofishing techniques under contract to West Virginia Division of Natural Resources (WVDNR) and shipped to the Tennessee Technological University (TTU) Water Center Laboratories. During the project, 121 fish were collected and analyzed from the following Ohio River pools: Hannibal, Belleville, Greenup, Meldahl, Cannelton, and Smithland.

Data for thirteen fatty acids and for total percent lipids were measured. Lipids were extracted from the white muscle tissue. Fatty acids were analyzed by gas chromatography and flame ionization detection with confirmation by gas chromatography—mass spectrometry. The data were analyzed using Statistical Analysis System (SAS) software.

Results

Fish Tagging Activities:

Percids:

Sauger, saugeye, and walleye were tagged from 1 November 2001 through 28 March 2003 at nine tailwater locations within the Ohio River sub-basin. A total of 5,554 sauger, 53 saugeye, and 432 walleye were tagged during the project period (Table 1). Tag retention was estimated at 90%. Total tagging-related mortality was estimated at 22% with 12 % attributed to tagging and 10% attributed to handling. Non-reporting by individual tailwaters is reported in Table 1 and ranged from 20-48%.

Tags were included in this analysis that were returned through March 2004A total of 559 (10%) sauger, 9 (17%) saugeye, and 52 (12%) walleye were reported recaptured by anglers. In addition, 51 sauger and 3 walleye were recovered during scientific-based surveys. Initially, anglers did not provide sufficient information for 70 recaptures, but with follow-up correspondence sufficient information was provide from 48 of the 70 (68%) resulting in 656 usable tag returns.

Length frequency distributions were significantly different for sauger and walleye between tagged and recovered individuals, as well as recovered and creeled individuals for walleye (Figure 1). No significant differences were found between recovered and creeled sauger. For all species, a greater proportion of larger individuals were angler-caught than were tagged.

Based on tags recovered from the 2001-2002 tagging period, corrected catch for sauger was 21% for the Ohio River and ranged from 9% for the R.C. Byrd tailwater to 44% for the J.T.Myers tailwater (Table 2). Riverwide annual angler exploitation was 15% ranging from 4% for the R.C. Byrd tailwater to 41% for the J.T.Myers tailwater. Variable percent harvested was a major factor in determining annual angling exploitation.

Of the 559 tagged sauger reported by anglers, 538 had sufficient information to ascertain movement patterns. Ninety percent (90%) of the sauger recovered was within the Ohio River proper with the remaining being recovered from Ohio River tributaries, No sauger were reported from outside the Ohio River sub-basin. Riverwide, 53% of the tagged sauger reported by anglers from the Ohio River proper displayed no movement (recovered within the tagged-pool), 1% displayed a downstream movement, and 46% displayed upstream movement. Geographically, The percent of tagged-sauger moving to

another pool was greatest for those fish tagged in the Smithland Pool (through J.T. Myers Locks and Dam complex) and the Greenup Pool (through R.C. Byrd Locks and Dam complex). Longitudally, sauger movement patterns were variable (Table 3). Smithland Pool tagged-sauger displayed the greatest affinity to move with only 13% being recovered within the tagged pool and the remainder moving in an upstream direction. The farthest a Smithland Pool tagged sauger moved was upstream through three locks and dam complexes into the McAlpine Pool. In contrast, sauger tagged in the Racine, Belleville, and Hannibal pools displayed an affinity not to move with greater than 70% displaying no movement patterns. Sauger tagged in other pools displayed intermediate movement patterns (Table 3). Few sauger moved upstream through the Markland, Meldahl or the Greenup locks and dam complexes.

Sauger exhibit a tendency to move into a few larger tributaries including the Wabash, Kentucky, Kanawha, and Allegheny rivers (Table 4). Most sauger captured within a tributary river did display an affinity for an adjacent river either entering the tagged-pool of a tributary entering a pool just upstream of the tagged-pool. An example is a fish tagged in the Greenup Pool displayed movement patterns which were characterized by traveling through the R.C. Byrd Locks and Dam complex and then upstream into the Kanawha River. One Smithland Pool tagged sauger did travel upstream through the J.T. Myers Locks and Dam complex and upstream in the Wabash River system into the East Fork of the White River. Sauger recovered in the Allegheny River and Beaver River systems were tagged in either the Hannibal or Pike Island pools and traveled through the New Cumberland, Montgomery, Dashields, and Emsworth locks and dam complexes prior to entering the Allegheny River system.

Although tagged and recovered to a lesser magnitude than sauger, saugeye and walleye displayed similar patterns. Both of these taxa showed a greater affinity not to move (78% of saugeye and 74% of walleye) and no fish moved to downstream pools.

White Bass:

Five hundred and ninety-five white bass were tagged during the project period (Table 1). Length frequency distributions were significantly different for white bass between tagged and recovered individuals (Figure 2). No significant differences were found between recovered and creeled white bass. A greater proportion of larger individuals were angler-caught than were tagged.

Fifty-two white bass were reported as recaptured by anglers. Sixty-five percent (65%) displayed no interpool movement, 2% moved downstream, and 33% moved upstream (Table 5). As with sauger, the percentage of white bass displaying interpool movement was greatest for fish tagged in the Smithland Pool (through the J.T. Myers Locks and Dam complex) and the Greenup Pool (through the R.C. Byrd Locks and Dam complex). Longitudinally, white bass tagged downstream of and including the Greenup Pool moved at a significantly greater rate (47%) than those tagged in upstream of the R.C. Byrd Locks and Dam Complex (22%). Outside of the Ohio River mainstem, white bass only were recovered from the Green River (1 tagged in the Smithland Pool) and Kanawha River (1 tagged in the Greenup Pool).

Percid and White Bass Movement Patterns in Relation to River Hydrologic Dynamics:

Although timing of fish passage was not a stated objective of this study, the time between tagging and recovery can be informative. Sauger were recovered by anglers over 800-days post tagging (Figure 3) and a greater percentage of fish were recovered from

upstream pools as compared to the tagging pool with increased time at-large. A more detailed evaluation of the relationship of time and hydrologic conditions to fish movement appears to be more informative.

The tendency of fish tagged in downstream pools of the river to move at greater rates than upstream-tagged fish suggest that river conditions differed between these two reaches. Sauger tagged in downstream pools displayed interpool movement within 20 days post tagging. In contrast, sauger in upstream pools displayed interpool movement 60 days post tagging (Figure 4). This suggested that sauger although having the opportunity to move through a lock did not readily use this avenue. The greater tendency for all species tagged in downstream pools to display interpool movement suggests that fish generally were afforded avenues other than lock chambers. These avenues may be related to river flow and stage conditions (i.e. when stage differentials between tailwater and pool elevations are minimal such that fish are able to swim through gate openings). In addition, the J.T. Myers Locks and Dam complex affords another avenue with a canal open for fish movement when river stage is at least attainable throughout the year.

Fish tagged in upstream pools did not display similar have a propensity to move through locks and dam complexes suggesting that minimal stage differentials are attained at less frequent intervals. River stages at locks and dams complexes are partially dictated by river levels, but some operational procedures may contribute to interpool fish movement. An evaluation of the difference between downstream and upstream river stages at the Willow Island Locks and Dam complex provided some insight into the operational opportunities for fish passage. Greater than average precipitation resulting in above average river stages was experienced during the study period. Consequently, on

several occasions, the river stage difference approached equilibrium (Figure 5). During one period (December 2001 through March 2002,) fish were tagged during typical river stages (December 16-20, 2001) and recovered by anglers in the same pool soon afterwards (Figure 5). Fish were not recovered upstream of the Willow Island complex until an atypical event resulted in the river stage approaching equilibrium (Figure 6). In December 2002 through March 2003 similar river conditions were present and similar results were observed to 2002.

The influence of river stage and movement patterns was evident when comparing the percent of hours that a locks and dam complex had water level near equilibrium (<=5 foot differential). All species moved through the R.C. Byrd Lock and Dam complex at a greater rate (63%) as compared to other mid-Ohio River lock and dam complexes (Belleville=22% and Willow Island=30%). River stage equilibrium (<=5 foot differential) was achieved 9.4% of the time at the R.C. Byrd Lock and Dam complex during the study period as compared to 1.4 % for the Belleville Lock and Dam complex and 1.6% for the Willow Island Lock and Dam complex (Figure 7). An equilibrium achievement rate of 2.9% at the Racine Lock and Dam complex would suggest opportunities for fish movement, and this was evident by passage of sauger tagged in the Greenup Pool through the Racine Lock and Dam complex (Table 3).

Paddlefish:

Paddlefish were collected primarily in downstream reaches of the Ohio River because of the greater abundance of the species in this section. ORFMT and project biologists handled 1,579 paddlefish during the 29-month period of the study. Fish were collected primarily by biologists using gill nets (1,352), and to a lesser degree by

commercial fishers (189) and electrofishing (29). Most paddlefish (1,516) were processed and released, but a few were either harvested by commercial fishers (58) or died (5) as the result of handling stress.

Six percent of the paddlefish handled by biologists had been inserted with CWTs, and less than 1% (24 of 6,430) of paddlefish handled by KDFWR creel clerks had CWTs. Jaw tags were recovered from 61 paddlefish (1%) of biologists-collected paddlefish. Project clerks at the J.T. Myers, McAlpine, Markland, and Greenup tailwaters recovered no jaw-tagged paddlefish, although over 300 paddlefish were examined. CWTs are being examined by MICRA staff and results will be available at a later date.

Length (eye-fork) frequency distribution were not significantly different between all paddlefish handled and recovered paddlefish (Figure 8). Paddlefish ranged in size from 200mm to 1050mm. No length information was available for paddlefish recovered by independent commercial fishers.

Jaw tags were inserted into 1,488 paddlefish during the project period (Table 6). Eye-fork length ranged from 350mm to 1000mm (Figure 7). Fifty-eight percent were collected and released from the Smithland-J.T. Myers Locks and Dam complexes with the remaining from nine Ohio River pools and Barkley Reservoir in the adjacent Cumberland River.

Movement patterns of recovered paddlefish were provided for 210 of 227 individuals. Commercial fishers were contacted if information was not provided, but a few declined to provide information. Fifty percent of the paddlefish recovered from the Ohio River proper were recaptured within their tagging pool, 22% moved downstream, and 28% moved upstream (Figure 9). Downstream movement was slightly biased since a

larger proportion of the paddlefish were tagged in the most downstream pools. All paddlefish tagged in the Greenup, Racine, and Belleville pools displayed no interpool movement. Small paddlefish (less than 400mm) also displayed no interpool movement (Table 7). Paddlefish were recovered from the Green (2), Tennessee (1), and Wabash (7) river systems. Each of these major Ohio River tributaries were adjacent to pools in which these paddlefish were tagged.

Eight paddlefish tagged within the Ohio River sub-basin were recovered from outside of the sub-basin. One fish was recovered from the Illinois River, one from the Missouri River, and six from the Mississippi River. These Mississippi River recovered individuals had moved both downstream and upstream of the Ohio-Mississippi confluence.

Fatty Acid Composition Activities:

Percent Lipids:

There was no significant difference (á = 0.05) among the mean percent lipids for sauger among the pools sampled. For white bass, percent lipids for the Meldahl Pool were significantly higher than for the Belleville or Greenup pools, with the data for Hannibal, Cannelton, and Smithland pools occurring intermediately.

Fatty Acid Composition:

The fatty acid composition profiles for 13 fatty acids were compared between species and among locations. The mass balances for weight percent of fatty acids for Belleville data were determined to be unacceptable relative to all other locations.

The data indicated that co-extracted interferences were found in the chemical results for Belleville Pool for both sauger and white bass. In order to overcome this

obstacle to data analysis, and produce data for Belleville Pool that could reasonably be compared to the other locations, the data for 11 selected fatty acids was reprocessed to assess the relative contribution of each identified fatty acid while excluding the interferences.

Using statistical procedures for analysis of variance and principal component analysis, the reprocessed data for fish collected in October was used to demonstrate (a) that fish species were separately identifiable within location using the fatty acid profile and (b) that as a biological marker the fatty acid profile indicated the existence of two distinct sub-populations, roughly separated into the upper and lower Ohio River reaches, for both sauger and white bass. The data are interpreted to result as an effect of dam structure on fish movement during the low flow period indicated by fish collected during October.

Discussion

Movement patterns are genetically and behaviorally programmed in many large river fishes and are linked to environmental conditions. Sauger have been reported to display a seasonally movement patterns linked to spawning and cued by river flow and temperature. Several studies suggest that sauger move to a staging area in proximity of an eventual spawning reach and, when conditions are appropriate move into these reaches. For many small to medium non-navigational rivers, large dams inhibit these movement patterns resulting in either loss of spawning opportunities or use of sub-optimal habitat for spawning. In large navigational rivers, the locks and dam complexes provide at least a minimal avenue for upstream migration through locks, but fish affinity for flowing conditions often reduce these avenues. Ohio River locks and dam complexes are fairly

unique in that "open river" conditions can be attained during slightly above normal flow conditions in downstream pools, and during extreme high flow conditions in more upstream pools. During the study period, these "open river" conditions were observed during appropriate seasons and upstream movement was determined. This suggests that when these conditions exist, fish passage occurs.

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Table 1. Non-reporting bias and number of tagged individuals of sauger, saugeye, walleye and white bass for nine Ohio River pools. November 2001 through March 2003.

			Number of Individuals Tagged			
Tailwater	**Pool**	**Non-Reporting**	**Sauger**	**Saugeye**	**Walleye**	**White Bass**
J.T. Myers	Smithland	32	689	0	2	72
McAlpine	Cannelton	36	512	0	0	44
Markland	McAlpine	48	808	5	25	58
R.C. Byrd	Greenup	20	717	8	67	83
Racine	R.C. Byrd	22	308	1	9	28
Belleville	Racine	22	646	11	72	4
Willow Island	Belleville	22	1247	27	225	86
Pike Island	Hannibal	40	457	1	21	161
New Cumberland	Pike Island	40	170	0	11	59
Ohio River		**36**	**5554**	**53**	**432**	**595**

Table 2. Percent tag return (non-adjusted), annual catch, annual exploitation and percent harvest for sauger from for seven Ohio River pools. November 2001 through May 2002.

Tailwater	**Pool**	**Percent Tag Returned**	**Annual Catch**	**Annual Exploitation**	**Percent Harvest**
J.T. Myers	Smithland	21	44	41	94
McAlpine	Cannelton	7	15	12	82
Markland	McAlpine	11	31	20	66
R.C. Byrd	Greenup	5	9	4	45
Willow Island	Belleville	9	22	13	60
Pike Island	Hannibal	6	14	7	50
New Cumberland	Pike Island	4	10	6	57
Ohio River		10	21	15	69

Table 3. Number and percent of sauger recovered by tagged pool and movement patterns for nine Ohio River pools. November 2001 through March 2004.

Movement Patterns	Ohio River		Tagged Pool							
			Smithland		Cannelton		McAlpine		Greenup	
	No.	%	No.	%	No.	%	No.	%	No.	%
D2	1	0	0	0	0	0	0	0	1	3
D1	5	1	0	0	0	0	0	0	1	3
NM	269	53	13	13	15	68	33	42	19	58
U1	137	27	52	54	3	14	26	33	6	18
U2	60	12	21	22	3	14	15	19	5	15
U3	19	4	10	10	1	5	3	4	1	3
U4	9	2	1	1	0	0	0	0	0	0
U5	5	1	0	0	0	0	2	3	0	0
U6	0	0	0	0	0	0	0	0	0	0
U7	1	0	0	0	0	0	0	0	0	0
Total	**506**	**100**	**97**	**100**	**22**	**100**	**79**	**100**	**33**	**100**
Movement Patterns	**R.C. Byrd**		**Racine**		**Belleville**		**Hannibal**		**Pike Island**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
D2	0	0	0	0	0	0	0	0	0	0
D1	0	0	0	0	2	2	1	3	1	9
NM	10	37	61	78	90	70	22	71	6	55
U1	11	41	14	18	21	16	4	13	0	0
U2	3	11	3	4	7	5	1	3	2	18
U3	0	0	0	0	2	2	0	0	2	18
U4	2	7	0	0	3	2	3	10	0	0
U5	1	4	0	0	2	2	0	0	0	0
U6	0	0	0	0	0	0	0	0	0	0
U7	0	0	0	0	1	1	0	0	0	0
Total	**27**	**100**	**78**	**100**	**128**	**100**	**31**	**100**	**11**	**100**

Table 4. Number of sauger recovered in tributaries of the Ohio River and movement patterns for eight Ohio River pools. November 2001 through March 2004.

	Tagged Pool							
	Smithland	**Cannelton**	**McAlpine**	**Greenup**	**Racine**	**Belleville**	**Hannibal**	**Pike Island**
Allegheny	0	0	0	0	0	0	3	2
Beaver	0	0	0	0	0	0	2	1
Big Sandy	0	0	0	1	0	0	0	0
Hocking	0	0	0	0	1	0	0	0
Kanawha	0	1	2	9	0	0	0	0
Kentucky	0	2	1	0	0	0	0	0
Muskingum	0	0	0	0	3	2	0	0
Wabash	2	0	0	0	0	0	0	0

Table 5. Number and percent of white bass recovered by tagged pool and movement patterns for nine Ohio River pools. November 2001 through March 2004.

	Tagged Pool									
Movement Patterns	**All**		**Smithland**		**McAlpine**		**Greenup**		**R.C. Byrd**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
D5	1	2	0	0	0	0	0	0	0	0
D4	0	0	0	0	0	0	0	0	0	0
D3	0	0	0	0	0	0	0	0	0	0
D2	0	0	0	0	0	0	0	0	0	0
D1	0	0	0	0	0	0	0	0	0	0
NM	34	65	4	57	4	67	5	38	3	75
U1	10	19	1	14	2	33	4	31	1	25
U2	7	13	1	14	0	0	4	31	0	0
U3	1	2	1	14	0	0	0	0	0	0
Total	**52**	**100**	**7**	**100**	**6**	**100**	**13**	**100**	**4**	**100**
Movement Patterns	**Racine**		**Hannibal**		**Pike Island**		**Belleville**			
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**		
D5	0	0	0	0	0	0	1	20		
D4	0	0	0	0	0	0	0	0		
D3	0	0	0	0	0	0	0	0		
D2	0	0	0	0	0	0	0	0		
D1	0	0	0	0	0	0	0	0		
NM	1	100	12	86	3	100	2	40		
U1	0	0	1	7	0	0	1	20		
U2	0	0	1	7	0	0	1	20		
U3	0	0	0	0	0	0	0	0		
Total	**1**	**100**	**14**	**100**	**3**	**100**	**5**	**100**		

Table 6. Number and percent of paddlefish handled and jaw tagged for eleven Ohio River sub-basin pools. November 2001 through December 2003.

	Handled		Jaw Tagged	
Pool	**No.**	**%**	**No.**	**%**
No. 52	235	15	235	16
Smithland/J.T. Myers	874	55	864	58
Cannelton	11	1	11	1
Newburgh	174	11	115	8
Racine	2	0	1	0
McAlpine	26	2	26	2
Medlahl	38	2	38	3
Markland	94	6	94	6
Greenup	80	5	73	5
Belleville	25	2	11	1
Barkley	20	1	20	1
Ohio River sub-basin	1,579	100	1,488	100

Table 7. Number and percent of paddlefish recovered by tagged pool and movement patterns for nine Ohio River pools. November 2001 through March 2004.

	Tagged Pool							
Movement Pattern	**All**		**Pool 52**		**Smithland/Myers**		**Newburgh**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
D6	1	1	0	0	0	0	0	0
D5	2	1	0	0	0	0	0	0
D4	0	0	0	0	0	0	0	0
D3	4	2	0	0	0	0	0	0
D2	6	3	1	14	3	2	0	0
D1	27	15	0	0	20	17	0	0
NM	90	50	5	71	51	42	5	83
U1	13	7	1	14	10	8	1	17
U2	36	20	0	0	36	30	0	0
U3	1	1	0	0	1	1	0	0
Total	180	100	7	100	121	100	6	100
	Tagged Pool							
Movement Patterns	**McAlpine**		**Meldahl**		**Markland**			
	No.	**%**	**No.**	**%**	**No.**	**%**		
D6	0	0	0	0	1	5		
D5	2	25	0	0	0	0		
D4	0	0	0	0	0	0		
D3	0	0	0	0	4	18		
D2	0	0	0	0	17	77		
D1	1	13	2	100	0	0		
NM	4	50	0	0	0	0		
U1	1	13	0	0	0	0		
U2	0	0	0	0	0	0		
U3	0	0	0	0	0	0		
Total	8	100	2	100	22	100		
	Tagged Pool							
Movement Patterns	**Greenup**		**Racine**		**Belleville**			
	No.	**%**	**No.**	**%**	**No.**	**%**		
D2	0	0	0	0	0	0		
D1	0	0	0	0	0	0		
NM	2	100	1	100	3	100		
U1	0	0	0	0	0	0		
U2	0	0	0	0	0	0		
U3	0	0	0	0	0	0		
U4	0	0	0	0	0	0		
U5	0	0	0	0	0	0		
U6	0	0	0	0	0	0		
U7	0	0	0	0	0	0		
Total	2	100	1	100	3	100		

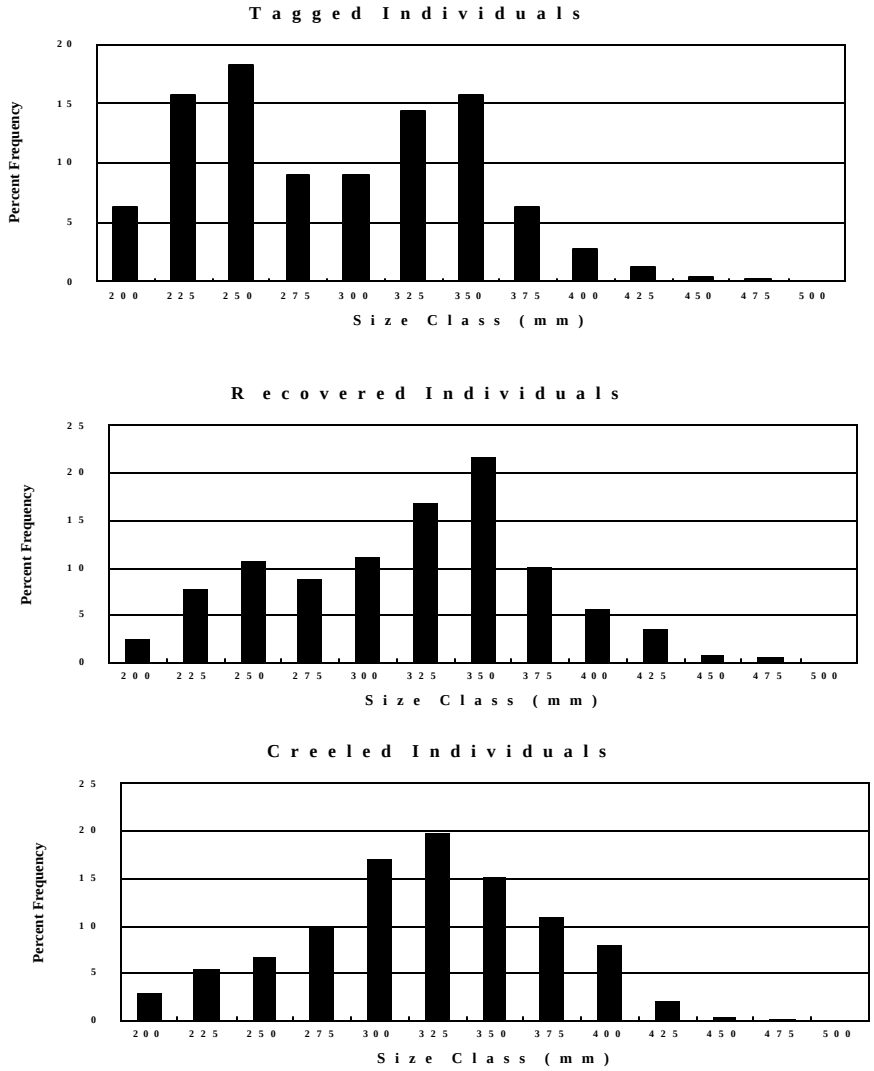


Figure 1. Length frequency histogram for three sub-samples of sauger tagged, recovered, and angler caught from the Ohio River sub-basin. December 2001 through March 2004.

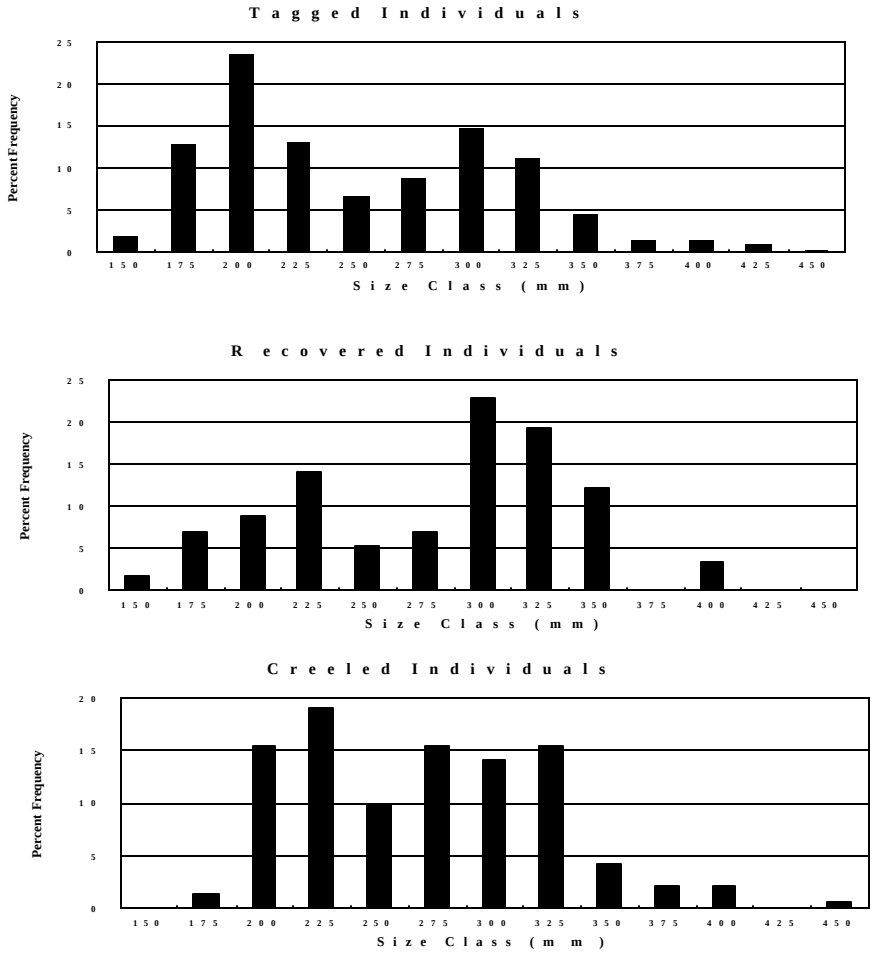


Figure 2. Length frequency histogram for three sub-samples of white bass tagged, recovered, and angler caught from the Ohio River sub-basin. December 2001 through March 2004.

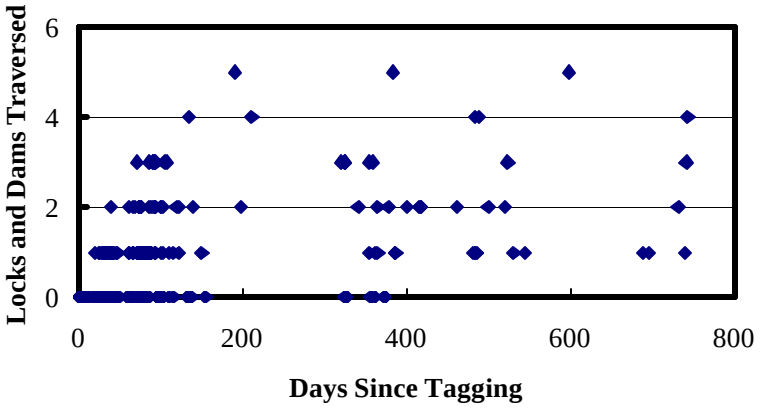
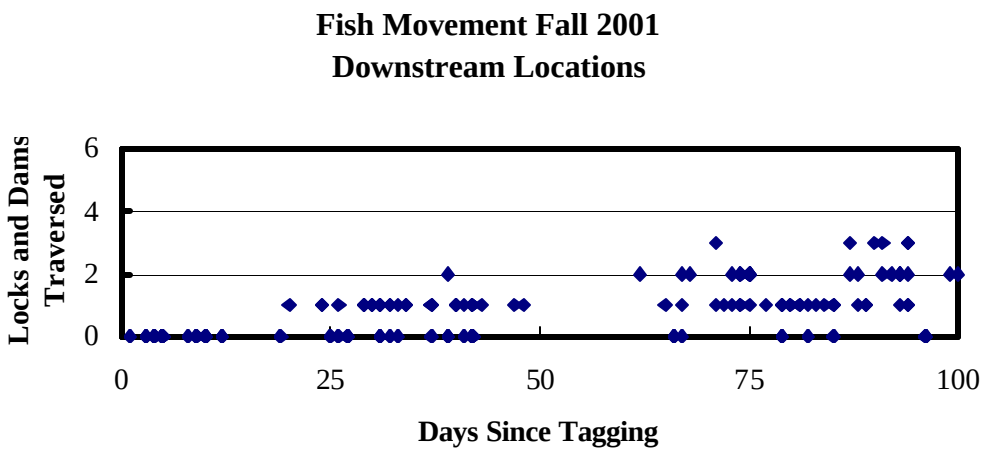


Figure 3. Number of locks and dam complexes traversed and days since tagging for sauger tagged during the Fall 2001 within the Ohio River sub-basin.



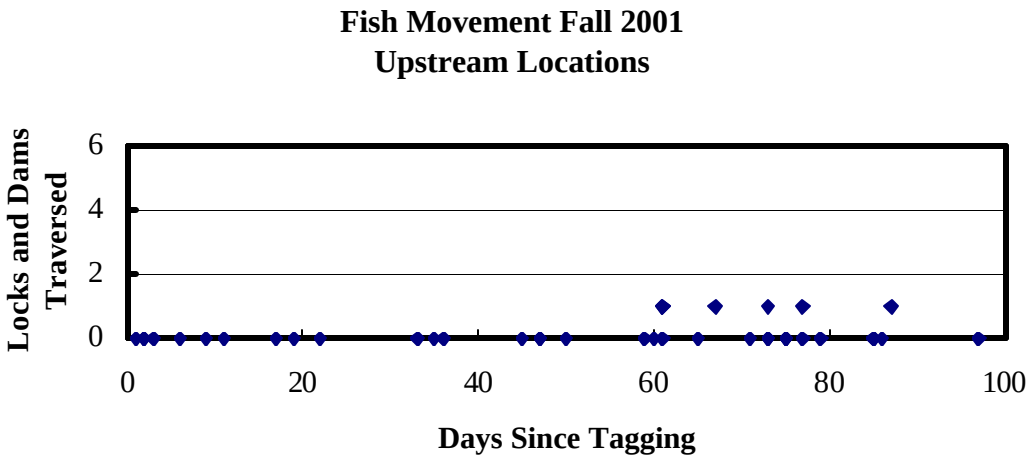


Figure 4. Number of locks and dam complexes traversed and days since tagging for two river locations within the Ohio River sub-basin. December 2001 through March 2002.

Downstream Locations = downstream and including McAlpine pools
Upstream Locations= upstream and including Belleville pools

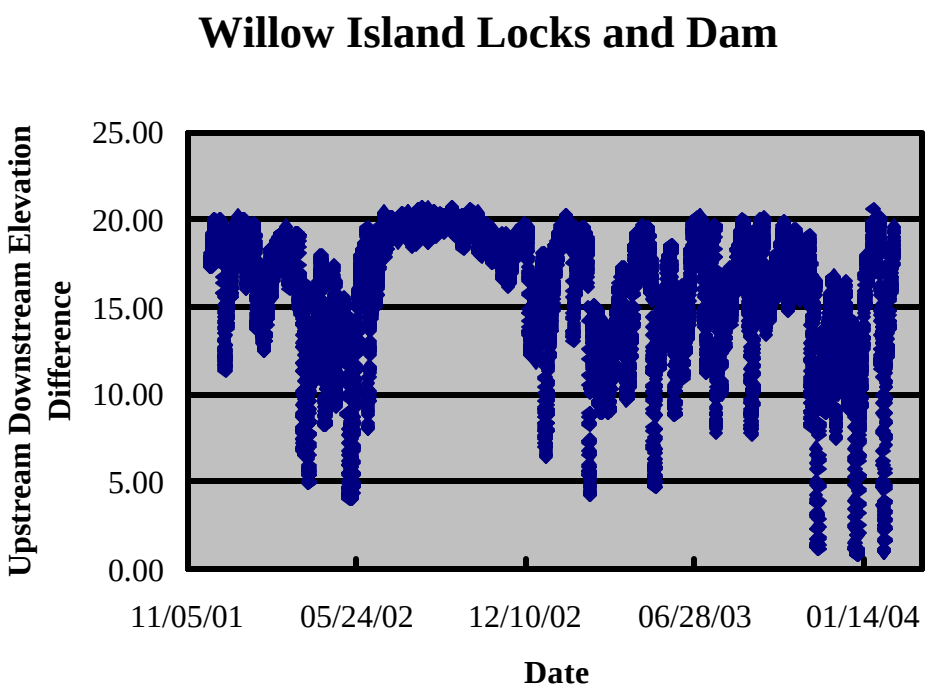


Figure 5. River stage differences (upstream-downstream) for the Willow Island Locks and Dam complex of the Ohio River. November 2001 through January 2004.

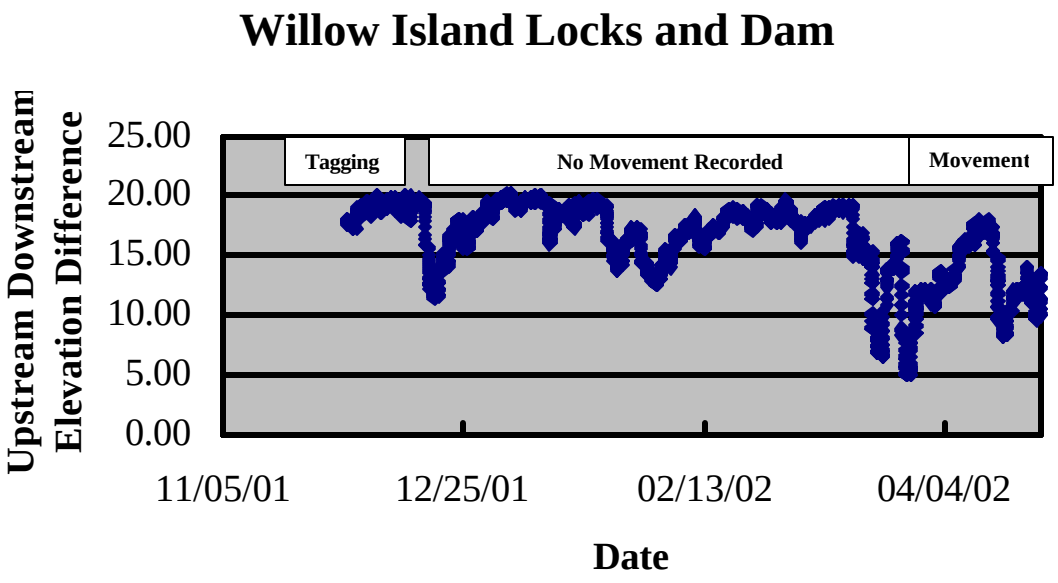


Figure 6. River stage differences (upstream-downstream) for the Willow Island Locks and Dam complex of the Ohio River (November 2001 through April 2002) in relationship to sauger tagging and movement.

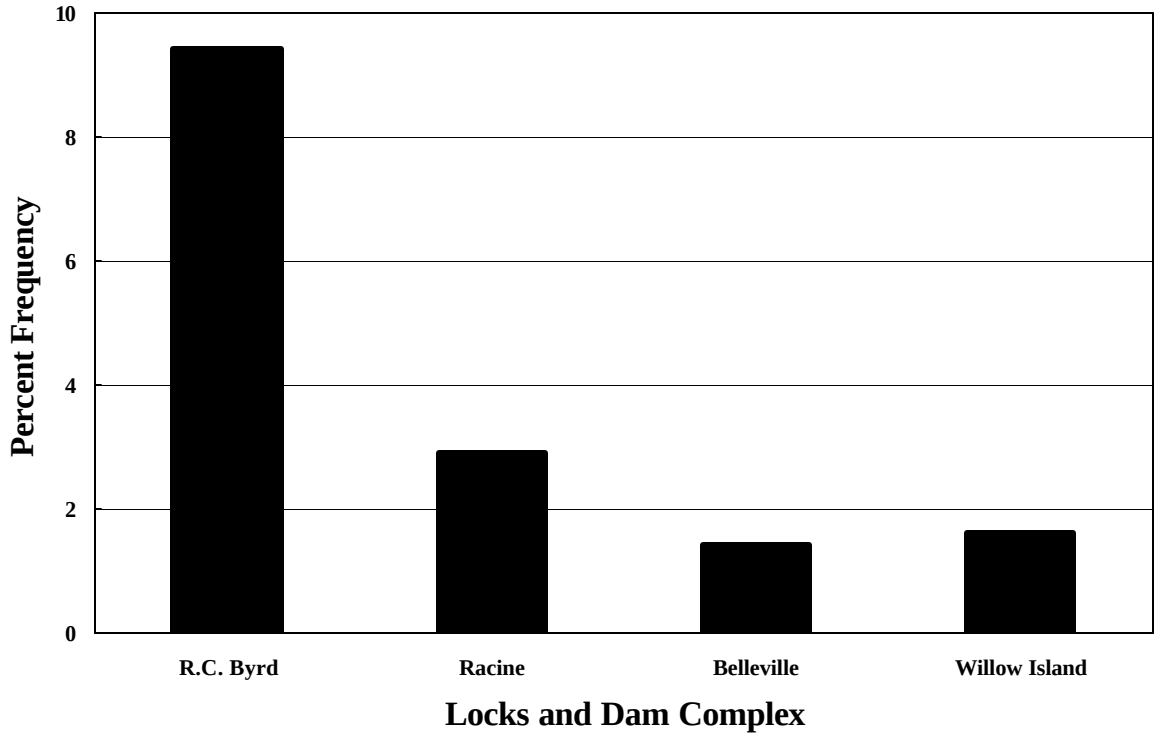


Figure 7. Percent of time by hours that river stage differences (upstream-downstream) is equal to or less than five feet on four middle Ohio Rive locks and dam complexes (November 2001 through January 2004).

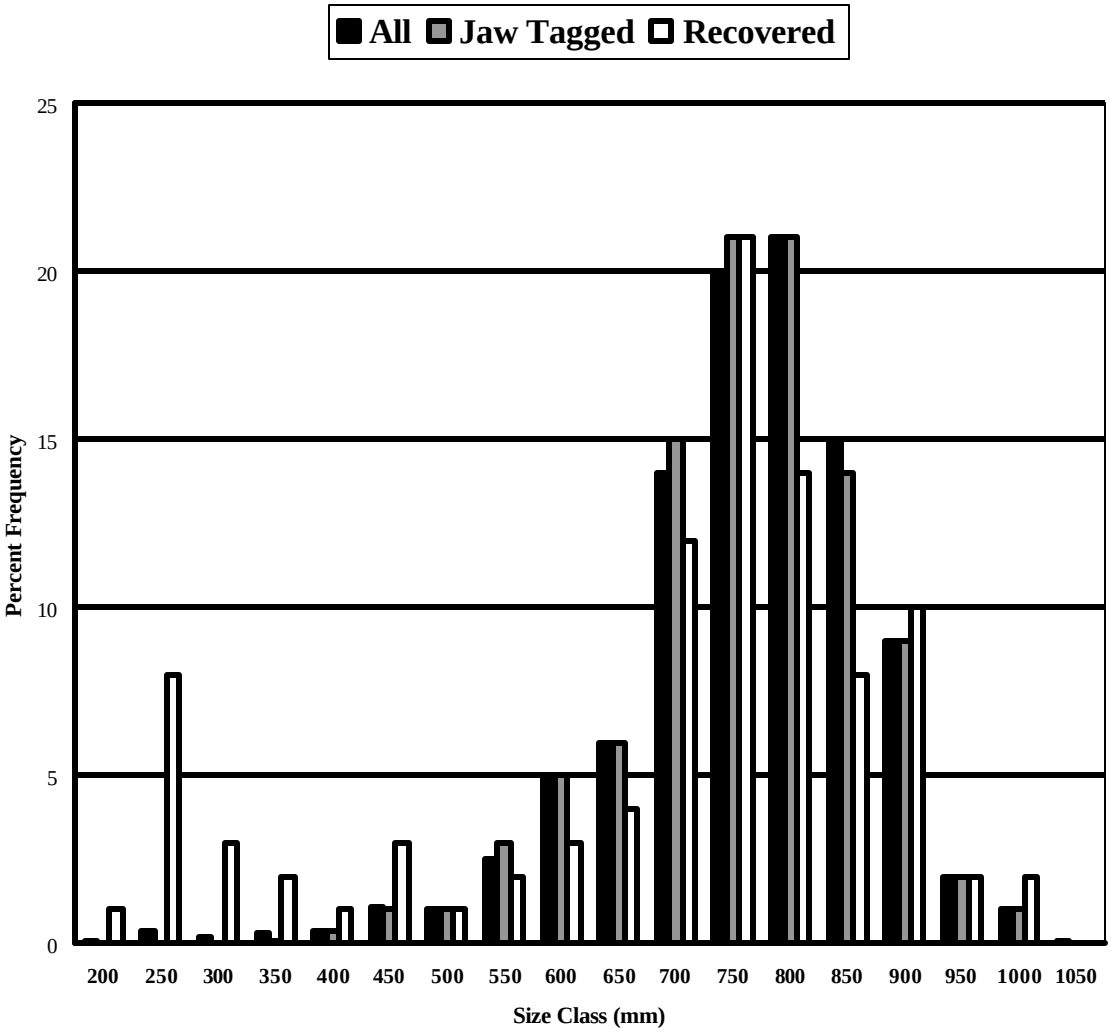


Figure 8. Length frequency histogram for three sub-samples of paddlefish handled, jaw tagged, and recovered from the Ohio River sub-basin. December 2001 through March 2003.

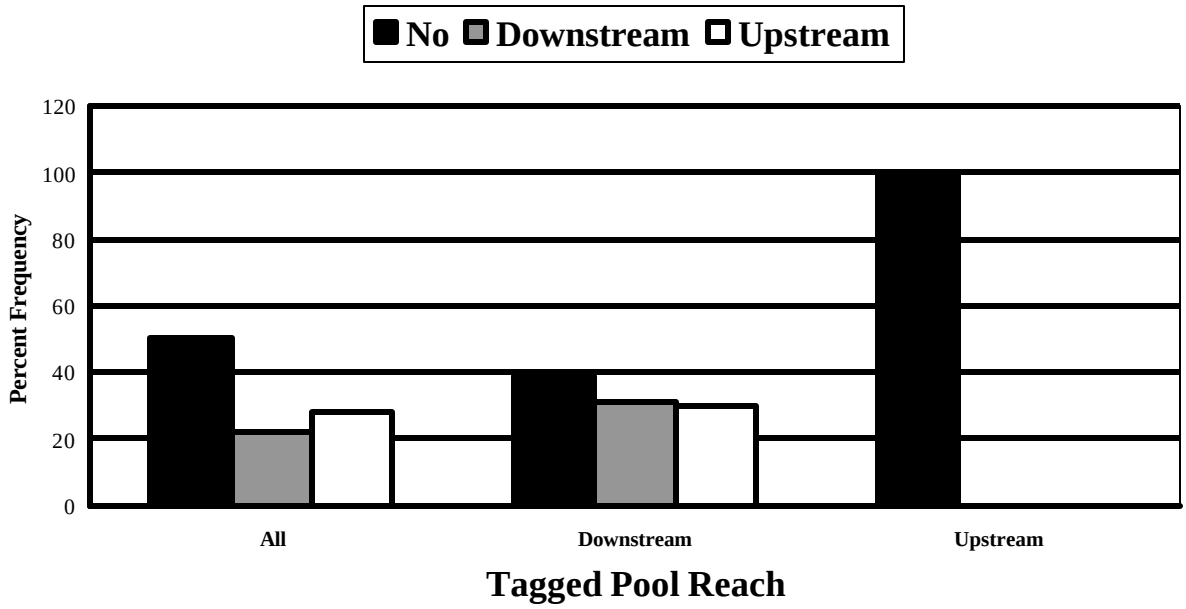


Figure 9. Movement patterns as described by percent frequency for Ohio River paddlefish tagged in three locations. December 2001 through March 2003.

Chapter 3

Ohio River Mainstem System Study (ORMSS)

Fish Passage: Direct Observation Task

Introduction

Fish passage through large navigational locks and dam complexes has been proposed as one factor in the paucity of re-colonization of many large river species within the Ohio River sub-basin (USACOE 2000). Although often common in downstream reaches, large river species have not efficiently re-colonized the upstream Ohio River reaches even with the vast improvement of water quality. This has lead many state and federal agencies to initiate restoration of large river species such as paddlefish and shovelnose sturgeon in the upper Ohio River sub-basin (Henley et al. 2002).

The construction of fifty low-head locks and dam complexes in 1800s and early 1900s initially lead to the temporal fragmentation of the Ohio River. Although, seasonally flooding did offer an opportunity for fish to migrate along the river course, this fragmentation was further enhanced with the completion of 20 high-lift dams maintaining a 2.7m channel (Pearson and Pearson 1989). This disruption of natural hydrologic regimes has resulted in a cascade of declining ecological conditions (Ligon et al. 1995).

Fish passage problems related to locks and dam complexes are well documented for salmonid fish species (Bergkamp et al. 2000). Warmwater species are not as well studies, but several species appear to be impacted. Pearson and Pearson (1989) attributed the elimination of Alabama shad in the Ohio River sub-basin to reduced movement due to

high lift dams. Reviews of tagging and distributional data suggest that decreased interpool movement opportunities of large river species such as paddlefish and shovelnose sturgeon may be a factor in impeding range expansion back to their historic accounts (Henley et al. 2002; ORSANCO 2002). This is especially important relative to improved water quality in the middle and upper Ohio River leading to increased habitat for large river fish species.

The suggestions that fish passage problems exist in the Ohio River sub-basin was expressed by both federal and state biologists. Consequently as part of the Ohio Roiver Mainstem System Study of navigational activities on the Ohio River, the study reported herein was proposed and funded.

Specific objectives were:

4. To determine if fish community structure within lock chambers are similar to tailwater related fish community,
5. To determine short-term movement patterns of target species, and
6. To ascertain hydrologic conditions which may promote the passage of the target species.

Approach

Field investigations were segmented into two phases. First, an investigation was conducted to determine if the fish community inhabiting lock chambers were representative of tailwater reaches. The second phase was to determine short-term movement patterns of targeted species.

The Winfield Locks and Dam complex was selected as the study site. This complex is located on the Kanawha River (KRM 31.1), a major tributary of the Ohio River. The tailwater reach of the Winfield Locks and Dam complex is open to the Ohio River and part of the R.C. Byrd Pool. Consequently, fish fauna are similar to Ohio River

tailwaters. Structural, the locks and dam complex is the newest within the Ohio River sub-basin being completed in 1997. The main lock is 34m feet wide and 244m long. Two smaller (17m x 110m) auxiliary locks are present.

Fish community structure was determined during May, August, and September 2002. Pulsed DC electrofishing equipment, gill nets, and hoop nets were employed to determine the fish composition of the tailwater. The lock chamber was surveyed in September 2002 using standard fish toxicant applications. The auxiliary chamber was used in this task. All fish were identified to species relative abundance determined. Because each technique provided a different catch per unit effort metric, no standard metric was available.

Intensive fish sampling tasks were conducted from 19 May 2003 through 29 July 2003. Specific study locations were the Winfield Locks and Dam complex tailwater (KRM 28.0-30.8), the R.C. Byrd Pool (KRM 19.0-28.0; ORM 240.0-237.5), the Winfield Pool (KRM 31.5-40; KRM 66.0-67.7). These locations were selected because of the proximity to the Winfield Locks and Dam complex (KRM 28.0-30.8, KRM 19.0-28.0, and KRM 31.5-40), as well as locations where fish were know to congregate (KRM 66.0-67.7; ORM 240.0-237.5). The Winfield Locks and Dam complex tailwater was the location of all tagging and marking tasks. Other locations, as well as the Winfield Locks and Dam complex tailwater, were surveyed for the recovery of tagged and/or marked fish.

Six fish species were selected to represent large river fishes occupying different behavior and habitat guilds. All species are common to the Ohio River sub-basin. Hybrid striped bass were selected because of their migratory tendencies. Results from an ongoing

study suggest that hybrid striped bass within the Ohio River move great distances (WVDNR 2004). Sauger and skipjack herring also were selected because of their migratory tendencies. Sauger represent a benthic species and skipjack herring a pelagic species. Channel catfish movement trends are not well-known, but are considered habitat generalists and are common in large rivers. Smallmouth buffalo and freshwater drum are both abundant in large river habitats, and are especially common in tailwater reaches associated with locks and dam complexes.

Hybrid striped bass were collected using pulsed DC boat-mounted electrofishing gear during six periods in May and June 2003 (Table 1). Each individual were separately measured and tagged with color-coded, uniquely numbered T-Bar anchor tags. A mailing address number and a reward announcement was printed on each tag. Prior to release, individual fish were retained for a minimum of 10-minutes to insure recovery and fish that appeared stressed were not released.

The remaining species also were collected using pulsed DC boat-mounted electrofishing gear during six periods in May and June 2003 (Table 1). Fish were held in well aerated live-wells prior to marking with elastomer injections. Fish were injected with three colors (yellow, red, and green) marks in either a caudal, pelvic, or pectoral fin. The combination of color and mark location enabled investigators to identify individuals as to the tagging day.

Upon the completion of tagging and/or marking, all fish were released within 0.4km of the end of the lock wall. Fish were observed to insure that equilibrium was achieved and that fish exhibited a positive response to water flow.

Recovery tasks included electrofishing surveys at the previously described

locations using pulsed DC boat-mounted electrofishing gear. At each location, investigators expended a minimum of 3-hours of peddle-time and attempted to collect as many of the target species as possible. Target species were netted and examined to determine the presence or absence of tags and/or marks. To expedite sampling and an attempt to increase sample size, no individual measurements were taken of target species during the recovery phase.

Anglers were encouraged to return tags from recaptured hybrid striped bass through both active and passive methods. Investigators questioned anglers at the Winfield, Racine, and Marmet tailwaters during the May-July period when surveys were conducted. In addition, posters were placed at local boat docks and ramps, and a news release was provided to local newspapers. Anglers were encouraged to return tags and provide information of location and date of recapture.

Water level and discharge information were acquired from USGS database (USGS 2003) and linked to specific time periods. Water levels at specific locks and dam complexes was acquired from the U.S. Army Corps of Engineers District offices and elevations between upstream and downstream points at locks and dam complexes were ascertained by subtracting the downstream elevation from the upstream elevation.

Movement was ascertained for all recaptured fish (tagged and marked) by both electrofishing and angling techniques. Movement was determined both longitudinal and temporal.

Results

Fish Composition:

Fish species composition was determined from the tailwater reach and the lock chamber to determine if communities were similar. Species common to both habitats were gizzard shad, the minnows and shiners (ghost shiner, emerald shiner, and channel shiner), and freshwater drum (Table 2). Species more common in tailwater habitats were white bass, skipjack herring, and sauger, and in lock chamber habitats were channel catfish, the sunfishes (*Lepomis* and *Pomoxis*), as well as hybrid striped bass. Species such as some of the catostomids and centrarchids were fairly uncommon in both types of habitats. More migratory species appeared to occupy both habitat types, but to a differing abundance. Abundant migratory species in the lock chamber habitat included hybrid striped bass and gizzard shad. White bass, sauger, and gizzard shad, all migratory species, were more common in the tailwater sections. Common more lenthic species, such as the centrarchids, were more common in the lock chamber habitats.

Short-term Movement Studies:

The selection of hybrid striped bass, sauger, smallmouth buffalo, skipjack, freshwater drum, and channel catfish as study species was partially based on findings reported in the previous section. These species were found to be both abundant and at least temporarily inhabiting a lock chamber.

Hybrid Striped Bass Movement Patterns: Hybrid striped bass were tagged with T-bar anchor tags on six occasions within 15-days. One-hundred and thirty-eight individuals were tagged ranging in size from 280-630mm in total length (Table 3). The majority of the fish were tagged and released on 20 May, 22 May, 27 May, and 28 May. Investigators recovered 4 (3%) tagged individuals within the first 15 days following tagging (Table 4). No fish were recovered using electrofishing techniques after 4 June, nor were any fish

recovered from outside of the Winfield Tailwater. Hybrid striped bass tagged on 22 May were recovered on 27 May and 2 June approximately 0.5km downstream of the Winfield Locks and Dam complexes. One hybrid striped bass tagged on 27 May was recovered on the dam side of the complex (w/in 0.25km of dam near the hydropower discharge) on June 2. A second hybrid striped bass tagged on 28 May and recovered on 2 June was located approximately 0.5km downstream of main lock chamber. Although hybrid striped bass were released in the area just downstream of the main and auxiliary lock, in the main lock, as well as the downstream of the miter gates, no fish were collected in these areas.

Anglers caught 15 (11%) of the tagged hybrid striped bass. Twelve recaptured hybrid striped bass were caught from either the R.C. Byrd Pool (Winfield Tailwater, Kanawha River, or the Racine Tailwater, two from the Racine Pool (Belleville Tailwater), and no recapture location was reported for one individual (Table 5). No hybrid striped bass displayed an upstream movement pattern through the Winfield Locks and Dam complex.

Most re-captured hybrid striped bas were angler-caught from the Winfield Tailwater (9 individuals) indicating little movement. Anglers caught tagged-individuals up to 76 days following tagging within the Winfield Tailwater. Two 20 May tagged-fish were reported captured within 5 days of tagging. Both individuals were caught in the Winfield Tailwater adjacent to the hydropower unit discharge. All other individuals were caught by anglers at least 15-days following tagging (Table 5).

Intra-pool movement patterns were noted for two individuals. One 20 May tagged-individual was recaptured 86 days later just downstream of the Racine Locks and

Dam Complex. An additional 22 May tagged-individual was caught at the confluence of the Ohio and Kanawha rivers following a 97-day period (Table 5).

Two tagged hybrid striped bass did display inter-pool movement patterns. Both individuals moved in a downstream pattern and through the Racine Locks and Dam Complex (Ohio River) prior to capture just downstream of the Belleville Locks and Dam Complex. These fish were at-large for a 31 and 43 day period (Table 5).

Two 20 May tagged-fish were reported captured within 5 days of tagging. Both individuals were caught in the Winfield Tailwater adjacent to the hydropower unit discharge. All other individuals were caught by anglers at least 15-days following tagging (Table 5).

Multi-species Short-term Movement Patterns: Sauger, channel catfish, smallmouth buffalo, and freshwater drum were selected based on behavioral characteristics and their abundance in the Ohio River sub-basin. Fish were inserted with either yellow, red, or green elastomer in either the caudal, pelvic, or pectoral fins (Table 3). Seventy-nine sauger, 81 smallmouth buffalo, 120 skipjack herring, 150 freshwater drum, and 120 channel catfish were inserted in May-June 2003. Recovery tasks were conducted for a period through 29 July 2003. No marked skipjack herring were recovered during the study period. Skipjack herring, although an excellent candidate species for a movement study, are difficult to maintain and easily stressed. Marked individuals of all other species were recovered during the study period.

Twelve sauger (15%) were recovered from the Winfield Tailwater within 10 days of marking. No sauger were recovered after 2 June or from locations outside of the Winfield Tailwater. Similarly, channel catfish (15 of 120-12%), smallmouth buffalo (3

of 81-4%), and freshwater drum (9 of 150-6%) were recovered only from the Winfield Tailwater within 10 days of marking (Table 6).

Discussion

The fish fauna inhabiting the lock chamber of large navigational facilities were often used to assess the biotic health of large rivers (Lowman 2000) and were historically considered representative of these unique river systems. A review of ORSANCO (2002) indicated that fewer larger river fishes (paddlefish etc) were collected in tradional lock chamber surveys. Species composition structure information collected in this study further suggests that lock chambers represent a fairly unique assemblage of fish species and may not be truly representative of the fish fauna found in tailwater reaches. This further suggests that many migratory species are not attracted to lock chamber and consequently are not afforded the opportunity to pass through these complexes when typical navigational lockage operations are preformed.

Short-term movement patterns reported in this study suggest that several factors may be important in providing opportunities to fish passage. Several investigators have suggested that river stage (primarily increasing) may influence fish movement behavior leading to an increased passage through locks and dam complexes. Fish were tagged during both an increasing and decreasing river stage in this study (Figure 1), but no movement was detected. Interestingly, upstream movement through locks and dam complexes were noted during an accompanying study of sauger and white bass. This movement appeared to be triggered by increasing water levels and the approachment of open river conditions. Although water levels were increasing and at above normal levels,

the condition at the Winfield Locks and Dam Complex did not reach open river condition until after 18 June.

A secondary factor that may explain the paucity of upstream movement and passage through the Winfield Locks and Dam Complex may be the geographical location of the complex. Several investigators have suggested that fish inhabiting a tributary river may show a greater affinity to the larger parental river. All fish recovered from this study that displayed movement were located downstream of the complex and several were in the Ohio River. This affinity for larger river by great river species, especially during abnormal high flows may be a behavioral trait that hinders the re-colonization of great river species in large tributary rivers. A review of ORSANCO (2002) and WVDNR (fish database) suggests that this may be occurring.

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Table 1. Survey scheme for tasks conducted at the Winfield Locks and Dam Complex, May through July 2003.

	May 2003									
Location	**19-May**	**20-May**	**21-May**	**22-May**	**23-May**	**27-May**	**28-May**	**29-May**	**30-May**	
Winfield TW										
Winfield Pool										
Racine TW										
R.C. Byrd Pool										
	June 2003									
Location	**2-Jun**	**3-Jun**	**4-Jun**	**5-Jun**	**6-Jun**	**9-Jun**	**10-Jun**	**11-Jun**	**12-Jun**	**13-Jun**
Winfield TW										
Winfield Pool										
Racine TW										
R.C. Byrd Pool										
	June/July 2003									
Location	**17-Jun**	**18-Jun**	**23-Jun**	**24-Jun**	**30-Jun**	**8-Jul**	**9-Jul**	**14-Jul**	**15-Jul**	**29-Jul**
Winfield TW										
Winfield Pool										
Racine TW										
R.C. Byrd Pool										
		Elastomer Marks								
		T-Bar Tags and Elastomer Marks								
		T-Bar Tags								
		Recovery of Tags and Marks								

.

Table 2. Species composition and abundance ranks for fish collected from the tailwater and lock chamber at the Winfield Locks and Dam Complex.

		Tailwater Reach		Lock Chamber
Species	**Family**	**Electrofishing Rank**	**Gill Net Rank**	**Toxicant Application Rank**
Gizzard Shad	Clupeidae	1	1	4
Skipjack Herring	Clupeidae	2	2	7
Shorthead Redhorse	Catostomidae	3	6	NA
White Bass	Moronidae	4	3	9
Emerald Shiner	Cyprinidae	5	NA	1
Freshwater Drum	Sciaenidae	6	4	5
Ghost Shiner	Cyprinidae	7	NA	3
Channel Shiner	Cyprinidae	8	NA	2
Smallmouth Buffalo	Catostomidae	9	7	11
Bluegill	Centrarchidae	10	NA	10
Longnose Gar	Lepisosteidae	11	5	8
Common Carp	Cyprinidae	12	8	14
Channel Catfish	Ictaluridae	13	9	6
Flathead Catfish	Ictaluridae	14	11	15
Sauger	Percidae	15	10	20
Largemouth Bass	Centrarchidae	16	NA	16
Hybrid Striped Bass	Moronidae	18	12	12
Longear Sunfish	Centrarchidae	19	NA	18
Spotted Bass	Centrarchidae	22	NA	17
White Crappie	Centrarchidae	27	NA	13
Green Sunfish	Centrarchidae	NA	NA	19

Table 3. Survey days, number of individuals tagged and/or marked and color and location scheme employed at the Winfield Locks and Dam Complex. May through June 2003.

	Date Tagged or Marked								
	19-May	**20-May**	**21-May**	**22-May**	**27-May**	**28-May**	**2-Jun**	**4-Jun**	**Total**
	T-Bar Anchor Tags								
Hybrid Striped Bass		34		46	26	24	3	5	138
	Elastomer Marks								
Sauger	12	15	16	22	9	0	5	0	79
Smallmouth Buffalo	10	10	15	17	10	0	19	0	81
Skipjack Herring	20	20	20	20	20	0	20	0	120
Freshwater Drum	25	25	25	25	25	0	25	0	150
Channel Catfish	20	20	20	20	20	0	20	0	120
Color	Yellow	Yellow	Yellow	Red	Red		Green		
Location	Caudal	Pelvic	Pectoral	Caudal	Pelvic		Pelvic		

Table 4. Recovery patterns of t-bar anchor tagged hybrid striped bass form the Winfield Locks and Dam Complex, May-June 2003.

	Date Recovered							
Date Tagged	**20-May**	**21-May**	**22-May**	**27-May**	**28-May**	**2-Jun**	**4-Jun**	**Total**
	Electrofishing Technique Recovery							
20-May		0	0	0	0	0	0	0
22-May				1	0	1	0	2
27-May				0	0	1	0	1
28-May					0	1	0	1
2-Jun							0	0
4-Jun								0
	Angling Recovery							
20-May		1	0	1	0	0	0	2
22-May			0	0	0	0	0	0
27-May				0	0	0	0	0
28-May					0	0	0	0
2-Jun					0	0	0	0
4-Jun							0	0

Table 5. Recovery patterns of angling recaptured t-bar anchor tagged hybrid striped bass from the Winfield Locks and Dam Complex.2003.

Date Tagged	Date Recovered	Days At-Large	Recaptured Location
20-May	21-May	1	Winfield TW
20-May	25-May	5	Winfield TW
20-May	14-Aug	86	Racine TW
22-May	22-Jun	31	Belleville TW
22-May	4-Jul	43	Belleville TW
22-May	28-Jul	67	Winfield TW
22-May	1-Aug	71	Winfield TW
22-May	17-Aug	89	Belleville TW
22-May	27-Aug	97	Kanawha River (KRM 2.0)
27-May	11-Aug	76	Winfield TW
27-May	11-Aug	76	Winfield TW
28-May	15-Jun	18	Winfield TW
28-May	1-Aug	65	Winfield TW
2-Jun	UK	UK	UK
4-Jun	29-Jul	55	Winfield TW

Table 6. Recovery patterns of boat-mounted electrofished recaptured elastomer marked sauger, channel catfish, smallmouth buffalo, and freshwater drum from the Winfield Locks and Dam Complex.2003.

Date Marked										
	Sauger					Channel Catfish				
Recovery	**19-May**	**20-May**	**21-May**	**27-May**	**2-Jun**	**19-May**	**20-May**	**21-May**	**27-May**	**2-Jun**
20-May	2					0				
21-May	0	3				0	1			
23-May	0	1	2			2	0	3		
27-May	1	0	1			0	0	1		
28-May	0	0	0	0		0	0	0	3	
30-May	0	0	0	0		0	0	0	2	
2-Jun	0	0	0	0		0	0	0	0	
4-Jun	0	0	0	0	1	0	0	0	0	0
9-Jun	0	0	1	0	0	0	0	0	0	0
10-Jun	0	0	0	0	0	0	0	0	1	2
12-Jun	0	0	0	0	0	0	0	0	0	0
13-Jun	0	0	0	0	0	0	0	0	0	0
Total	3	4	4	0	1	2	1	4	6	2
Percent	25	27	25	0	20	10	5	20	30	10
Date Marked										
	Smallmouth Buffalo					**Freshwater Drum**				
Recovery	**19-May**	**20-May**	**21-May**	**27-May**	**2-Jun**	**19-May**	**20-May**	**21-May**	**27-May**	**2-Jun**
20-May	0									
21-May	1					2	0			
23-May	0	0	0			0	0	0		
27-May	0	0	0			0	0	2		
28-May	0	0	0	1		0	0	0	0	0
30-May	1	0	0	0		0	0	0	3	0
2-Jun	0	0	0	0		0	0	0	1	0
4-Jun	0	0	0	0	0	0	0	1	0	0
9-Jun	0	0	0	0	0	0	0	0	0	0
10-Jun	0	0	0	0	0	0	0	0	0	0
12-Jun	0	0	0	0	0	0	0	0	0	0
13-Jun	0	0	0	0	0	0	0	0	0	0
Total	2	0	0	1	0	2	0	3	4	0
Percent	20	0	0	10	0	8	0	12	16	0

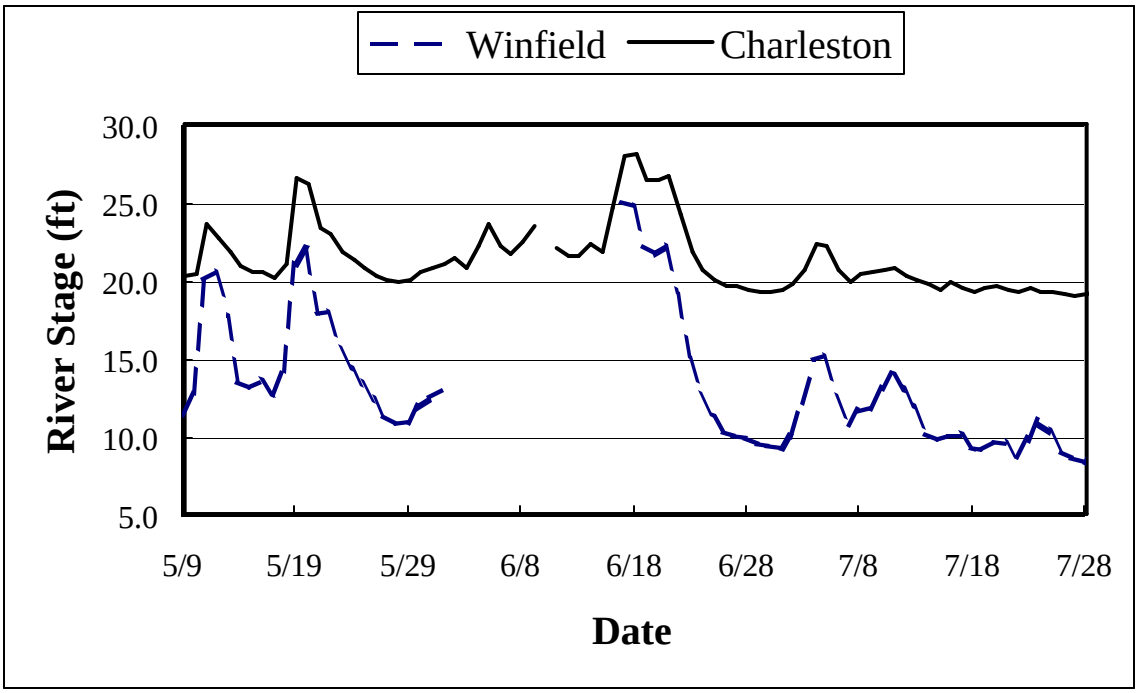

Figure 1. River stages from two gage locations on the Kanawha River for the period May 1 through July 31, 2003.

Chapter 4

Ohio River Mainstem System Study (ORMSS)

Recreational Fishery Survey Task

Introduction

Recreational angling activities provide enjoyment and potential food for many anglers, as well as an economic benefit to local businesses and communities. In 2001, over 34.1 million Americans fished spending 557 million days pursuing both freshwater and saltwater fishes. Americans spent over 35 billion dollars during this period of which over 14 billion were spent directly on angling trips. Anglers seeking freshwater fishes represented 83% of the American fishing public with over 90% of these anglers fishing in systems other than the Great Lakes (USFWS 2003a).

Over 5.5 million anglers within the six Ohio River bordering states fished in 2001 spending over $ 15.00 per trip (USFWS 2003b). In West Virginia, greater than 35% of the population over 16 years of age fished during 2001. Anglers fishing in non-Great Lakes waters spent over 30% of their angling-time fishing in rivers. In West Virginia, anglers spent over 70% of their angling-time fishing in rivers (USFWS 2002b). Consequently, angling is an important recreational activity to many living within the states bordering the Ohio River. In addition, economic benefits to local businesses are vital to their continued financial well-being.

Ohio River angling opportunities are diverse both in species sought and habitat available. Major recreational fisheries exist for sauger, walleye, white bass, hybrid striped bass, as well as the catfishes and black basses. Open river sections, embayments and

backwaters, as well as tailwaters provide habitat for both anglers and fishes. Schell et al. (1996) reported that tailwaters comprise only 1% of available angling habitat in the Ohio River, but generated more than 66% of the total catch. Sauger, catfish, and *Morone* species were reported highly sought in this 1991 survey. Angler expenditures were estimated at 23.7 million dollars in 1992 and 10.2 million dollars for selected Ohio River pools. Tailwaters associated angler expenditures represented nearly 58% of the total expenditures for these two years (Schell et. al 1996).

Tailwater areas are high-use reaches for the Ohio River fisheries. Access to tailwaters by shore anglers is generally excellent providing opportunities to both young and more mature anglers. The maintenance of multi-purpose recreational sites at a few locks and dam complexes by the U.S. Army Corps of Engineers provide one avenue of angler access. Other less developed access sites are designed primarily for the angling and wildlife viewing public. Boat anglers access is more limited with few ramps within close proximity to tailwaters (ORFMT 1995). Safety and land ownership issues often hinder the development of boat access sites, as well as use of tailwater reaches by boating anglers.

Contaminant issues are persistent in the Ohio River in spite of the remarkable clean-up of water quality problems. One legacy of our non-regulated industrial heritage is the continued elevated levels of contaminants in many freshwater fishes. The issuing of consumption advisories on many Ohio River fishes by state health agencies is one aspect of protecting public health. Recently, risk assessment procedures have outlined both the potential risk and benefit of eating fish.

The presence of locks and dam complexes for navigation purposes on the Ohio River and the resulting angling high-use tailwater reaches created by these complexes were paramount in the decision-making process to assess recreational angling activities. In addition, the presence of data collection biologists at tailwater areas during peak sauger and white bass fishing periods would enhance the recapture of tagged individuals in coordination with a related study.

Specific objectives were:

7. To determine recreational angling effort at several Ohio River tailwaters,
8. To ascertain catch and harvest parameters of selected sport fishes,
9. To provide some demographic trend information, and
10. To compare current recreational angling activities with results from previous surveys.

Approach

Angler recreational surveys were conducted at eight tailwaters for a minimum of 12 months (Figure 1). Data collection biologists conducted surveys three days per week (1 weekend period and 2 weekday periods) for an eight-hour period. Survey dates were randomly selected on a seasonal frame. Start times were assigned as either dawn or ½ of the daylight period following dawn on a seasonal frame. Daily survey periods did not overlap. Count times were randomly assigned at four 15-minute intervals per day. These data were used to estimate total angling effort in hours.

A modified bus-stop method was employed at most tailwaters were more than one access site was present (Jones and Robson 1991). Surveys were conducted either on foot at access sites or via boat where access was limited. Boat surveys were conducted primarily at the J.T. Myers and New Cumberland tailwaters.

The ORFMT state agencies developed survey forms that were consistent with past investigations (Schell et al. 1996; Pierce et al. 1983). Information on species caught and

released, directed effort (what species group an individual angler-trip was seeking), length of harvested individuals, and some demographic information were included for query. Prior to the survey, data collection biologists were instructed as to the protocol, as well as provided on-site training by ORFMT state biologists. Most data collection biologists had multi-years of experience and those who did not have extensive experience were initially checked on-site weekly. ORFMT biologists also randomly visited tailwater locations to insure compliance with schedules and protocols. All interviews were conducted by angler groups.

Data were recorded on paper copy and checked monthly by an experienced data collection biologist. Once approved, data were entered using an entry template developed by the Ohio Division of Wildlife. Data sets were visually reviewed, as well as scanned by a program to insure quality. Once, deemed of approved quality, the Ohio Division of Wildlife Inland Fisheries Research Group conducted analysis using a SAS-based analytical package with the methods described in Pollock et el. (1994). Results were reported as catch rate (no./hr), effort (hours), and directed effort (%), and length of harvested individuals (mm; total length except for paddlefish which was recorded as eye-fork length).

Results obtained in the survey described herein were compared with results reported by Schell et al. (1996) and ORFMT (2001). Comparisons were limited because of differences in survey periods, locations, and protocol. A previous study (Pierce et al. 1983) did not provide appropriate comparative data.

Results

Tailwaters were surveyed from September 2001 through February 2003. Most surveys were initiated in either September or October 2001. The Markland tailwater

survey was initiated in February 2002 because of personnel hiring problems. All surveys were concluded by October 2002 except for the Markland, McAlpine, and J.T. Myers tailwaters. These surveys were extended until February 2003 primarily to collect more information for paddlefish tag recovery tasks or to fulfill contractual commitments.

Interviews were conducted on over 8,500 angler-trips at the eight tailwaters. Directed effort groups were dominated by any species (33%) and percids (24%) river-wide. Catfish (17%), *Morone* species (16%), paddlefish (10%), and black bass (1%) were represented. Directed effort groups did differ among tailwaters. The any species group and percid group (Table 1; Figure 2) dominated most upper tailwaters (i.e. including and upstream of the R.C. Byrd tailwater). Catfish were of greater importance in lower river tailwaters. Fifty-seven percent of total angling effort at the J.T. Myers tailwater was directed towards catfish. Paddlefish were of importance at the Markland tailwater with 43% of the effort being expended on this group (Table 1). The Greenup tailwater fishery was dominated by *Morone*-seeking anglers (44%).

Angling effort (hours) was determined monthly by tailwater. Angling effort peaked in the June-August period and in the late-fall for all tailwaters (Table 2; Figure 3). These peaks most likely were related to the catfish fishery (summer), as well as the percid and *Morone* fishery (late-fall). Because not all tailwaters were surveyed during the same 12-month period, comparisons by tailwaters were made only for the February 2002 through September 2002 period (Figure 4). The McAlpine and Willow Island tailwaters had the greatest total angling effort during this period with hours of 19,969 and 15,917 respectively. Also, during this period total angling hours exceeded 10,000 for the Greenup tailwater (12,918 hrs), the J.T. Myers tailwater (12,533 hrs), and the R.C. Byrd

tailwater (10,631 hrs). The Pike Island tailwater (9,475 hrs) and the New Cumberland tailwater (4.924 hrs) experienced the least angling effort during this period (Figure 4).

Catch rates by directed species group are reported herein for sauger, all percids (sauger, saugeye, walleye), hybrid striped bass, white bass, and channel catfish (Table 3). Other species catch rates are available in the accompanying data files. Sauger catch rates ranged from 1.86/hr for the Pike Island tailwater to 0.22/hr for the Markland tailwater (Figure 5). Total percid catch rates ranged from 1.89/hr for the Pike Island tailwater to 0.22/hr for the Markland tailwater (Figure 5). In the Markland, McAlpine, and J.T. Myers tailwaters, the percid fishery was dominated (>98%) by sauger. In other tailwaters, percid directed anglers also caught saugeye and walleye.

Hybrid striped bass catch rates were greatest at the Greenup tailwater (1.64/hr) and least at the R.C. Byrd tailwater (0.19/hr). White bass catch rates were dissimilar with catch rates exceeding 0.75/hr at the Pike Island tailwater (1.28/hr), R.C. Byrd tailwater (0.88/hr), and Willow Island tailwater (0.79/hr). Several tailwaters experienced intermediate catch rates for both hybrid striped bass and white bass (Figure 5).

Channel catfish catch rates were greatest at the J.T. Myers tailwater (0.68/hr) and lowest at the Willow Island tailwater (0.04/hr). Catch rates at the R.C. Byrd and Greenup tailwaters exceeded 0.40/hr (Figure 5).

Paddlefish were only caught at the J.T. Myers and Markland tailwaters in adequate numbers to determine catch rates. Paddlefish catch rate at the Markland tailwater was 0.20 and 0.19/hr. at the J.T. Myers tailwater. An estimated 2,064 paddlefish were caught at all Ohio River tailwaters of which 92% were harvested. The majority of

paddlefish were caught at the Markland tailwater (867-99% harvested) and J.T. Myers tailwater (967-99% harvested).

Estimated number caught of major species at each tailwater for the entire period is presented in Table 4. Over the study period, sauger, hybrid striped bass, and white bass were the dominant species caught. Percent harvested ranged from 92% for paddlefish to 3% for hybrid striped bass. River-wide 34% of sauger, 13% of white bass, 31% of channel catfish and 77% of blue catfish were harvested (Table 4). Percent harvested of major sportfish was influenced by geographic location. Anglers at the J.T. Myers tailwater harvested over 50% of all major sportfish caught. In contrast, anglers at the Willow Island tailwater harvested less than 10% of all sportfish caught (Figure 6).

Anglers harvested sportfish at sizes that suggest some selection (Figure 7). Sauger were harvested at sizes ranging from 150-650mm with the majority in the 300-350mm size classes. Walleye were harvested ranging from 275-625mm with the majority within the 350-475mm size classes. White bass were harvested from a range from 175-450mm with the majority in the 225-325mm size class. Hybrid striped bass were harvested in a range from 275-775mm with the majority in the 400-500mm size class. Striped bass were harvested at a slightly larger size class than hybrid striped bass (Figure 7).

Catfish species length at harvest showed similar results (Figure 8). Blue catfish were caught at a wide range of lengths with only a slight peak in the 350-400mm length range. In contrast, channel catfish length frequency distribution was narrower with the majority in the 400-600mm size classes. Flathead catfish displayed a more skewed length frequency distribution towards larger individual. Eye-fork length of harvested paddlefish

was dominated by individuals in the 700-900mm size classes, but individuals were harvested as small as 300mm (Figure 8).

Anglers resided primarily within the bordering states adjacent to the tailwaters (Table 5). J.T. Myers tailwater anglers were primarily from Kentucky and Illinois. Kentucky is a bordering state, while Illinois anglers have easy boat access. The Willow Island tailwater anglers were primarily from West Virginia. A data set of all zip code information is provided.

Discussion

Ohio River tailwater-anglers sought primarily those species related to tailwater habitats. Directed effort towards percids (24%), catfish (17%), *Morone* species (16%), and paddlefish (10%) were dominate, although in some tailwaters those anglers seeking any species exceeded species-directed anglers. Species such as centrarchids not associated with tailwater reaches were not sought or caught. Schell et al. (1996) reported that 21% of all Ohio River anglers were seeking black bass; in contrast, less than 1% of the tailwater anglers sought this species group. Schell et al. (1996) also reported that directed effort toward any species (50%) and catfish (12%) were the dominant groups in the 1992-1993 survey for the entire pool. Although no definitive tailwater directed use data are provided by Schell et al. (1996), catches of percids and *Morone* sp. were reported primarily from tailwater areas suggesting a greater use by those directed effort anglers in tailwaters.

Geographic differences of directed effort were evident with the upstream tailwater fisheries dominated by any species and percid groups, the Greenup tailwater by the *Morone* sp. group, and the J.T. Myers tailwater dominated by catfish group. It appears

that the diverse interest in these fisheries are directed by culture, abundance of a given fish species, and the presence or perception of a consumption advisory or health risk. Catfish angling is of greater importance in mid-west and southern states where catfish are often considered a trophy fish (USFWS 2003b, Burlingame and Guy 1999). TVA (1998) reported that anglers sought catfish (20%) at the Watts Bar tailwater on the Tennessee River. Both blue and channel catfish are present in downstream Ohio River tailwaters, and are often extremely abundant. In upstream tailwaters, blue catfish are uncommon or are considered extirpated. Consumption advisories have and continue to be present in the upper Ohio River with a Do Not Eat restriction for channel catfish greater than 430mm, and a six meals per year restriction of channel catfish and flathead catfish less than 430mm (WVDNR 2004). The importance of percids and *Morone* species in upstream tailwaters is partially the result of the abundance of these species as compared to other game species inhabiting tailwater reaches, the hydrologic conditions at locks and dam complexes that congregate these species, and the overall cultural importance of angling and the seasonal trends of these fisheries.

Paddlefish were only sought at the J.T. Myers and Markland tailwaters. By catch was reported at other lower river tailwaters. Directed paddlefish angling is prohibited in the Ohio-West Virginia reach of the Ohio River (WVDNR 2004), consequently no legal fishing is present. The Markland tailwater has historically been popular for paddlefish angling, and hydrologic conditions at this locks and dam complex congregate this species (Henley et al. 2002).

Angling effort (hours) was compared with previous Ohio River recreational survey. Angling effort was greatly reduced in the present survey compared to that

reported by Pierce et al. (1983), Schell et al. (1996), and ORFMT (2001). A reduction of over 50% was found for the same period in 2000 as 2002 for the New Cumberland, Pike Island, Willow Island, Greenup, and Markland tailwaters. The Greenup tailwater represented the greatest reduction with over 90% fewer hours expended in 2002 than 2000. Factors contributing to these reductions appear to be related to both water levels and security issues. Water levels were considerable higher in 2002 than 2000 resulting in loss of angling days (Figure 9). During extremely high water levels, angling success or the perception of success is diminished or safety issues become apparent. Homeland security issues following the September 11, 2001 events resulted in the temporary closure of several access points at Ohio River locks and dam complexes. This was evident at all Ohio River complexes at the lock side of the complex. In addition, a popular access area in the Greenup tailwater was closed from September 2001 through May 2002. O'Bara (1991) reported that both natural and human-induced factors may result in annual fluctuations in angler use and success, and care should be taken in the interpretation in all angler-based information.

Channel catfish catch rates were greatest at the J.T. Myers tailwater (0.68/hr) and lowest at the Willow Island tailwater (0.04/hr). Catch rates reported from the Missouri River (0.13.hr) and the Tennessee River-Watts Bar tailwater 0.02/hr) were within this range (Stanovick 1999; TVA 1998). Ohio River tailwater catch rates exceeded that found for the Tennessee River-Watts Bar tailwater from all major sport fish species (Sauger: Ohio River: 0.22—1.86/hr; Tennessee River: 0.05/hr; White bass: Ohio River: 0.75—1.22/hr; Tennessee River: 0.12/hr).

Percent of fish harvested was lowest in upstream tailwaters. Consumption advisories may be one important factor. Sauger, walleye, largemouth bass, white bass, hybrid striped bass, catfish species, freshwater drum, and common carp all have meal restriction advisories in the West Virginia-Ohio reach of the Ohio River (WVDNR 2004). This reduced harvest also was evident in angler exploitation results reported in an accompanying study.

Access appeared to be a factor affecting use by anglers residing in adjacent states. Better access is afforded on the Ohio bank at Pike Island and New Cumberland tailwaters, resulting in a greater percentage of Ohio residing anglers. In contrast, angler access is easier on the West Virginia bank of the Willow Island tailwater consequently; a higher percent of West Virginia anglers fished this tailwater. At tailwaters where easy access is on both banks, angler use by residence was similar (R.C. Byrd tailwater: Ohio 51% and West Virginia 49%). Increased public awareness of the quality of angling in Ohio River tailwaters on a more regional frame should result in attracting a greater non-resident angling public.

The influence of locks and dam complexes on recreational angling effort and catch is well-documented (TVA 1998l, Schell et al. 1996). The congregation of percids, *Morone* sp., and paddlefish directly downstream of locks and dam complexes can be attributed to both natural and human-induced conditions. True riverine conditions usually only exist in tailwater reaches (not more than a few km downstream of a locks and dam complex) in the Ohio River with a longitudinally trend towards more lenthic conditions in mid-pool and lower-pool reaches. In addition, riverine conditions conducive to riverine-species spawning are usually only found in tailwater reaches where persistent

flows promote gravel beds or allow for the buoyancy of eggs and larval fish. In addition, riverine conditions conducive to riverine-species spawning are usually only found in tailwater reaches where persistent flows promote gravel beds or allow for the buoyancy of eggs and larval fish. Therefore, these more natural lotic conditions associated with tailwater reaches promote the congregation of riverine species.

The potential inability of migratory species to pass through locks and dam complexes also encourage the congregation of riverine species in tailwater reaches. Results from the accompanying fish passage study found that greater than 50% of tagged and recovered sauger, white bass, and paddlefish at eight Ohio River pools were recaptured within the tagged-pool. This percent of non-movement increased to over 70% at those locks and dam complexes where hydraulic conditions associated with these complexes have greater impedances to fish passage. It appeared that only when extremely high river flows are present do these riverine fish species pass through dam gates. True river species such as sauger, white bass, and paddlefish consequently inhabit these tailwater reaches.

A second aspect of recreational angling associated with tailwater reaches is linked with human behavior. Access to the entire Ohio River is restrictive because of land ownership, natural conditions, and safety concerns. In most pools, bank anglers are restricted to only a few public fishing areas and to the tailwater reaches in close proximity to a lock and dam complex. Although not always high quality facilities, these tailwater fishing access areas are often the only areas that a bank angler can fish. The congregation of riverine fish especially during spawning periods result in high quality angling opportunities that are not offered throughout the Ohio River. This results in a

high density of anglers in a minimal area. Results from Schell et al. (1996) indicated that 66% of the total catch was from that tailwaters which only comprised 1% of available angling habitat in the Ohio River. Although only tailwater anglers were interviewed in this present study, it is believed that tailwater reaches do contribute to a majority of angling in the Ohio River.

Fishery managers are often concerned when both anglers and fish congregate leading to a potential for overexploitation of a given species or conflicts of angler directed groups. Tailwater fisheries in the Ohio River are such a situation. Large numbers of anglers are seeking a congregation of fish over a defined period of time. These conditions are usually in the late-fall through early-spring for percids, *Morone* species, and paddlefish.

Regulations are one technique to reduce harvest and moderate exploitation. The Ohio River paddlefish recreational fishery is restricted by season and bag limits, as well as a closed season in the upper river. The Ohio River percid fishery is subjected to a bag limit (10 fish per day) with no size and season restrictions; and a bag and size limit is imposed on the *Morone* species fishery.

A second more natural factor in reducing overexploitation is the natural hydrologic conditions of the Ohio River. In 2002 and 2003, high river flows reduced angling effort primarily due to safety concerns and access problems. These low angling effort periods induced by river conditions appear to provide a natural refugia for a seasonal fishery such as percids, *Morone* species, and paddlefish. Total effort was reduced by greater than 50% during these high water seasons as compared to low or normal seasons (ORFMT 2001).

The percid community is one of concern. Study results suggest that sauger and walleye do congregate downstream of locks and dam complexes, their passage is restrictive by locks and dam complexes especially in the upper river, and are sought after by anglers. ORFMT (2004) found that although angler annual exploitation is relatively low (13% river-wide), annual mortality is high (greater than 60% for ages 1-5). Several factors may be contributing to the high annual mortality including natural factors, delayed angling-associated mortality, and human-induced stressors. These factors will be addressed in future ORFMT sponsored studies.

The linkage between locks and dam complexes, fish passage issues, the elimination of vast riverine habitat due to locks and dam complexes in navigational waterways, and recreational fishing is well-documented. Tailwaters reaches are important in providing angling opportunities in large navigational waterways, but also congregate certain fish species during critical periods. This assimilation of anglers and fish at a limited time and geographic location does promote the potential for adverse affects on fish populations. It is hoped that through wise fishery and water management, this potential can be reduced.

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Table 1. Percent of directed effort for anglers from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

	Percent					
Tailwater	**Percid**	**Black Bass**	**Morone**	**Catfish**	**Paddlefish**	**Anything**
New Cumberland	27.3	2.3	9.1	2.9	0.0	58.4
Pike Island	22.0	3.7	7.4	7.6	0.0	59.3
Willow Island	26.5	0.3	23.8	3.2	0.0	46.2
R.C. Byrd	47.6	0.0	3.9	3.4	0.0	45.1
Greenup	18.8	0.3	43.9	6.8	0.0	30.2
Markland	13.9	0.0	9.9	16.8	42.9	16.5
McAlpine	35.3	0.0	11.5	9.7	0.0	43.5
J.T. Myers	22.2	0.0	12.6	57.2	2.4	5.6

Table 2. Estimated angling effort by month for all anglers from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

Estimated Hours									
Month Year	J.T. Myers	McAlpine	Markland	Greenup	R.C. Byrd	Willow Island	Pike Island	New Cumberland	Monthly Total
Sept 01				1,941			1,168	231	3,340
Oct 01	264	62		1,384	1,414	2,201	1,496	299	7,120
Nov 01	227	3,041		2,522	2,450	1,839	2,543	860	13,482
Dec 01	47	1,431		2,799	1,203	1,852	1,778	560	9,670
Jan 02	1,021	2,368		92	754	632	543	174	5,584
Feb 02	1,279	3,004	1,208	114	626	1,234	144	255	7,864
Mar 02	330	1,568	1,838	325	432	1,171	649	322	6,635
Apr 02	38	361	1,549	424	806	1,330	804	443	5,755
May 02	170	570	731	555	933	1,561	1,435	687	6,642
Jun 02	2,548	4,064	2,128	3,899	2,529	3,946	1,443	1,295	21,852
Jul 02	4,324	4,582	1,734	3,097	3,241	1,601	2,902	923	22,404
Aug 02	2,492	3,430	2,233	2,089	1,224	2,822	1,328	859	16,477
Sept 02	1,352	2,390	1,636	2,415	840	2,252	770	140	11,795
Oct 02	622	2,207	1,572			1,194			5,595
Nov 02	485	1,239	579						2,303
Dec 02	382		311						693
Jan 03	168	697	16						881
Feb 03	992	297	887						2,176
Total	16,741	31,311	16,422	21,656	16,452	23,635	17,003	7,048	150,268

Table 3. Catch rate (#/hr) for directed effort species angling groups for selected species from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

Tailwater	Catch Rate (#/hr)					
	Sauger	All Percid	Hybrid Striped Bass	White Bass	Channel Catfish	Paddlefish
New Cumberland	0.91	1.02	0.30	0.37	0.32	
Pike Island	1.86	1.89	0.40	1.28	0.36	
Willow Island	0.59	0.68	0.90	0.79	0.04	
R.C. Byrd	1.18	1.25	0.19	0.88	0.48	
Greenup	1.48	1.64	1.76	0.61	0.40	
Markland	0.22	0.22	0.89	0.28	0.18	0.20
McAlpine	0.92	0.92	0.50	0.23	0.37	
J.T. Myers	1.30	1.30	0.62	0.08	0.68	0.19

Table 4. Estimated number harvested (H), released (R), and percent harvested by years for selected species from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

2001												
	Sauger		White Bass		Hybrid Striped Bass		Paddlefish		Channel Catfish		Blue Catfish	
Tailwater	**H**	**R**	**H**	**R**	**H**	**R**	**H**	**R**	**H**	**R**	**H**	**R**
New Cumberland	93	1,237	40	506	7	253	0	0	0	99	0	0
Pike Island	956	10,948	109	4,419	8	329	0	0	9	105	0	0
Willow Island	6	1,910	0	658	15	1,280	0	0	0	227	0	0
R.C. Byrd	1,744	3,921	36	149	0	7	0	0	0	259	0	0
Greenup	2,969	3,076	56	1,284	12	1,239	0	0	35	276	0	24
McAlpine	1,189	1,881	0	104	0	0	0	0	0	117	0	8
Myers	1,377	72	2,060	68	73	68	2	0	21	0	275	9
Total No.	8,334	23,045	2,301	7,188	115	3,176	2	0	65	1,083	275	41
2002												
	Sauger		White Bass		Hybrid Striped Bass		Paddlefish		Channel Catfish		Blue Catfish	
Tailwater	**H**	**R**	**H**	**R**	**H**	**R**	**H**	**R**	**H**	**R**	**H**	**R**
New Cumberland	80	0	278	962	166	360	0	0	26	206	0	0
Pike Island	36	599	24	3,003	40	753	0	0	53	316	0	0
Willow Island	286	1,667	0	1,956	81	4,579	0	0	27	560	0	0
R.C. Byrd	143	313	37	1,123	0	833	0	0	117	1,042	0	10
Greenup	102	1,043	0	4,782	33	11,762	0	0	70	765	0	15
Markland	170	193	79	952	151	3,381	832	3	29	102	44	417
McAlpine	4,331	2,036	95	461	137	1,272	47	165	499	1,064	57	234
Myers	1,628	851	223	60	178	59	550	0	1,552	224	4,588	843
Total No.	6,776	6,702	736	13,299	786	22,999	1,429	168	2,373	4,279	4,689	1,519
2003												
	Sauger		White Bass		Hybrid Striped Bass		Paddlefish		Channel Catfish		Blue Catfish	
Tailwater	**H**	**R**	**H**	**R**	**H**	**R**	**H**	**R**	**H**	**R**	**H**	**R**
Markland	0	0	0	0	0	0	32	0	0	0	0	0
McAlpine	164	54	0	0	0	0	16	0	0	0	0	0
Myers	430	353	0	0	0	0	414	3	16	11	146	0
Total No.	594	407	0	0	0	0	462	3	16	11	146	0
2001-2003 Total	15,704	30,154	3,037	20,487	901	26,175	1,893	171	2,454	5,373	5,110	1,560
Percent Harvest	34		13		3		92		31		77	

Table 5. Percent of state of residence for anglers from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

	States							
Tailwater	**AL**	**IL**	**IN**	**KY**	**OH**	**WV**	**PA**	**NY**
New Cumberland	0	0	0	0	81	17	2	0
Pike Island	0	0	0	0	76	22	1	1
Willow Island	1	0	0	0	9	89	0	0
R.C. Byrd	0	0	0	0	51	49	0	0
Greenup	0	0	0	38	63	0	0	
Markland	0	0	75	19	6	0	0	0
McAlpine	0	0	40	60	0	0	0	0
J.T. Myers	0	24	6	70	0	0	0	0

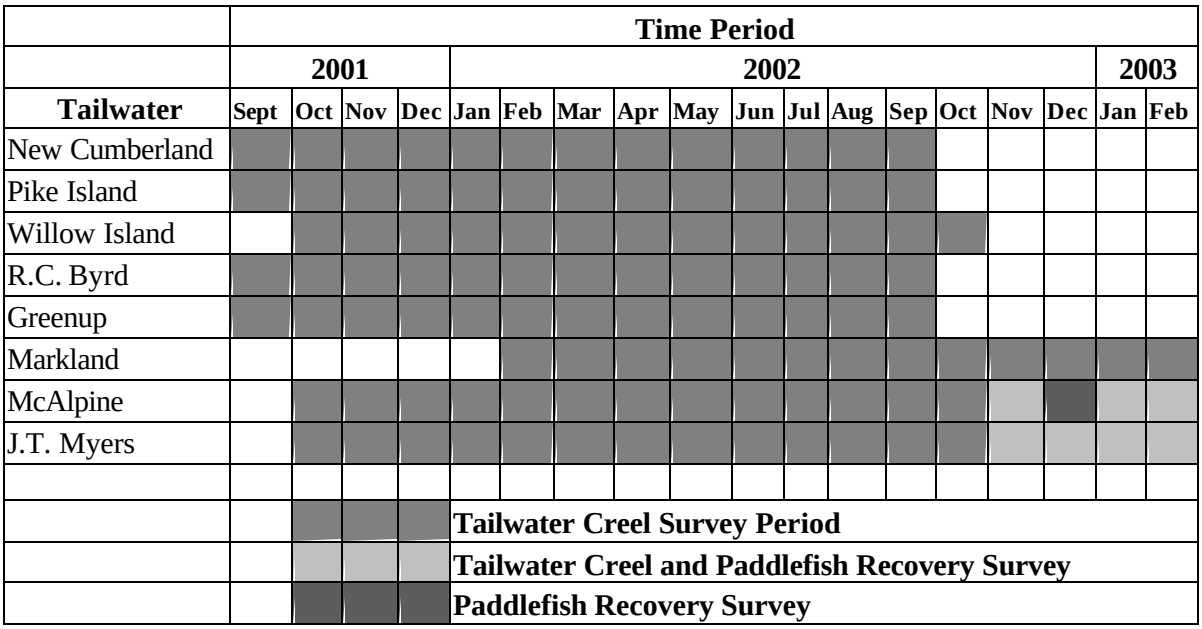


Figure 1. Monthly activity of data collection activities for a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

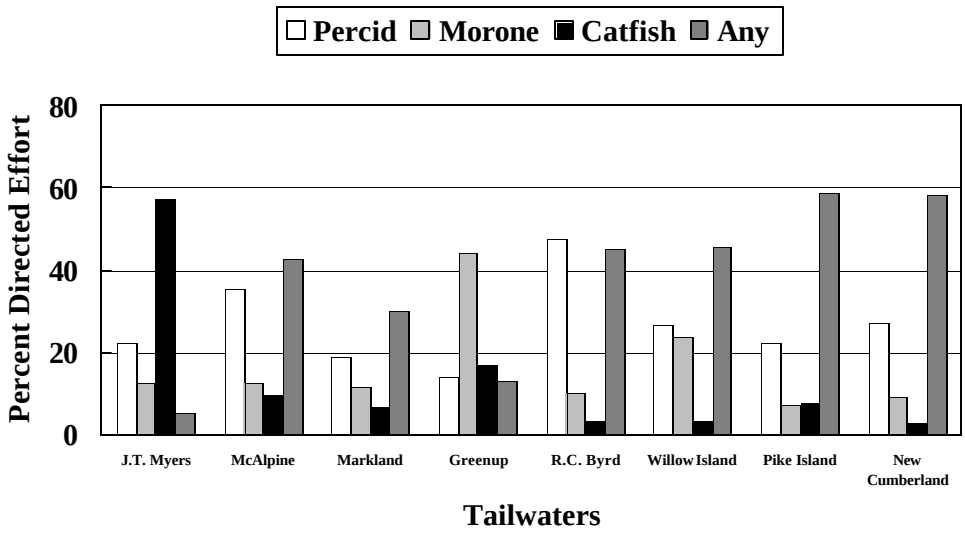


Figure 2. Percent directed effort for four groups from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

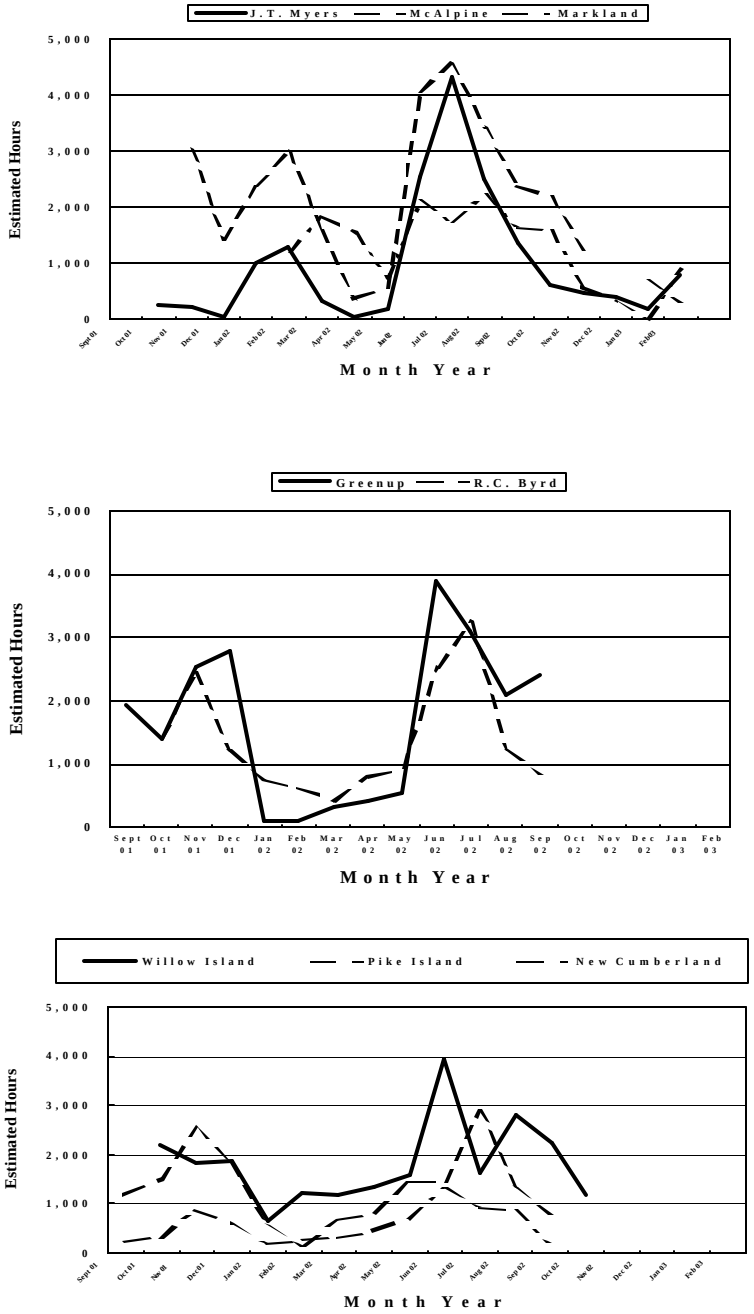


Figure 3. Estimated angling effort (hours) by month from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

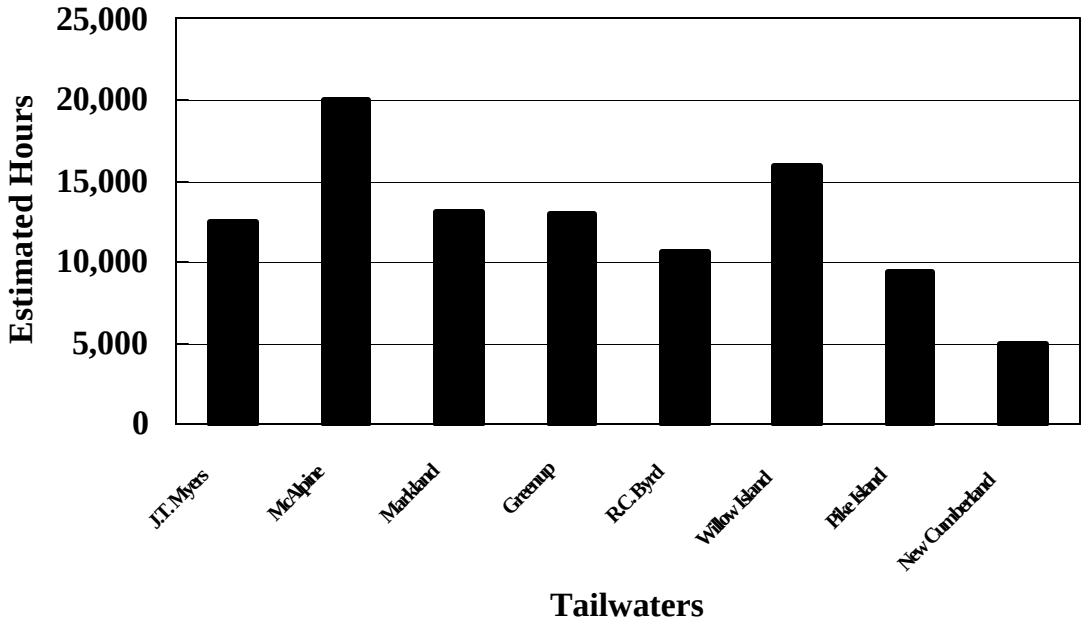


Figure 4. Estimated angling effort (hours) from February 2002 through September 2002 from a recreational angling survey of eight Ohio River tailwaters.

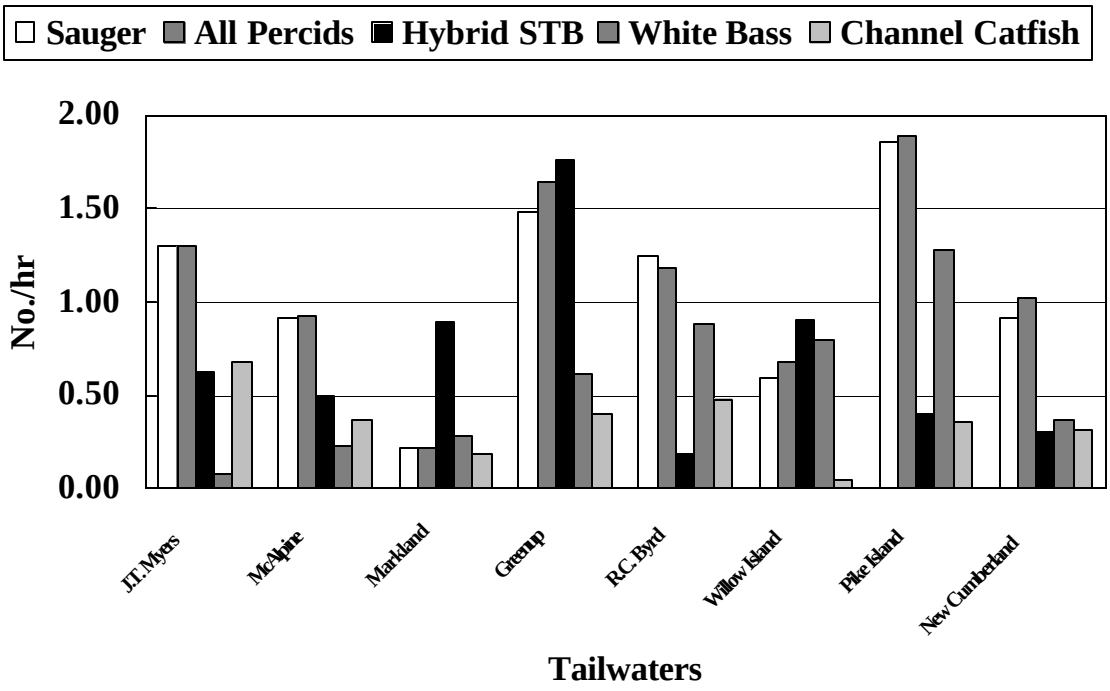


Figure 5. Catch rate (#/hr) for directed effort species angling groups for selected species from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

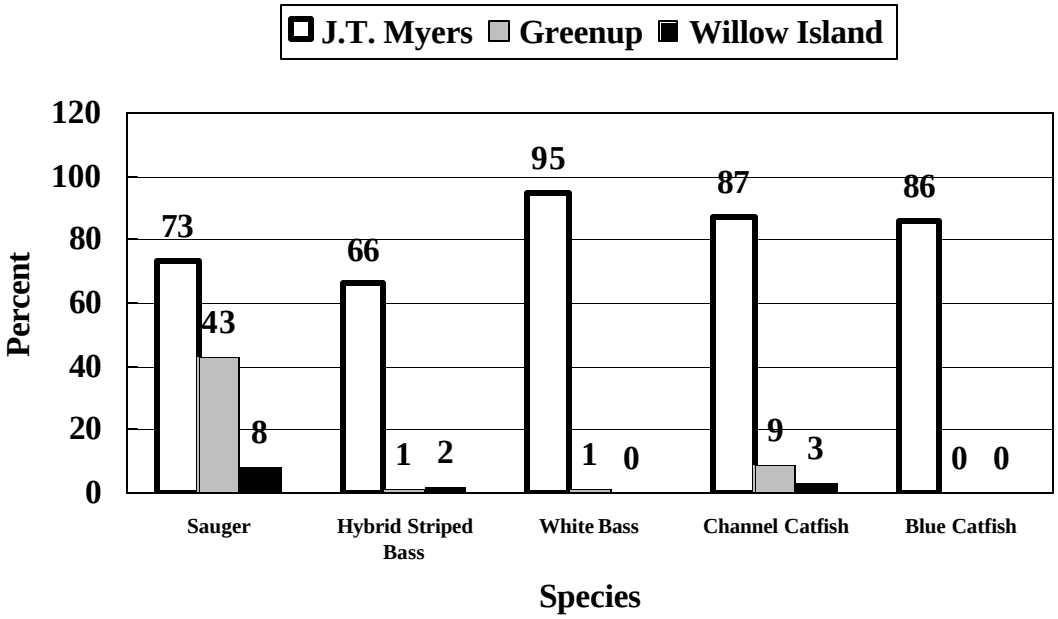


Figure 6. Percent harvested by species for three representative tailwaters from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

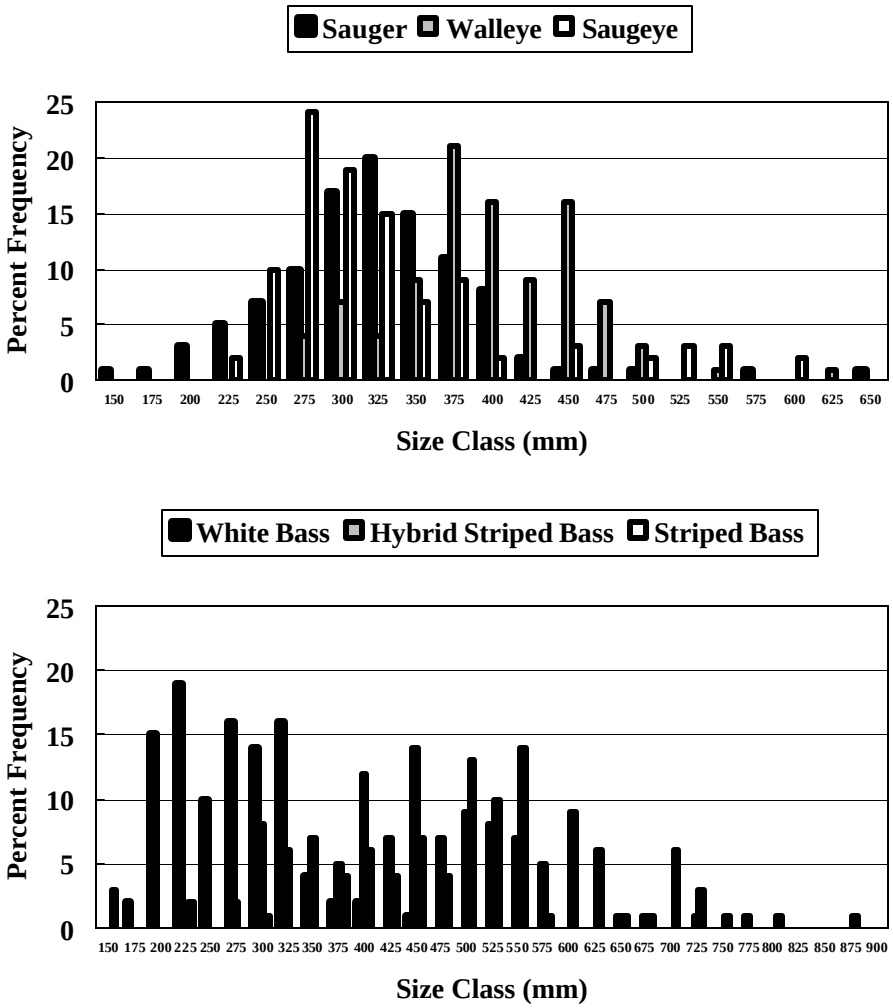
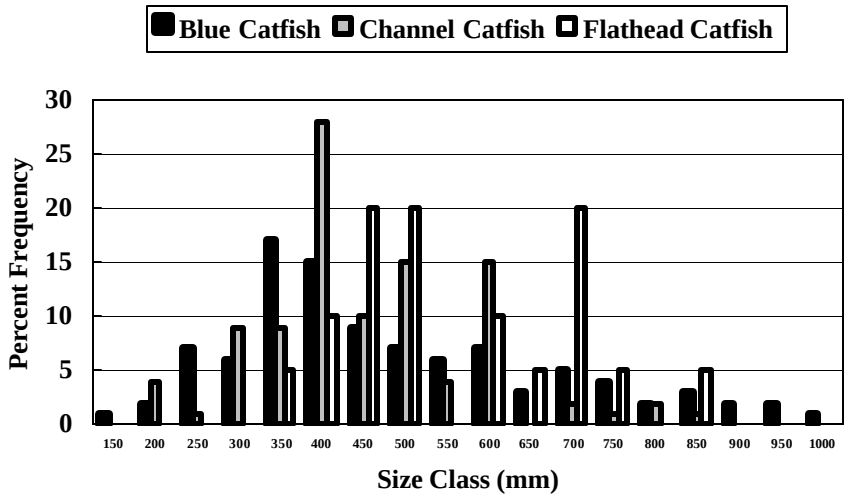


Figure 7. Length frequency distribution for harvested percids and *Morone* species group from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.



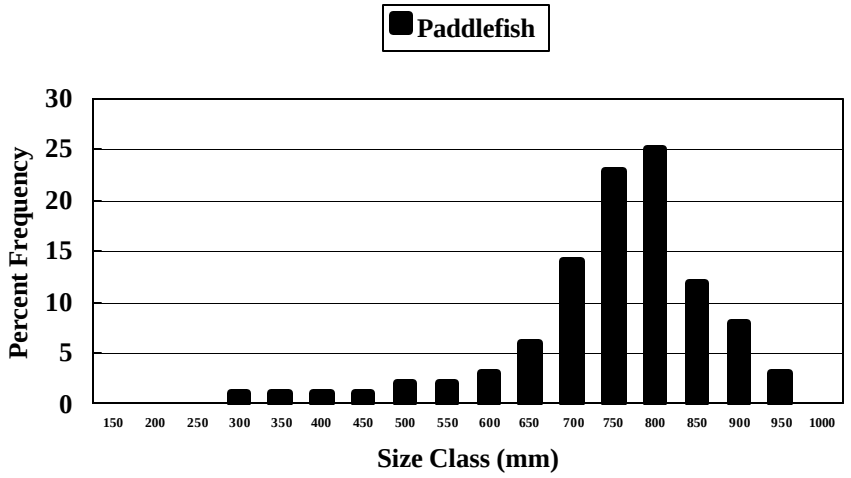


Figure 8. Length frequency distribution for harvested catfish species and paddlefish and from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

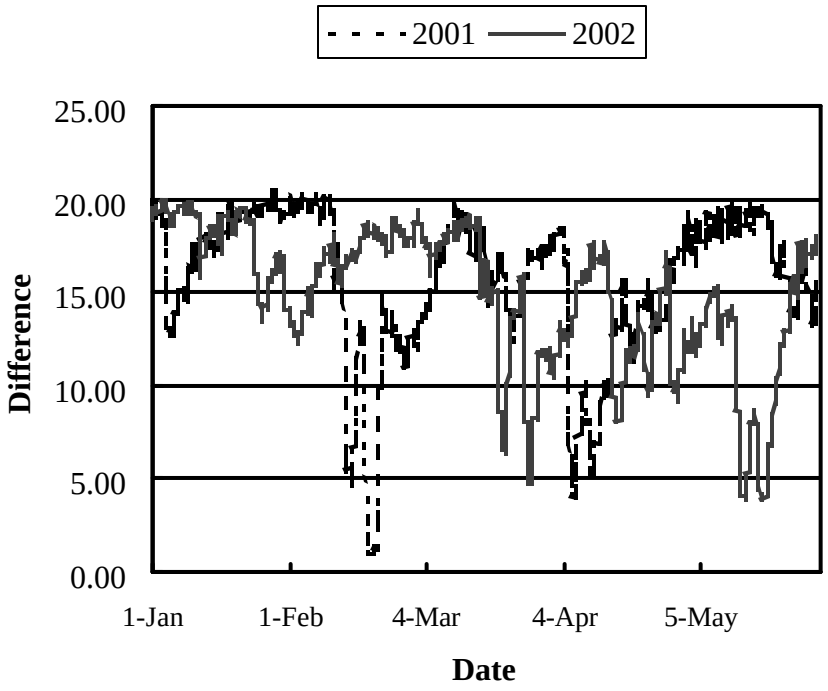


Figure 9. River stage differences (upstream-downstream) for the Willow Island Locks and Dam complex of the Ohio River. January through May 2001 and 2002.

Chapter 5

Ohio River Mainstem System Study (ORMSS)

Presence of Glochidial Infestation on Ohio River Species Task

Introduction

Freshwater mussels exhibit a highly specialized life history in that modified larvae, glochidia, experience a period as an obligate parasite on the gills, fins, and potentially other external structures of fish. Female mussels brood glochidia until mature, and then release these larvae either singly or in clusters through their siphons. Released glochidia must encounter a suitable fish host, become encysted for a period of time while metamorphosing into juvenile mussels, and finally release from the fish host. If suitable fish hosts are not encountered, the glochidia will be rejected (Kat 1984).

Knowledge of fish host and infestation rates is essential in the conservation of North American mussel fauna (Haag and Warren 1997). Many fish host studies have been conducted in a laboratory environment where potential fish hosts are either directly or indirectly infested with glochidia (Watters and O'Dee. 1998). Others investigators have used a field-based approach and examined potential fish hosts collected in a more natural environment (Neeves and Widlak 1988, Weiss and Layzer 1995). In many of these studies low infestation rates have hampered the investigators ability to gain an understanding of host-glochidia relationship.

The decline of the North American freshwater mussel fauna is well-documented (Williams et al. 1993). Human-induced alterations from a suite of activities have reduced

mussel populations throughout the native range. Dams, through altering flow regimes, have caused the extirpation of 30%-60% of the native mussel species in selected United States rivers (Williams et al. 1992). Competition from non-endemic mollusks has also lead to the decline in native mussel fauna. Zebra mussels have increased their range from early colonization in the Great Lakes to throughout the Mississippi River basin. These range extensions have often been linked to commercial navigation uses.

Concern for native freshwater mussel populations in the Ohio River sub-basin and the potential influence of commercial navigation and locks and dam complexes resulted in the proposing of a study to at least minimally address some potential issues. The infestation of potential fish hosts and the problems associated with fish passage on the Ohio River was one aspect proposed to be addressed.

Specific objectives were:

11. To determine infestation rates of a wide diversity of Ohio River fish species, and
12. To ascertain potential impacts of fish passage problems associated with infested fish species.

Approach

Fish were collected using pulsed DC boat-mounted electrofishing equipment at selected locations throughout the Ohio River sub-basin. Fish were initially held for up to 10-minutes in an aerated live-well during collection tasks. At the end of collection period, fish were placed in individual plastic bags, the bags placed on ice, and returned to the laboratory for processing. Once at the laboratory, fish were identified to species, measured to total length, and dissected. Gills and fins were removed, and placed in individual coded bags containing 95% denatured ethyl alcohol.

Samples (gills and fins) were held for no more than 3-months prior to examinations. Initially, all samples (individual fish) were examined for the presence and/or absence of glochidia, but with the low number of glochidia found in initial examinations, samples were then randomly selected. Using a random selection process, it was attempted to examine at least 40% of all samples by fish species and location. This was instituted after consultation with U.S. Army corps of Engineers and U.S. Fish and Wildlife Service project reviewers.

Tissue (fins and gills) were washed with distilled water and placed in a sodium hydroxide solution (N/50) for up to one week to allow for clearing of glochidia. Investigators used a dissecting scope to determine the presence and/or absence of glochidia on all tissue. If potential glochidia were noted, glochidia were excised, placed in tissue vials containing 95% denatured ethyl alcohol and sent for further review to a trained malacologist. Upon confirmation, the glochidia were sent to Ohio State University Museum of Biological Diversity for species identification.

A data base was developed using *Microsoft Excel* to manage all information. Information on the fish species examined, location of capture, date of capture, and presence/absence of glochidia were included in the database. At the conclusion of the task, this information was linked with the GIS data base developed in an accompanying task.

Results

Fish were collected from 10 different locations within the Ohio River (Table 1). The most downstream location was the J.T. Myers tailwater (ORM 850) and the most upstream location was the New Cumberland tailwater (ORM 55). Most collections were made in tailwater reaches because of the potential presence of freshwater mussels in these

free-flowing sections, and the congregation of fish species just downstream of the locks and dam complexes. One location, Belleville Pool at Blennerhassett Island (ORM 185.5), was selected because of the known presence of freshwater mussels in this area. One additional location was selected, Kanawha River-Winfield tailwater (KRM 32), because of the movement of many fish species from the Ohio River upstream to the first locks and dam complex on this major tributary.

Collections were made at all four seasons and under varying water temperature and flow conditions. It was thought that fish might be predestined to move during elevated water levels and flows, thus collections were made during a few high water events.

Thirty-one fish species were collected representing a wide range of behavioral and habitat guilds (Table2). Taxonomically, these 31 species represented 12 families and over 20 genera. Common large river species included the gizzard shad, freshwater drum, redhorses, sauger, and white bass. Non-endemic species included the grass carp, common carp, saugeye, and hybrid striped bass. Uncommon species included the blue sucker and goldeye.

One-thousand and sixty-seven individuals were processed (identified, measured, and dissected). Of these, 536 were examined for the presence of glochidia (Table 2). All samples taken in the winter and spring were examined, as were 64% of the summer samples, and 42% of the fall samples (Table 3 and 4). Only gizzard shad (84 of 307, 27%) were examined at a less than the 40% criteria of common species. Other less common species that were examined at less than 40% were longear sunfish (1 of 4) and

logperch (3 of 10). Samples from all locations except the Belleville tailwater (37%) were examined at the 40% criteria.

Four fish (<1%) were found to be infested with glochidia. These included three individuals from the R.C. Byrd tailwater collection in June 2002 and one individual from the J.T. Myers tailwater collection in October 2002. Fish species infested were longnose gar, gizzard shad, and skipjack herring from the R.C. Byrd tailwater collection, as well as a spotted bass from the J.T. Myers tailwater collection. No additional fish were found to be infested from May and October collections at the R.C. Byrd tailwater.

Seasonally, no fish were found to be infested in either the summer or winter collections, less than 1 percent in the fall, and 4 percent in the spring. No differences were detected at varying water levels or flows.

Discussion

The low number of fish found to be infested with glochidia during the survey limits any meaningful analysis. Similar low infestation rates have been found in several river systems including the Green River, a major tributary to the Ohio River (Weiss and Layzer 1995).

Seasonally, glochidia were found in both the spring (June) and fall (October). Several investigations have proposed reproductive models that suggest freshwater mussels are reproductively active throughout the year. Early investigators suggested two strategies, a winter and summer period when glochidia would be present in the marsupia (Skerki 1895). More recently, several investigators have reported the presence of glochidia infested on fish during all seasons, as well as the presence of glochidia in the water column (Jansen 1991, Weiss and Layzer 1995, Neeves and Widlak 1988). Watters

and O'Dee (2000) suggested that timing of glochidial release was water temperature dependent resulting in releases from May through October.

Although the knowledge of fish host is lacking for many freshwater mussels, the fish species found to be infested in this study have been found to serve as hosts (Haag and Warren 1997). Longnose gar, gizzard shad, skipjack herring, and spotted bass also have been reported to serve as host for species of Ohio River mussels (OSU Division of Mollusks-Host Database).

The presence of glochidia in free ranging fishes is problematic because of the natural low rate of infestation. If fish passage issues do exist in relation to glochidia infestation and leading to the decline of unionid populations, it is suggested that a more informative approach may be the modeling of potential fish hosts and their association with high-lift dams and passage mechanisms.

Passage through high-lift dams by species such as sauger, walleye, white bass, and paddlefish were found to be at least minimally restricted in the present study. Knight et al. (2002) suggested that fish passage is a problem at many Ohio River high-lift dams except at high flows and open river conditions. These modeled predictions (Knight et al. 2002) were correlated with results found in the present study. Study findings strongly suggest that sauger moved only during open water periods. Open water conditions only were present at less than 5% of the years modeled for all complexes upstream of the Racine Locks and Dam Complex. In contrast, this condition was achieved for 50% of the years modeled at the J.T. Myers and Newburgh complex (Knights et al. 2002). If glochidial infestation is not present during these open water periods and fish host species are not in the vicinity of the locks and dam complex, it appears unlikely that glochidia

will pass through high-lift dams via fish. The extremely low infestation rate (<1%) found in this study suggests that these conditions are not readily achievable.

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Table 1. Collection locations, pools and dates, the number of fish processed and examined, and number of fish with glochidia present from a survey conducted within the Ohio River sub-basin, 2002.

Collection Location	Collection Pool	Collection Date	Number		Number of Fish Glochidia Present
			Processed	Examined	
Belleville Tailwater	Racine	08/13/02	71	26	0
Belleville Pool-ORM 185.5	Belleville	09/30/02	132	31	0
Greenup Tailwater	Meldahl	06/12/02	9	9	0
Greenup Tailwater	Meldahl	10/21/02	165	77	0
J.T. Myers Tailwater	Smithland	10/29/02	75	48	1
Markland Tailwater	McAlpine	10/30/02	75	29	0
New Cumberland Tailwater	Pike Island	05/30/02	9	9	0
Pike Island Tailwater	Hannibal	03/07/02	21	21	0
Pike Island Tailwater	Hannibal	10/07/02	113	66	0
R.C. Byrd Tailwater	Greenup	05/02/02	29	29	0
R.C. Byrd Tailwater	Greenup	06/04/02	31	31	3
R.C. Byrd Tailwater	Greenup	10/10/02	159	32	0
Winfield Tailwater	R.C. Byrd	08/28/02	55	55	0
Willow Island Tailwater	Belleville	10/03/02	123	73	0
		Total	1067	536	4

Table 2. The number of individual fish processed and examined, and number of fish with glochidia present by species from a survey conducted within the Ohio River sub-basin, 2002.

Fish Species	Number		Percent Examined	Number Glochidia Present	Percent Glochidia Present
	Processed	Examined			
Blue Sucker	1	1	100	0	0
Northern Hogsucker	2	2	100	0	0
Quillback	29	20	69	0	0
River Redhorse	22	12	55	0	0
Shorthead Redhorse	80	44	55	0	0
Smallmouth Buffalo	79	33	42	0	0
Black Crappie	9	6	67	0	0
Bluegill	16	8	50	0	0
Green Sunfish	3	2	67	0	0
Largemouth Bass	39	22	56	0	0
Longear Sunfish	4	1	25	0	0
Redear Sunfish	2	1	50	0	0
Smallmouth Bass	26	20	77	0	0
Spotted Bass	15	11	73	1	9
White Crappie	8	6	75	0	0
Gizzard Shad	307	84	27	1	1
Skipjack Herring	50	27	54	1	4
Common Carp	15	8	53	0	0
Grass Carp	1	1	100	0	0
Goldeye	1	1	100	0	0
Channel Catfish	21	12	57	0	0
Flathead Catfish	43	18	42	0	0
Hybrid Striped Bass	42	23	55	0	0
Striped Bass	27	20	74	0	0
White Bass	44	34	77	0	0
Logperch	10	3	30	0	0
Sauger	73	60	82	0	0
Saugeye	3	3	100	0	0
Walleye	3	2	67	0	0
Freshwater Drum	55	26	47	0	0
Longnose Gar	37	25	68	1	4
Total	1067	536	50	4	1

Table 3. The number of individual fish processed by species from specific locations from a survey conducted within the Ohio River sub-basin, 2002.

	Number of Fish Processed			
	New Cumberland	Pike Island	Pike Island	Willow Island
	Tailwater	Tailwater	Tailwater	Tailwater
Species	May-02	Mar-02	Oct-02	Oct-02
Black Crappie	0	0	1	1
Bluegill	0	0	4	2
Blue Sucker	0	0	0	0
Channel Catfish	1	2	2	1
Common Carp	0	0	2	2
Flathead Catfish	0	0	5	7
Freshwater Drum	0	0	1	9
Gizzard Shad	0	0	45	33
Goldeye	0	0	0	0
Grass Carp	0	0	0	0
Green Sunfish	0	0	0	0
Northern Hogsucker	0	0	2	0
Hybrid Striped Bass	1	2	2	0
Largemouth Bass	0	0	6	5
Logperch	0	0	0	0
Longnose Gar	0	0	3	3
Longear Sunfish	0	0	2	0
Quillback	0	0	0	1
Redear Sunfish	0	0	0	0
River Redhorse	0	0	0	0
Sauger	3	10	0	0
Saugeye	0	0	0	0
Shorthead Redhorse	0	0	10	21
Skipjack Herring	0	0	3	5
Smallmouth Bass	2	1	6	3
Smallmouth Buffalo	0	0	14	7
Spotted Bass	0	0	2	0
Striped Bass	0	0	0	0
Walleye	0	0	1	0
White Bass	2	6	2	22
White Crappie	0	0	0	1
Total	9	21	113	123

Table 3. continued.

	Number of Fish Processed				
	Belleville	**Belleville Pool**	**Winfield**	**R.C. Byrd**	**R.C. Byrd**
	Tailwater	**ORM 185.5**	**Tailwater**	**Tailwater**	**Tailwater**
Species	**Aug-02**	**Sep-02**	**Aug-02**	**May-02**	**Jun-02**
Black Crappie	1	1	1	0	0
Bluegill	1	1	3	0	0
Blue Sucker	0	0	0	0	0
Channel Catfish	0	0	3	0	3
Common Carp	3	0	0	2	2
Flathead Catfish	2	10	4	0	2
Freshwater Drum	6	2	7	0	7
Gizzard Shad	11	71	8	6	5
Goldeye	0	0	0	0	0
Grass Carp	0	0	0	0	0
Green Sunfish	0	0	0	0	0
Northern Hogsucker	0	0	0	0	0
Hybrid Striped Bass	2	0	1	0	2
Largemouth Bass	0	7	0	0	0
Logperch	0	2	1	0	0
Longnose Gar	2	0	2	1	8
Longear Sunfish	0	0	1	0	0
Quillback	11	0	0	8	0
Redear Sunfish	0	0	0	0	0
River Redhorse	0	0	0	5	0
Sauger	0	3	0	6	0
Saugeye	0	0	0	1	0
Shorthead Redhorse	7	16	7	0	0
Skipjack Herring	0	2	12	0	2
Smallmouth Bass	5	5	0	0	0
Smallmouth Buffalo	19	7	2	0	0
Spotted Bass	1	5	1	0	0
Striped Bass	0	0	0	0	0
Walleye	0	0	0	0	0
White Bass	0	0	2	0	0
White Crappie	0	0	0	0	0
Total	71	132	55	29	31

Table 3. continued.

	Number of Fish Processed				
	R.C. Byrd	Greenup	Greenup	Markland	J.T. Myers
	Tailwater	Tailwater	Tailwater	Tailwater	Tailwater
Species	Oct-02	Jun-02	Oct-02	Oct-02	Oct-02
Black Crappie	0	0	4	0	0
Bluegill	0	0	3	0	2
Blue Sucker	0	0	0	1	0
Channel Catfish	0	1	3	2	3
Common Carp	0	0	0	0	4
Flathead Catfish	10	0	2	0	1
Freshwater Drum	5	0	11	1	6
Gizzard Shad	71	2	23	26	6
Goldeye	1	0	0	0	0
Grass Carp	0	0	0	0	1
Green Sunfish	0	0	0	0	3
Northern Hogsucker	0	0	0	0	0
Hybrid Striped Bass	11	1	7	12	1
Largemouth Bass	13	0	1	2	5
Logperch	4	0	3	0	0
Longnose Gar	7	0	6	4	1
Longear Sunfish	1	0	0	0	0
Quillback	0	0	5	0	4
Redear Sunfish	0	0	1	0	1
River Redhorse	0	0	8	7	2
Sauger	0	4	35	3	9
Saugeye	0	0	2	0	0
Shorthead Redhorse	16	0	3	0	0
Skipjack Herring	1	0	9	7	9
Smallmouth Bass	1	1	0	2	0
Smallmouth Buffalo	11	0	14	4	1
Spotted Bass	0	0	0	0	6
Striped Bass	0	0	20	2	5
Walleye	0	0	1	1	0
White Bass	7	0	1	0	2
White Crappie	0	0	3	1	3
Total	159	9	165	75	75

Table 4. The number of individual fish examined by species from specific locations from a survey conducted within the Ohio River sub-basin, 2002.

	Number of Fish Examined			
	New Cumberland	Pike Island	Pike Island	Willow Island
	Tailwater	Tailwater	Tailwater	Tailwater
Species	May-02	Oct-02	Oct-02	Mar-02
Black Crappie	0	1	1	0
Bluegill	0	1	2	0
Blue Sucker	0	0	0	0
Channel Catfish	1	0	0	2
Common Carp	0	1	0	0
Flathead Catfish	0	4	3	0
Freshwater Drum	0	4	0	0
Gizzard Shad	0	22	16	0
Goldeye	0	0	0	0
Grass Carp	0	0	0	0
Green Sunfish	0	0	0	0
Northern Hogsucker	0	0	2	0
Hybrid Striped Bass	1	0	2	2
Largemouth Bass	0	3	6	0
Logperch	0	0	0	0
Longnose Gar	0	3	3	0
Longear Sunfish	0	0	0	0
Quillback	0	1	0	0
Redear Sunfish	0	0	0	0
River Redhorse	0	0	0	0
Sauger	3	0	0	10
Saugeye	0	0	0	0
Shorthead Redhorse	0	11	8	0
Skipjack Herring	0	5	3	0
Smallmouth Bass	2	2	6	1
Smallmouth Buffalo	0	0	10	0
Spotted Bass	0	0	1	0
Striped Bass	0	0	0	0
Walleye	0	0	1	0
White Bass	2	14	2	6
White Crappie	0	1	0	0
Total	9	73	66	21

Table 4. continued.

	Number of Fish Examined				
	Belleville	**Belleville Pool**	**Winfield**	**R.C. Byrd**	**R.C. Byrd**
	Tailwater	**ORM 185.5**	**Tailwater**	**Tailwater**	**Tailwater**
Species	**Aug-02**	**Sep-02**	**Aug-02**	**May-02**	**Jun-02**
Black Crappie	1	1	1	0	0
Bluegill	0	0	3	0	0
Blue Sucker	0	0	0	0	0
Channel Catfish	0	0	3	0	3
Common Carp	1	0	0	2	2
Flathead Catfish	2	3	4	0	2
Freshwater Drum	1	2	7	0	7
Gizzard Shad	2	3	8	6	5
Goldeye	0	0	0	0	0
Grass Carp	0	0	0	0	0
Green Sunfish	0	0	0	0	0
Northern Hogsucker	0	0	0	0	0
Hybrid Striped Bass	0	0	1	0	2
Largemouth Bass	0	3	0	0	0
Logperch	0	0	1	0	0
Longnose Gar	0	0	2	1	8
Longear Sunfish	0	0	1	0	0
Quillback	5	0	0	8	0
Redear Sunfish	0	0	0	0	0
River Redhorse	0	0	0	5	0
Sauger	0	1	0	6	0
Saugeye	0	0	0	1	0
Shorthead Redhorse	3	8	7	0	0
Skipjack Herring	0	2	12	0	2
Smallmouth Bass	3	3	0	0	0
Smallmouth Buffalo	7	2	2	0	0
Spotted Bass	0	3	1	0	0
Striped Bass	0	0	0	0	0
Walleye	0	0	0	0	0
White Bass	1	0	2	0	0
White Crappie	0	0	0	0	0
Total	26	31	55	29	31

Table 4. continued.

	Number of Fish Examined				
	R.C. Byrd	Greenup	Greenup	Markland	J.T. Myers
	Tailwater	Tailwater	Tailwater	Tailwater	Tailwater
Species	Oct-02	Jun-02	Oct-02	Oct-02	Oct-02
Black Crappie	0	0	1	0	0
Bluegill	0	0	1	0	1
Blue Sucker	0	0	0	1	0
Channel Catfish	0	1	0	1	1
Common Carp	0	0	0	0	2
Flathead Catfish	0	0	0	0	0
Freshwater Drum	1	0	0	1	3
Gizzard Shad	4	2	11	3	2
Goldeye	1	0	0	0	0
Grass Carp	0	0	0	0	1
Green Sunfish	0	0	0	0	2
Northern Hogsucker	0	0	0	0	0
Hybrid Striped Bass	2	1	5	6	1
Largemouth Bass	4	0	1	2	3
Logperch	2	0	0	0	0
Longnose Gar	2	0	3	2	1
Longear Sunfish	0	0	0	0	0
Quillback	0	0	2	0	4
Redear Sunfish	0	0	0	0	1
River Redhorse	0	0	3	2	2
Sauger	0	4	24	3	9
Saugeye	0	0	2	0	0
Shorthead Redhorse	6	0	1	0	0
Skipjack Herring	1	0	0	2	0
Smallmouth Bass	1	1	0	1	0
Smallmouth Buffalo	4	0	6	2	0
Spotted Bass	0	0	0	0	6
Striped Bass	0	0	15	1	4
Walleye	0	0	0	1	0
White Bass	4	0	1	0	2
White Crappie	0	0	1	1	3
Total	32	9	77	29	48

AQUATIC STUDIES

EXHIBIT D

SUMMARY OF
OSU MUSSEL DATABASE

FISH PASSAGE STUDY CONDUCTED FOR ORMSS – DISTRIBUTION OF MUSSELS AND FISH WITHIN THE OHIO RIVER

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Prepared for the US Army Corps of Engineers
7 January 2003

Background

Mussel – Fish Host Associations

Minute bivalved larvae, or glochidia, develop over a period of days to months, depending on water temperature and species. Glochidia are a type of specialized veliger larvae. Freshwater mussels, and freshwater molluscs in general, lack the trochophore larva so common to marine molluscs. When first discovered by Leeuwenhoek in 1697, glochidia were considered by some (but not by Leeuwenhoek) to be parasites living in the mussel's gills, and were given the scientific name *Glochidium parasiticum* by Rathke (1797). For nearly three quarters of a century, a lively debate ensued as to whether these 'agglomerations of animicules,' as Prévost called them (1826), were mussel parasites or mussel larvae. Leydig (1866) appears to have been the first to identify glochidia on fishes, and Braun (1878a,b) experimentally demonstrated their parasitic role and their true identity as larval mussels.

North American freshwater mussels are historically divided into two behavioral groups based upon the duration that glochidia are held in the marsupia. Tachytictic, or short-term, breeders spawn in the spring or summer and release their glochidia later the same year, usually by July or August. Bradytictic, or long-term, breeders spawn in the summer or early autumn, form glochidia, and typically hold these larvae in the marsupium until the following spring or summer. There is evidence that glochidia that overwinter till spring in the marsupium experience less mortality once on the host than those glochidia of the same species that are released in the autumn and metamorphose that same year (Corwin, 1921; Higgins, 1930; Tedla & Fernando, 1969; Zale & Neves, 1982). But some otherwise "bradytictic" individuals release glochidia in autumn or winter

to overwinter on their hosts. They remain dormant on their host until a threshold temperature is reached the following spring, at which time they metamorphose and excyst (Watters & O'Dee, 1999). Some species, such as *Pyganodon grandis* and *Leptodea fragilis*, apparently utilize host-overwintering glochidia as part of their normal life history. The ability to overwinter on hosts is related to the duration the glochidia spend attached to the host, with overwintering success declining with time. Overwintering of glochidia on hosts may aid in dispersal of the species, and confer greater fitness on those glochidia capable of remaining attached till spring. Whether these glochidia overwinter in the marsupia or on their hosts, this prolonged developmental stage may be necessary for bradytictic species. There is mounting evidence that some temperate species have multiple broods. In these cases, a species may have both tachytictic (in the summer) and bradytictic (over winter) reproduction. Approximate gravid periods for Ohio River mussel species are given in Appendix B, where known.

Nearly all freshwater mussels are obligate vertebrate parasites as larvae. Of the approximately 300 species in North America, only one, the salamander mussel *Simpsonaias ambigua*, is believed to use exclusively a non-fish host, the mudpuppy *Necturus maculosus* (Howard, 1915, 1951). The remainder are believed to use fishes, but may be capable of parasitizing amphibians as well (Watters, 1997a; Watters & O'Dee, 1998). Although claims have been made that several species may complete their metamorphosis without a host (Lefevre & Curtis, 1911; Howard, 1914b), evidence suggests that most North American mussels must parasitize a host to complete their life cycle. Only one North American species (Barfield & Watters, 1998; Lellis & King, 1998), an African mutelid species (Kondo, 1990), and several South American mussels (Mansur & Campos-Velho, 1990) are known to bypass the parasitic stage completely.

Hosts are infested with glochidia when they come into contact with them in the water, on the substrate, or by attempting to ingest them. Different mussel species have different methods of releasing these larvae. Some simply expel the glochidia along with water and waste products. Hosts either take in suspended glochidia and pass them over their gills, where they attach, or they contact larvae on the substrate, where the parasites attach to the fins or skin. Some mussels, such as *Anodonta suborbiculata*, *Anodontoides ferussacianus*, and *Utterbackia imbecillis*, release "webs" or "trot lines" of mucus containing glochidia that ensnare passing fishes (Hove et al., 1995; Watters & O'Dea, 1997d). Other mussels bind glochidia into matrices called conglutinates (Chamberlain, 1934; Fuller, 1971). Several types of conglutinates have been identified. The simplest are formed entirely of glochidia, each enclosed in a fragile envelope. A more complex type is formed from eggs and glochidia. In these, the majority of the mass is composed of sterile eggs. In some species up to 85% of the total number of eggs have this structural, rather than reproductive, function, and apparently are never destined to be fertilized (Barnhart, 1997). The eggs function to give shape and color to the entire mass, which has functional glochidia imbedded in it or attached to it. Another type of conglutinate, found in *Strophitus undulatus*, is composed of a mucus rod containing the glochidia. When released by the female, the glochidia squeeze through pores in the conglutinate wall and move to the outside (Watters, 2002). Other conglutinates are even more complex, such as

the "fish-fry" lures of *Ptychobranchus fasciolaris*, which are multi-layer constructions complete with discrete pigmented areas and adhesive pads (Watters, 1999). Conglutinates also may resemble worms, insect larvae, or other food items (Barnhart & Roberts, 1997), or simply be fragile structures that rapidly disassociate into free glochidia. The latter probably act only to facilitate the movement of the glochidia out of the marsupia. Some mussels, such as *Lampsilis*, apparently can release either conglutinates or free glochidia, perhaps dependent on the time of year or the presence or absence of hosts. Glochidia or conglutinates may be moved to the suprabranchial chamber and expelled through the excurrent opening, but in many lampsilines, the distal portion of the marsupia rupture and conglutinates are expelled directly to the outside. Recently, "superconglutinates" were discovered in several southern species (Haag et al., 1995; Hartfield & Butler, 1997). Superconglutinates are groups of individual conglutinates formed into a single lure. The lure is played out in the water on a strand of mucus up to 2.5 m long. No Ohio River species has been found with superconglutinates.

Some species have modified the mantle into lures resembling fishes, insects, and other food items. These structures may undulate in swimming-like motions (Kraemer, 1970). Often the marsupial portion of the gills is protruded out of the shell between these flaps. When struck by a predatory fish, females snap their shells closed on the protruded marsupia, causing the marsupia to rupture and release clouds of glochidia. These attach to the would-be predator. Radically different mantle lures have been found in the same "species," such as *Lampsilis fasciola*, suggesting either the presence of sibling species, or a startling polymorphism in mantle pigmentation and morphology within single species, even in a single population. There is some evidence that mussels and glochidia can detect nearby hosts and modify their behavior to increase their chances of attracting or attaching to them (Henley & Neves, 1997). Mantle tissue is sensitive to changes in light intensity, and may react to the shadows of passing fishes (Hove & Anderson, 1997). In addition, it has been suggested that mantle tissue may release chemical attractants for hosts (Pepi & Hove, 1997).

Once shed by the female, glochidia must acquire a suitable host or die, usually within 24-48 hours. "Free" glochidia are preyed upon by numerous predators: insects, bottom-feeding fishes, flatworms, hydras, etc. Infective glochidia may travel some distance downstream in currents (Clark & Stein, 1921; Neves & Widlak, 1988). The estimated chances of a glochidium surviving to metamorphose and excyst range from 0.0001% (Jansen, 1991) to 0.000001% (Young & Williams, 1984). Although some species may compensate for this with high fecundity over many years (Bauer, 1987b), other species have been shown to develop late and then reach early senescence (Downing et al., 1993). Species having lures and conglutinates generally produce fewer glochidia, but are not able to parasitize as wide a range of hosts as those that broadcast large numbers of glochidia (Watters, 1997b). Because of the manner in which hosts acquire glochidia (lures, conglutinates, webs, etc.), it is not surprising to find that glochidia are overdispersed, that is, most hosts are either unparasitized, or carry but a few glochidia, whereas a very small number of hosts bear most of the parasite burden (Bangham, 1940, 1955; Weir, 1977; Dartnall & Walkey, 1979; Neves & Widlak, 1988). However, even

heavily infested hosts show few ill effects, with few exceptions. Recently parasitized fishes may become lethargic and secretive, but usually recover within 24 hours. Large, hooked glochidia, such as occur in *Strophitus undulatus*, may cause great agitation to hosts when attaching.

Glochidia clamp down on the host tissue, causing cells to rupture. This cellular fluid forms part of the food for the developing parasite (Arey, 1924b, 1932b; Blystad, 1924). A host wound reaction forms a capsule by the movement of host cells over the glochidium (Faussek, 1895; Arey, 1921, 1932a). During growth, the larva will resorb much of its own tissue, including the adductor muscle and much of the mantle, as well as feeding on the host (Young, 1911; Blystad, 1924). The glochidia of most mussel species, except those of the margaritiferids and the axe-head shaped glochidia of *Potamilus*, do not appreciably change size during encystment. After a certain amount of time (from days to months), depending on water temperature and mussel species, the glochidium metamorphoses into a juvenile and excysts (Schierholz, 1889; Howard & Anson, 1923). Even at the same temperature, the duration of metamorphosis varies with host species. For instance, metamorphosis of *Megalonaias nervosa* on gar took several weeks longer than metamorphosis on bass (Watters, unpubl.). Lower threshold temperatures necessary for completion of metamorphosis were identified for *Lampsilis cardium*, and undoubtedly exist for all species (Watters & O'Dee, 1997b, 1999). At temperatures below these thresholds, metamorphosis may be delayed indefinitely. The duration of metamorphosis decreases with increasing temperature, until an upper threshold is reached. At this point, glochidia excyst, fail to metamorphose, and die (Dudgeon & Morton, 1984). Barnhart and Roberts (1997) found that although higher water temperatures greatly decreased the time to metamorphosis, metamorphosis occurred on more hosts species at lower temperatures. Glochidia metamorphose into juvenile mussels. Whereas the glochidium lacks a foot and gills, and has a single adductor muscle, the juvenile has a functional foot, gill "buds", and two adductor muscles. In many species (except anodontines), the glochidial shell is white, but turns tan or brown after metamorphosis. Anodontione glochidia typically are tan. The glochidial shell is incorporated into the adult shell, and may be visible in exceptionally well-preserved specimens (Hoggarth, 1987)

Once metamorphosed, the juvenile drops from the host and burrows into the substrate (Bauer, 1986; Clarke, 1986; Buddensiek et al., 1993) or attaches to a larger object with a byssal thread. This buried juvenile stage may last several years, and has been referred to as the mesoconch (Clarke, 1986). The thread is lost in adults, but persists for a year or more in some species (i.e., *Truncilla donaciformis*). The thread is formed by a gland within the foot, and is very similar to the byssal threads of marine bivalves, such as *Mytilus*.

Potential hosts may possess one of two types of immunity to attached glochidia. Natural immunity occurs in unsuitable hosts, which have tissue responses against the glochidia (Howard, 1914a; Bauer & Vogel, 1987). Acquired immunity occurs when a suitable host has been previously parasitized, and has built up a temporary immunity. The number of exposures needed to achieve acquired immunity depends on the degree of prior

infestations and duration between them (Lefevre & Curtis, 1910; Surber, 1913; Reuling, 1919; Arey, 1924a; Bauer, 1987a). For example, for Largemouth Bass exposed to *Lampsilis cardium*, three to four exposures over 30 day intervals are required to elicit complete immunity (Watters, 1996b). Acquired immunity to one unionid species was thought to give the host immunity to others (Reuling, 1919), but this has not been substantiated. Indeed, Largemouth Bass possessing a complete immunity to *Lampsilis cardium* were successfully infected by glochidia of *Utterbackia imbecillis* (Watters, 1996b) and even its congener *Lampsilis fasciola* (Watters & O'Dee, 1997c). Although acquired immunity may be demonstrated in the laboratory, acquired immunity in wild-caught fishes has been observed only once, and its overall prevalence in wild fishes is unknown (Watters & O'Dee, 1996). In both natural and acquired immunity, encysted glochidia are killed by the host, and either sloughed off or absorbed (Arey, 1932c; Fustish & Millemann, 1978; Zale & Neves, 1982; Waller & Mitchell, 1989). Acquired immunity apparently may be lost if no subsequent reinfestation occurs within a certain time period, and the fish may become susceptible to parasitization again. However, the amount of time needed to lose acquired immunity is not precisely known.

Host specificity varies greatly among mussels. Some species, usually widespread and abundant, are able to parasitize many species of fishes, including exotics (Trdan & Hoeh, 1982; Watters & O'Dee, 1997a; Watters & O'Dee, 1998). Other mussel species, usually localized and rare, may use only a few fish species. This has been substantiated in numerous laboratory trials. These hosts typically are members within a fish family that share the same habitat as the mussel. Regardless, fishes must be present at the right time and the right place to serve as hosts. This is particularly true of migratory fishes. Because this symbiosis is obligatory, plans to conserve and manage rare and endangered mussels must include management of the host as well. It is suspected that some mussel populations are not reproducing because their hosts no longer occur with them. The hosts of the great majority of mussels have not been identified, and it is not known if hosts identified in laboratory infections actually function as hosts in the wild.

This host-parasite relationship apparently arose as a means of dispersal for the unionids. Lacking internal fertilization and great motility as adults, unionid populations would be doomed to be carried to the sea over many generations. By attaching themselves to a highly motile host, such as a fish, they are dispersed within and between drainages. Records of dispersal on the feet of waterfowl are largely apocryphal (Rees, 1965), and the idea that glochidia swim by clapping their shells, once the preferred theory, has been abandoned. Obviously, other freshwater mollusc groups are equally as successful as freshwater mussels, without resorting to parasitism for dispersal. Time and again in nature we see such juxtapositions of disparate evolutionary "solutions" to common problems. Asking why this solution arose instead of that one is probably an exercise in futility.

Effects of Impoundment

Rivers have been dammed by humans for millennia for many purposes: to run mills and

hydroelectric turbines, to irrigate otherwise inarable land, to control floods, to allow navigation of waterways, and for recreation. But impoundments are not the same as naturally occurring pools in a river. Impoundments have a different hydrology than natural pools, with different flow patterns, topographies, and temperatures. These differences often result in a change in the aquatic fauna, including mussels. For example, 15 mussel species were found in Lake Cooper, a man-made impoundment on the Mississippi River, but in adjacent Lake Pepin, a naturally-formed pool, 30 species were encountered (van der Schalie, 1938).

The loss of these mussels and their hosts is due to habitat modifications caused by impoundment. A free-flowing river has riffles, runs, pools, shoals, water-willow stands, and meanders. But impoundment dramatically reduces this habitat heterogeneity (Bates, 1962; Blalock & Sickel, 1996). The original channel remains but is buried under deeper water. However, most mussels do not occur in deep water, and those that do are often stunted (Haukioja & Hakala, 1974; Lewandowski & Stanczykowska, 1975). This channel begins to accumulate sediments, smothering most mussels and eliminating breeding areas for hosts. Ellis (1936) showed that a silt accumulation of one-quarter to one inch depth resulted in mortality approaching 90% in the mussels he tested.

If not smothered outright by accumulating sediments, mussels may be affected adversely in other ways. Reproduction may be reduced or stopped entirely, and growth may be slowed. Bates (1962) found no evidence of mussel reproduction in the channel of Kentucky Lake of the Tennessee River, even though adult mussels were present. Rivers having high levels of suspended solids result in slower mussel growth (Semenova et al., 1992). Juvenile mussels, which live buried for several years, may be killed by overlaying sediments (Bauer et al., 1980; Buddensiek et al., 1993). Silt results in the loss of light penetration, reducing algal food available to mussels, and leads to oxygen depletion. The bottom waters of the channel may become cold enough to stunt the growth of mussels (Harman, 1974; Ghent et al., 1978; Semenova et al., 1992) and interfere with reproduction (Hruska, 1992).

After impoundment, the original mussel fauna may be eliminated or greatly reduced (Holland-Bartels, 1990), or changed in favor of silt-tolerant species, such as anodontines and species of *Leptodea* and *Potamilus* (Bates, 1962; Blalock & Sickel, 1996; Clark & Gillette, 1911; Ellis, 1931; Isom, 1969; Klippel & Parmalee, 1979; Parmalee & Hughes, 1993). These often occur in the now permanently inundated floodplains. Thus, while some impoundments may contain numerous mussels, these invariably are invading soft-substrate adapted species that have replaced the original fauna.

Dams may represent physical barriers to mussel hosts. Some mussel populations may no longer be recruiting juveniles because their hosts are absent (Suloway et al., 1981; Jones, 1991; Burkhead et al., 1992). Watters (1996a) showed that dams as low as one meter in height affected host movements and restricted the range of some mussels. Tailwaters tend to accumulate mussels, which is another source of evidence that the dam is acting as a barrier.

Tailwaters are affected as well (Ligon et al., 1995). Fluctuating water levels may strand or otherwise expose mussels to extreme temperatures, resulting in mass mortalities. (Riggs & Webb, 1956; Neck & Howells, 1994). Low temperatures associated with some tailwaters may affect mussel reproduction and growth. High-volume water discharges and abrupt stoppages cause instability of substrate below dams (Miller & Payne, 1992; Nagel, 1992; Yeager, 1993). Sedimentation in tailwaters reduces fish diversity and abundance by altering necessary habitats, thereby removing necessary mussel hosts (Petts, 1984; Holland & Huston, 1985; Nelson et al., 1987). Mussels may be absent for miles below some dams due to these problems.

That impoundments are detrimental to aquatic life, and most mussels in particular, has been demonstrated by many case studies. Perhaps several dozen mussel species in North America, and numerous more freshwater snails, were driven to extinction by the affects of impoundments (Stansbery, 1973; Layzer et al., 1993; Lydeard & Mayden, 1995). Although mussel faunas change through time, with or without dams, and species become extinct as a matter of course, the interference of humanity has dramatically accelerated this process. For example, the Tennessee River's mussel diversity decreased from 100 species to 44, mainly due to impoundment (Isom, 1969). In the Fort Loudoun Reservoir alone on the Tennessee River, Isom (1971) found only four mussel species, while Ortmann (1918) reported 64 species from the same general area before impoundment. The area of the Chickamauga Reservoir of the Tennessee River supported 46 species for perhaps 2000 years prior to impoundment (Parmalee et al., 1982). After impoundment, 28 species were extirpated, and several are now extinct, all in the blink of an evolutionary eye. Similar reductions in diversity after impoundment were documented for the Cumberland River (Layzer et al., 1993; Schmidt, 1986), where the construction of the Center Hill hydroelectric dam resulted in the loss of 78% of the original mussel species. In the Little Tennessee River, only six of the original 50 mussel species at Tellico Lake remained after impoundment (Parmalee & Hughes, 1993). The mussels of other rivers have met a similar fate, including mussels of the Kaskaskia River (Suloway et al., 1981) and the Tombigbee River (Williams et al., 1992).

Mussel Indices

The OSU Mussel Database uses two indices to quantify mussels in the Ohio River mainstem:

1) Index of Mussel Potential (IMP)

This index is simply the sum of all matches between fish hosts and a given mussel species for all pools on the Ohio River mainstem. The number, therefore, is based on the number of pools in which a mussel species lives and the number of available fish hosts for that species in the pools. The higher the number the more “potential” that mussel species has to survive within the Ohio River mainstem, all other things being equal.

2) Index of Pool Potential (IPP)

This index is similar to the IMP, but matches between mussels and fish hosts are summed within a pool. The result may be used as an indicator of the "potential" of a given pool to maintain mussels. The value is driven by the diversity of both mussels and fish.

Additional details concerning these indices are included on the database CD.

Discussion

The Ohio River has been sampled for freshwater mussels since the at least the 1700's. In some instances these specimens still exist, with sufficient locality data, to be useful in reconstructing the original mussel fauna of the Ohio River. The records used here date back to 1800 in several instances, providing a lengthy record of mussels in several pools. Prior to impoundment the average depth of the Ohio River was ~ 1 ft. deep. Frontier accounts clearly depict the Ohio River as an often wadeable, meandering series of riffles, runs, and pools. As today in relatively unaltered riverine systems, we know that mussels occupied distinct river reaches – some species were most common in riffles and runs while others preferred pools and backwaters. The construction of dams eliminated the riffles and pools, presumably driving some species (and/or their hosts) to extirpation or even extinction. All of the currently extinct North American mussel species, predominately in the genus *Epioblasma*, were big river riffle/run species.

The charts presented here show a mixed effect of the dams on the mussel fauna. In pools such as Hannibal, McAlpine, and Smithland, the effects are marked. But in other pools little effect is apparent: Dashields, Greenup, and Markland, for example. Often the effect is not immediate; in some cases nearly a decade passes before declines are apparent. This is due to two causes. First, an artifact created by the timing of the next survey post dam construction – if the next survey is ten years after the dam is placed in operation, then the diversity estimate will not be updated until that time. Second, there may be a biological reason for the lag time. This may reflect the lack of recruitment in some mussel populations while their adults age and eventually die off in the pool.

Based upon historical records we know that each pool or reach supported 40-50 species of mussels; today many have less than ten. Pools now have an average of 60-80 species of fishes. Unlike mussel species, most fish species have persisted in pools for the past several decades. No fish species is considered extirpated from the Ohio River mainstem.

In nearly all cases the most dramatic declines in mussels are obviously associated with the arrival of zebra mussels in the Ohio River in 1991. Often these declines are precipitous. However, the overall diversity is usually found to be already in decline prior to zebra mussels, and this decline is often attributable to impoundment. Thus, the overall loss of mussels in each pool is rarely attributable to any one cause; rather zebra mussels seem to work on an already declining diversity caused by impoundment, loss of hosts,

and pollutants. The loss of mussels does not seem to be attributable to a loss of hosts; most pools have a wide variety of fish that could act as hosts to these mussels. While it is possible that some very host specific mussels, perhaps now extinct, may have been affected by the loss of the proper fish, this is probably the exception.

The following section presents pool-by-pool results starting with Emsworth Pool at Pittsburgh, the most upstream pool, and continuing downstream to near Cairo, IL, at the Ohio's confluence with the Mississippi River.

Emsworth

There are no historical mussel records for this pool. Only 32 species of fish have been recorded, all but one since 1988. *Pimephales notatus* has not been collected since 1958.

Dashields

The Dashields Pool has one of the longest records of mussels in the river, dating to 1800's. Records indicate that this reach once supported a thriving mussel community of perhaps 40 species, including the extinct *Epioblasma torulosa*, last seen in 1800. Recent surveys have found less than ten species. It is clear that the decline began as early as the late 1800's. The dam was not placed in operation until 1929 and no further surveys were conducted until the 1970's. At that time the Pool probably still supported over 20 species. No marked decline attributable to the dam is apparent in the data. Species richness began to decline ~1980. After briefly leveling off in the late 1980's, the fauna dramatically declined with the arrival of zebra mussels in 1991. The fauna today is largely comprised of mussels using freshwater drum or catfish as their hosts. The endangered *Cyprogenia stegaria* probably still exists in the pool. Dashields Pool has 54 fish species recorded from it. Only *Ameiurus melas* has not been found since 1958.

Montgomery

The mussel data from this pool are insufficient to draw any conclusions. Only two species occur in the database; neither is rare and both are more properly considered stream and lake species. Seventy-four fish species have been recorded, the majority of them recaptured in the past decade.

New Cumberland

The few mussel records available from this pool all date from the 1990's, after both dam construction and zebra mussel introduction have taken place. The data suggest a dramatic decline in mussel diversity. The IPP for this pool is only 8; fish host availability may be a problem here. Ninety-five fish species have been reported, all since 1968.

Pike Island

There is little information available for this pool – few surveys have been conducted although records date to 1900. Only five species have been recorded, four of which have been found in the 1990's. There are no records of extinct or endangered mussels from Pike Island Pool. The IPP for this pool is very low, 2, probably the result of inadequate data. Eighty-nine fish species have been recorded here, all since the 1970's.

Hannibal

Mussel data date from the early 1900's. The effects of both dam construction and zebra mussels are evident. The only endangered mussel recorded from the pool is *Pleurobema plenum*, last seen in 1901. Hannibal Pool has a low IPP of 8; relatively few of the known host fish are recorded from this pool. Eighty fish species occurred in this pool; six have not been seen since 1957-1959: *Ameiurus natalis, Hypophthalmichthys molitrix, Lythurus ardens, Notropis bucahnani, Noturus exilis,* and *Noturus nocturnus*.

Willow Island

Willow Island mussel data only dates to 1983, shows a dramatic decline immediately after the arrival of zebra mussels – from >20 taxa to <5. The only endangered mussel reported from the pool is *Pleurobema clava*, which has never been found living or fresh dead there. Willow Island Pool has an average IPP, 15. Willow Island has 73 fish species. Three have not been collected since the 1950's: *Catostomus commersoni, Luxilus chrysocephalus*, and *Pimephales promelas*.

Belleville

Belleville has among the best historical records of any Ohio River pool, dating back to the early 1800's. Except for a small decline in the 1880's, the diversity has remained fairly constant until the late 1970's. This may reflect the construction of the dam in the 1960's. However, a marked decline is associated with the advent of zebra mussels. Of the several endangered species recorded from the reach, only *Cyprogenia stegaria* apparently still exists here. Belleville Pool has a fairly high Index of Pool Potential (IPP): 23. Eighty-five fish species have been reported from this pool; only four species (*Ictalurus furcatus, Luxilus cornutus, Percopsis omiscomaycus, Polyodon spathula*) have not been recollected since 1958.

Racine

There is little historic mussel data available for the Racine Pool and none from prior impoundment in 1967. By the time of the first surveys in the 1970's, the mussel fauna is precipitously declining from nearly 50 taxa to ~30, although many of the species seen in the earlier surveys were weathered or subfossil shells. After leveling off in the late 1980's, the fauna was again decimated by zebra mussels. Today perhaps less than ten mussel species remain. The extinct *Epioblasma torulosa* occurred in this pool. The endangered *Cyprogenia stegaria* still exists in the Racine pool. Racine Pool has a high IPP, 23. Racine Pool has 75 species of fishes. All but two, collected in the 1950's (*Luxilus cornutus* and *Phenacobius mirabilis*), have been recently found.

Byrd

There is little information on mussels in the Byrd Pool. The diversity was already in decline when first surveyed, but has declined precipitously since the arrival of zebra mussels. The only endangered species, *Lampsilis abrupta*, was seen here in 1993. The very rare *Simpsonaias ambigua*, virtually unknown from the Ohio River mainstem, was found in 1995. The IPP for this pool is average for Ohio River pools: 19. The fish fauna

of this pool is particularly rich, with 94 recorded species. All species have been collected since 1973.

Greenup

Greenup mussel data show an alarming decline in diversity after the arrival of zebra mussels – from nearly 40 species to less than five. The endangered *Lampsilis abrupta* apparently still occurs in this reach. Greenup has a very high IPP (26), indicating that most of the necessary host fish are present in the pool. Ninety-five fish species are reported from this pool. Only one species, *Ameiurus melas*, has not been recaptured since 1959.

Meldahl

Mussel data date back to the early 1900's. Over 50 mussel species originally lived in this river reach. Surveys reveal a constant decline in mussel diversity. The effect of the Meldahl Dam was to speed up this decline; the arrival of zebra mussels has led to a severe decline in diversity. Two extinct mussels once occurred here: *Epioblasma torulosa* and *Epioblasma obliquata obliquata.* Several other endangered species also are recorded from here but none have been see in the past 50 years. Meldahl Pool has a high IPP of 24, suggesting that host fish loss is not a serious problem in this reach. Meldahl Pool has 86 fish species. Only three of these have not been captured since the 1950's: *Ameiurus natalis, Ameiurus nebulosus*, and *Notropis atherinoides*.

Markland

The Markland Pool may have more mussel data than any other Ohio River reach. Data is available form the 1800's through 2000, revealing an original mussel diversity exceeding 60 species. A marked decline in mussel diversity occurred in the 1840's. The fauna slowly declined to the early 1980's, past the construction of the dam. Another obvious decline occurred at this time, followed by yet another decline when zebra mussels arrived. Numerous rare, endangered, and extinct species once lived in this reach. With the exception of *Cyprogenia stegaria*, apparently still living here, none of these species have been seen in the past 50 years. Markland Pool has the highest IPP: 27.This pool has 94 fish species reported from it. All species have been captured since 1970.

McAlpine

Mussel data are available from 1800. The affect of dam construction on the mussel fauna is obvious. Mussel diversity has declined dramatically to ~1990, the last date for which we have data. Several rare or endangered mussels are known only as weathered or subfossil shells – *Cyprogenia stegaria, Lampsilis abrupta, Obovaria retusa, Plethobasus cicatricosus, Pleurobema clava*, and *Pleurobema plenum*. McAlpine Pool has an average IPP of 12. The pool has a relatively low diversity of fish: 44 species. Many have not been seen since the 1950's and 1960's.

Cannelton

Cannelton mussel records date to ~1900 and suggest a robust original fauna of ~40 species. The extinct *Epioblasma torulosa*, and other very rare species, were found as

subfossil material in 2000, but when they were lost from the pool is not known. Most of the fauna persisted until the construction of the dam in 1972, and then declined during the late 1970's into the 1980's. Mussel diversity plummeted after the arrival of zebra mussels. *Quadrula pustulosa* is the most abundant species in the pool today. The endangered *Cyprogenia stegaria* is uncommon in the Cannelton Pool. Cannelton Pool has an IPP of 16, average. Sixty-eight fish species are reported from Cannelton Pool. All have been collected since at least 1957.

Newburgh

Mussel data for the Newburgh Pool are not available before the dam was placed in operation. The few surveys performed since suggest a declining fauna, particularly after the arrival of zebra mussels. Several rare species, including the extinct *Epioblasma torulosa*, are known from the pool only as weathered or subfossil specimens. Newburgh Pool has an average IPP, 16. Newburgh Pool also has 76 fish species recorded. All have been collected since the late 1960's.

Myers

We have mussel data for the Myers Pool dating back to the early 1900's. Mussel diversity seems to have remained fairly constant until the advent of zebra mussels. After that point, the mussel diversity has precipitously declined. The Myers Pool has two mussel species that are usually considered more southern taxa – *Plectomerus dombeyana* and *Quadrula apiculata aspera*. This probably represents the northernmost extent of these species. Myers Pool has an average IPP, 18. Myers Pool has 76 fish species reported. Only three, *Notropis stilbius*, *Noturus eleutherus*, and *Noturus nocturus*, have not been collected since 1957.

Smithland

Records for the Smithland Pool date to 1800 and clearly show the impact of impoundment in 1980. The fauna has been reduced from its original 36 taxa to less than 15. This includes the extinct *Epioblasma torulosa* and several endangered species. Effects from zebra mussels are not as dramatic here as in other pools. Smithland Pool has an average IPP, 15. Eighty-nine fish species have been found here. Four species have not been collected since the 1950's: *Cycleptus elongatus*, *Notropis stilbius*, *Noturus exilis*, and *Rhinichthys oculus*.

Olmsted

Mussel data for the Olmsted Pool dates back only to the early 1980's, well after the dam was constructed in 1928-29. Diversity has declined from nearly 30 species to perhaps less than ten. Because of the paucity of records, all species are indicated as rare. *Plethobasus striatus* was found in 1987 and *Potamilus capax* in 1991; both are endangered. Olmsted Pool has a high IPP, 20. Fish data are separated into Locks 52 and 53 for this pool. Lock Pool 52 has 64 species, Lock Pool 53 has 77. Six species have not been collected since the 1950's.

Lock and Dam 53

This river segment, which is not impounded, has relatively few mussel data and few conclusions may be drawn from them. Not surprisingly, several southern species, *Arcidens confragosus* and *Quadrula apiculata aspera*, occur here. The very rare and endangered *Plethobasus striatus* was found here as late as 1982. Fish data were not available for this river reach near Cairo, IL.

Data Notes

The database is only as good as the data it contains. In a perfect world, we would know the distribution of every mussel and fish, and which fish act as hosts for which mussels. In the real world we have only incomplete data. In particular we have only partial lists for host-mussel associations. Thus the data, and the conclusions drawn from them, must be carefully examined in light of these shortcomings.

Acknowledgments

We thank Heidi Dunn (Ecological Specialist, Inc.), Patty Morrison (USFWS), and Peter Dodgion (USACOE) for contributing data. We also wish to thank Jeff Thomas of ORSANCO, Randy Sanders of the ODNR Division of Wildlife, Dennis Mishne of the OEPA, EA Engineering, Science and Technology, and Geo-Marine, Inc. for providing us with the data from their fish collections on the Ohio River. Kurt Snider (USFWS) supplied the ArcView basemap. Funding for this project was provided by the U.S. Army Corps of Engineers.

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Contents of OSU Mussel Database CD

1. Mussel-Fish Access Database
2. ArcView File
3. Excel format Pool Rankings (ohio-coe1.xls)
4. Excel format Gravid Periods (breeding.xls)
5. Excel format Mussel Species List by Pool (“poolnameX”.xls)
6. Excel format Fish Species List by Pool (fishpools.xls)
7. Excel format Mussel Common Names (clamnames.xls)
8. Excel format Fish Common Names (fishnames.xls)
9. Excel format Cumulative Mussel Distributions by Pool (damplots.xls)
10. Word format (COEreport.doc)

United States Department of the Interior

FISH AND WILDLIFE SERVICE
3761 Georgetown Road
Frankfort, Kentucky 40601

February 6, 2006

Veronica Rife, PM-C
U.S. Army Corps of Engineers
Louisville District
P.O. Box 59
Louisville, Kentucky 40201-0059

Subject: FWS#06-0484; Planning Aid Letter regarding ORMSS PEIS

Dear Ms. Rife:

The U.S. Fish and Wildlife Service (Service) has prepared this Planning Aid Letter (PAL) for the Ohio River Mainstem Systems Study Programmatic Environmental Impact Statement the Corps is developing. This PAL is provided in accordance with the Fish and Wildlife Coordination Act (FWCA) (16 U.S.C. 661 et seq.) and section 7 of the Endangered Species Act (ESA) of 1973, as amended (87 Stat. 884; 16 U.S.C. 1531 et seq.).

This PAL does not constitute the report of the Secretary of the Interior as required by section 2(b) of the FWCA, nor does it constitute a biological opinion under section 7 of the ESA. This PAL provides guidance and recommendations regarding the ongoing ORMSS and development of the PEIS by the Corps.

The Corps focus of this PEIS differs from most EIS's developed in the past for proposed construction at one or a few sites. This PEIS should present economic, engineering, and environmental information to evaluate broad system investment alternatives, and it should also provide information regarding overall impacts of the program, including cumulative effects, so that the decision-makers can make a reasoned judgment of the merits of the actions at the present state of planning or development through consideration of effects of navigation improvements on environmental sustainability. As a Federal agency, the Corps has had the major role in creating and maintaining the current navigation system. The Corps role in determining how this navigation system will look into the future includes the responsibility to do everything it can to minimize its impacts to the natural resources and to create conditions in which the natural resources can be enhanced, recovered, and sustained throughout the extent of the river. We urge the Corps to include in the ORMSS PEIS a commitment to maximize the overall project benefits to federal trust resources and to provide details on how it will avoid, minimize, and/or compensate for any trust resources that are adversely impacted.

The Cumulative Effects Assessment (CEA), which the Corps is working on to include in the ORMSS PEIS, analyzes the impacts on the environment that result from implementation of the Ohio River mainstem navigation system modernization when added to other past, present, and reasonably foreseeable future actions regardless of what agency or person undertakes such other

TAKE PRIDE IN AMERICA

actions. We urge the Corps to be as detailed as possible regarding this cumulative effects assessment and to include how actions completely unrelated to the proposed action have and/or will affect the natural resources.

The Service has participated with the Corps on this project for several years primarily in the capacity of the Interagency Working Group (IWG). The Service believes the IWG has been effective and can continue to provide input and guidance to the Corps on this project. We urge the Corps to continue to involve the IWG during completion of the ORMSS PEIS, and to continue its involvement as the Corps moves forward developing specific projects.

The Corps has been providing several sections or chapters of the PEIS for Service review. Many of these have been draft documents for which the Service has not seen the final version. The Service has been providing input to the Corps on these draft documents; however, it would be helpful if these sections or chapters could be reviewed in a final form before the Service prepares the FWCA Report for this project for inclusion into the final PEIS. We anticipate providing a draft FWCA to our state partners for review within the next few weeks. We also anticipate including their input into the draft FWCA we present to the Corps in the near future. The Service will continue to cooperate with the Corps regarding the ORMSS PEIS. We believe its success is crucial to providing guidance to future Corps projects on the Ohio River and how these activities may impact federal trust resources.

Thank you for the opportunity to comment on this important matter. Please contact Leroy Koch at 502-695-0468 if you have any questions regarding this letter.

Sincerely,

Virgil Lee Andrews, Jr.
Field Supervisor

cc: Corps, Huntington, WV (David Rieger)
Corps, Nashville, TN (Tom Swor)
USFWS, Marion, IL (Joyce Collins, Mike Thomas)
USFWS, Bloomington, IN (Mike Litwin, Scott Pruitt)
USFWS, Reynoldsburg, OH (Mary Knapp, Jeromy Applegate)
USFWS, Elkins, WV (Tom Chapman)
USFWS, Parkersburg, WV (Patty Morrison)
USFWS, Marion, IL (Rob Simmonds, Greg Conover)

DRAFT PROGRAMMATIC AGREEMENT
AMONG

THE U.S. ARMY CORPS OF ENGINEERS, PITTSBURGH, HUNTINGTON AND LOUISVILLE DISTRICTS, THE ADVISORY COUNCIL ON HISTORIC PRESERVATION, AND THE STATE HISTORIC PRESERVATION OFFICERS OF PENNSYLVANIA, OHIO, WEST VIRGINIA, KENTUCKY, INDIANA AND ILLINOIS REGARDING THE MODERNIZATION OF THE OHIO RIVER NAVIGATION SYSTEM

WHEREAS, the U.S. Army Corps of Engineers, Pittsburgh, Huntington and Louisville Districts (Corps), propose to modernize the existing Ohio River Navigation System, consisting of Locks and Dams located in Pennsylvania, West Virginia, Ohio, Kentucky, Indiana and Illinois; and

WHEREAS, the Corps has determined that modernization of the Ohio River Navigation System and concomitant environmental mitigation efforts (Project) may have an effect upon properties included in or eligible for inclusion in the National Register of Historic Places (National Register) and has consulted with the Advisory Council on Historic Preservation (Council) and the State Historic Preservation Officers of Pennsylvania, West Virginia, Ohio, Kentucky, Indiana and Illinois (SHPOs) pursuant to Section 800.14 of the regulations (36 CFR Part 800) implementing Section 106 of the National Historic Preservation Act (NHPA, 16 U.S.C. 470f), and Section 110(f) of the same Act (16 U.S.C. 470h-2(f)); and,

WHEREAS, pursuant to 36 CFR 800.2, the Corps conducted a series of public and agency meetings between July 10, 2001 and August 7, 2001, throughout the project area, designed to give all interested parties an opportunity to comment on the overall Project; and

WHEREAS, the Project shall be defined as those activities undertaken by the Corps that are required to modernize Locks and Dams, including all construction staging areas, all flowage easement acquisitions, all disposal sites, all publicly owned shoreside facilities relocated at Federal expense, and all environmental mitigation; and as defined excludes activities undertaken by the private sector as a consequence of the Project, which may affect historic

properties, the Section 106 obligations of which will be addressed separately through Department of the Army permitting authority under Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403), and Section 404 of the Clean Water Act (33 U.S.C. 1344);

WHEREAS, the Corps, in order to facilitate the assessment of Project effects, has prepared a National Register of Historic Places-level contextual report, which has been coordinated through the SHPOs; and

WHEREAS, the Corps, has conducted a historic architectural survey of all extant and former Corps lock and dam facilities along the Ohio River, through consultation with the SHPOs; and has completed the appropriate state inventory forms for agency review. The final report will be completed and distributed by the Winter of 2005/06; and

NOW, THEREFORE, the Corps, the Council and the SHPOs agree that the Project shall be administered in accordance with the following stipulations to satisfy the Corps' Section 106 responsibility for all individual undertakings of the Project.

Stipulations

The Corps shall ensure that the following measures are carried out:

I. Completion of Historic Property Surveys

A. The Corps shall ensure that historic property surveys will be performed in the Project's area of potential effects as defined in the Council's regulations at 36 CFR Section 800.16(d). The objective of these surveys is to identify both recorded and unrecorded potentially historic properties within the area of potential effects that may be affected by the Project either directly or indirectly, and determine whether they meet the criteria for inclusion to the National Register of Historic Places as specified in the Department of Interior's regulation at 36 CFR Part 60.4.

B. Historic property surveys will be performed in accordance with the Secretary of the Interior's Standards and Guidelines for Archaeology and Historic Preservation

and other applicable professional standards as described below.

II. **Identification and Treatment of Archaeological Properties**

A. Identification and Evaluation

1. Phase I archaeological survey will be performed on all lands that will be disturbed by the Project. The surveys will be conducted in a manner consistent with the Secretary of the Interior's Standards and Guidelines for Identification (48 FR 44720-23) and take into account the National Park Service publication The Archaeological Survey: Methods and Uses (1978), and specific state guidelines.

2. All surveys shall be conducted in consultation with the SHPO who has jurisdiction where the surveys will take place. All reports will meet the standards of the appropriate SHPO and shall be submitted to that SHPO for review and comment.

3. Where the Phase I archaeological survey results in the identification of a historic property, but yields insufficient information to properly determine the National Register of Historic Places eligibility for that property, a Phase II archaeological testing program will be developed and coordinated with the appropriate SHPO. The goal of the Phase II testing program will be to glean sufficient information about the property to make an eligibility determination.

4. The Corps, in consultation with the appropriate SHPO and following the Secretary of Interior's Standards for Evaluation, shall apply the National Register Criteria to properties that may be affected by this project. If the Corps and the appropriate SHPO agree that a property is eligible under the criteria, the property shall be considered eligible for the National Register for purposes of this Agreement. If the Corps and the appropriate SHPO agree that the criteria are not met, the property shall be considered not eligible for the National Register for purposes of this Agreement. If there is no agreement between the Corps and the appropriate SHPO on National Register eligibility, or if the Council so requests, prior to the start of any work at the site the Corps shall submit

the property for a formal determination of eligibility from the Keeper of the National Register, National Park Service, whose determination shall be final.

5. For those archaeological properties which the Corps and appropriate SHPO agree are not eligible for the National Register, no further archaeological investigations will be required, and the proposed project may proceed in those areas. If the survey results in the identification of properties that the Corps and the appropriate SHPO determine to be eligible for the National Register, such properties shall be treated in accordance with Stipulation II(B) below.

6. NAGPRA

a. Federal Fee Title Lands.

i. In the event that Native American human remains, associated and unassociated funerary objects, sacred objects, and/or objects of cultural patrimony are encountered during any phase of the project on tribal land, or federal fee title lands, or on lands in which the federal real property interests are virtually equal to fee title, the burial discovery is subject to NAGPRA, Section 3 (Public Law 101-601-Nov.16, 1990) and the Department of the Interior’s NAGPRA Regulations (43 CFR Part 10).

ii. The Corps and appropriate federally recognized tribal entity shall notify the appropriate SHPO and the Council of the outcome of tribal consultation and disposition.

iii. The SHPOs and the Council shall be consulted to amend the provisions of this agreement if the NAGPRA tribal consultation and subsequent disposition impairs the Corps’ ability to execute this agreement.

b. Non Fee Title Lands

In the event that Native American human remains, associated and unassociated funerary objects, sacred objects, and/or objects of cultural patrimony are encountered during any phase of the project on state, local, or private lands, the burial discovery is subject to state burial laws.

B. Determination of Effect and Treatment

The Corps, in consultation with the appropriate SHPO and the Council, shall determine the effect the Project will have on each listed or eligible archaeological properties and develop a treatment plan for any archaeological properties that will be adversely affected by the Project.

a. Preservation In Place

i. Wherever feasible, preservation in place shall be the preferred treatment. Such properties shall be avoided either through project design changes, use of temporary fencing or barricades, or other measures to protect sites.

ii. The Corps, in consultation with the appropriate SHPO, shall develop and implement a plan for long term protection of archaeological sites avoided and preserved in situ on lands affected by the Project.

iii. The Preservation plan will be submitted to the appropriate SHPO and the Council for 60 days (from receipt of documentation) for review and approval. The parties shall consult to resolve any objections to the preservation plan as proposed prior to implementation. If no response is received from the SHPO or the Council after 60 days (from receipt of documentation), the plan shall be implemented as submitted.

b. Archaeological Data Recovery

i. For those eligible archaeological sites that the Corps, the appropriate SHPO, and the Council agree cannot be avoided, a data recovery plan for the retrieval of significant archaeological information will be developed and implemented.

ii. A data recovery plan that addresses substantive research questions will be developed in consultation with the appropriate SHPO for the recovery of relevant archaeological data. The plan shall be consistent with the Secretary of the Interior's Standards and Guidelines for Archaeological Documentation (48 FR 44734-37) and take into account the Council's publication, Treatment of Archaeological Properties and the appropriate

state publication. It shall specify, at a minimum, the following:

(a). The property, properties, or portions of properties where data recovery is to be carried out;

(b). The research questions to be addressed through the data recovery, with an explanation of their relevance and importance;

(c). The methods to be used, with an explanation of their relevance to the research questions;

(d). The appropriate treatments and methodologies, and consultation procedures to be employed if any materials specific to NAGPRA are encountered;

(e). A proposed schedule for the submission of progress reports to the SHPO.

iii. The data recovery plan shall be submitted to the appropriate SHPO and the Council for 60 days (from receipt of documentation) for review and approval. The parties shall consult to resolve any objections to the data recovery plan as proposed. The data recovery plan shall then be implemented. If no response is received from the SHPO or the Council after 60 days (from receipt of documentation), the plan shall be implemented as submitted.

iv. The data recovery plan will be carried out by or under the direct supervision of an archaeologist(s) who meets, at minimum, the Secretary of the Interior's Professional Qualifications Standards (48 FR 44738-9).

v. An adequate program of site security to protect the site from vandalism during data recovery will be developed in consultation with the appropriate SHPO and then implemented.

vi. Curation and Dissemination of Information:

(a). In consultation with the appropriate SHPO, all materials and records resulting from the survey, evaluation, and data recovery conducted for the Project will be curated in accordance with 36 CFR Part 79. The Corps will curate all materials in a repository meeting federal standards within the appropriate state. All

material and records recovered from non-Federally owned land shall be maintained in accordance with 36 CFR Part 79 until their analysis is complete and, if necessary, are returned to their owners.

(b). The Corps shall ensure that all final archaeological reports resulting from actions pursuant to this Agreement will be provided to the SHPOs, the Council, and upon request, to other interested parties. All such reports will be responsive to contemporary standards and to the Department of the Interior's Format Standards for Final Reports of Data Recovery Programs (42 FR 5377-79). Precise locational data will be withheld from the general public or provided under a separate appendix to the reports if the Corps and the appropriate SHPO agree to the data's release.

III. **Identification and Treatment of Above-Ground Historic Properties**

A. Identification and Evaluation

1. The Corps, in consultation with the appropriate SHPO, shall ensure that a historical architectural survey will be conducted in those areas affected by the Project but not previously investigated as part of the Ohio River Navigation System. This survey will be conducted by a qualified architectural historian who meets, at minimum, the standards set forth in the Secretary of the Interior's Professional Qualifications Standards (48 FR 44738-9).

2. All of the areas surveyed will be clearly identified and the rationale used in eliminating areas from the survey (e.g. because either no above ground facilities will be located in view of extant structures, no flowage easements will be acquired, etc.), will be described. The criteria to be used in eliminating survey areas will be established in consultation with the appropriate SHPOs.

3. Particular attention will be given in the survey to the visual integrity (setting) of identified historic properties, and how the setting may be affected by view of the navigation structures or other Project-related activities.

4. The Corps will ensure that the architectural survey meets the standards of the appropriate SHPO, and is consistent with the recommended approaches in the Secretary

of the Interior's Standards and Guidelines for Identification (48 FR 44720-3) and the Council's and National Park Service's publication Identification of Historic Properties (1988).

5. As necessary to supplement the review of above-ground historic property documentation, the appropriate SHPO may conduct an inspection of National Register-listed or eligible properties. The appropriate SHPO shall report each determination, along with the rationale for their decision.

6. The Corps, in consultation with the appropriate SHPO and following the Secretary of Interior's Standards for Evaluation, shall apply the National Register Criteria to properties that may be affected by this Project. If the Corps and the appropriate SHPO agree that a property is eligible under the criteria, the property shall be considered eligible for the National Register for purposes of this agreement. If the Corps and the appropriate SHPO agree that the criteria are not met, the property shall be considered not eligible for the National Register for purposes of this Agreement. If the Corps and the appropriate SHPO do not agree on eligibility, or if the Council so requests, the Corps shall obtain a determination from the Keeper of the National Register, whose determination shall be final.

B. Determination of Effect and Treatment

1. The Corps, in consultation with the appropriate SHPO and the Council, shall determine the effect the Project will have on each Register-listed or eligible historic building, structure, landscape, or archaeological site.

2. The Corps, in consultation with the appropriate SHPO and the Council, shall develop proper treatments for Register-listed and eligible historic buildings, structures, landscapes, and archaeological sites that will be adversely affected by the Project.

a. The preferred alternative is avoidance of effects to historic properties. If, in consultation with the appropriate SHPO and the Council, all parties agree this is not feasible, the Corps will develop and implement plans to minimize or reduce the effect.

b. The Corps shall prepare Memoranda of Agreement (MOA) that detail mitigation plans that are developed in consultation with the appropriate SHPO and the Council. Plans will also be made available for review and comment to interested parties, affected landowners, and appropriate local interest groups. Any such comments shall be made available to the appropriate SHPO and the Council and shall be taken into account by the parties to this agreement. The appropriate SHPO and Council shall have 60 days from receipt of adequate information in which to review and comment on the MOA. If the appropriate SHPO or the Council fails to respond within 60 days, that party shall be deemed to have consented to the matter proposed. The MOA shall contain dispute resolution language that will guide consultation if there is a disagreement over adequacy, appropriateness, or extent of a mitigation plan. If the disagreement cannot be resolved, it will be handled in accordance with Stipulation V. G. below.

IV. **Public Outreach And Education**

The Corps, on a case-by-case basis, will consult with the appropriate SHPO regarding the appropriateness and level of effort for a public outreach and education program. This consultation will occur through the development of MOAs for individual undertakings within the overall study reach.

V. **Review of this Programmatic Agreement**

A. The terms of this Agreement shall remain in effect through the completion of the project in the year 2060 unless changes have been negotiated and approved as specified below.

B. The signatories to this Agreement shall consult every five years through the life of the project to review implementation of the terms of this Agreement. Prior to the review, a report shall be provided to the signatories detailing how obligations pursuant to this Agreement have been carried out. The report shall also be made available for public inspections (information regarding the location of archaeological sites shall be withheld). If revisions to this Agreement are needed, the signatories to this Agreement will amend the agreement in accordance with Stipulation V.E. below.

C. The Council and the SHPOs may monitor activities carried out pursuant to this Agreement, and the Council will review such activities if so requested. The Corps shall cooperate with the Council and the SHPOs in carrying out their respective monitoring and review responsibilities.

D. This Agreement will be circulated for public and agency review as part of an Environmental Impact Statement (EIS) being prepared for the project under the National Environmental Policy Act (NEPA) and Section 106 of the NHPA. In consultation with the SHPOs, the Corps shall develop additional means to inform the interested public of the existence of this Agreement, and about how the obligations under the terms of the Agreement are to be met. Copies of this Agreement and relevant documentation prepared under it shall be made available for public inspection (information regarding the locations of archaeological sites shall be withheld). Any comments received from the public under this Agreement shall be taken into account.

E. This Agreement may be amended by a consensus of the parties to this Agreement. Any party to this Agreement may request that it be amended, whereupon the parties will consult in accordance with 36 CFR Section 800.14 to consider such amendment. Amendments shall be in writing and signed by all parties to this Agreement.

F. Any party to this Agreement may terminate it by providing thirty days notice to the other parties, provided that the parties will consult during the period prior to termination to seek agreement on amendments or other actions that would avoid termination. In the event of termination, the Corps will comply with 36 CFR Subpart B, Sections 800.3 through 800.8 with regard to individual undertakings covered by this Agreement.

G. Should any party to this Agreement submit an objection in writing to the Corps regarding any action taken or proposed with respect to implementation of this Agreement, the Corps shall consult with the objecting party and attempt to resolve the objection. If the Corps determines that the objection cannot be resolved, the further comments of the Council shall be requested in accordance with 36 CFR Part 800.7 with reference to the

subject of the dispute. Responsibility to carry out all other actions under this Agreement that are not the subject of the dispute will remain unchanged.

H. Execution and implementation of this Programmatic Agreement evidences that the Corps has satisfied its Section 106 responsibilities for all individual undertakings of the Project, and that the Corps has afforded the Council an opportunity to comment on the undertaking and its effects on historic properties.

U.S. ARMY CORPS OF ENGINEERS, HUNTINGTON DISTRICT

By:_____
Date:_____
William E. Bulen, Colonel, Corps of Engineers,
District Engineer

U.S. ARMY CORPS OF ENGINEERS, LOUISVILLE DISTRICT

By:_____
Date:_____
Raymond G. Midkiff, Colonel, Corps of Engineers,
District Engineer

U.S. ARMY CORPS OF ENGINEERS, PITTSBURGH DISTRICT

By:_____
Date:_____
Stephen L. Hill, Colonel, Corps of Engineers,
District Engineer

ILLINOIS STATE HISTORIC PRESERVATION OFFICER

By:_____
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William L. Wheeler, State Historic Preservation Officer

INDIANA STATE HISTORIC PRESERVATION OFFICER

By:_____
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KENTUCKY STATE HISTORIC PRESERVATION OFFICER

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By:_____
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Barbara Franco, State Historic Preservation Officer

WEST VIRGINIA STATE HISTORIC PRESERVATION OFFICER

By:_____
Date:_____
Troy Brody, Interim State Historic Preservation Officer

ADVISORY COUNCIL ON HISTORIC PRESERVATION

By:_____
Date:_____
John M. Fowler, Executive Director

OHIO RIVER MAIN STEM CONTEXT STUDY

HISTORIC CONTEXTUAL STUDY

September 2001

Prepared for

U.S. Army Corps of Engineers
Pittsburgh District
1000 Liberty Avenue, Room 2038
Pittsburgh, PA 15222-4186

ACKNOWLEDGMENTS

Preparation of this report would not have been possible without the assistance of many employees of the U.S. Army Corps of Engineers and the National Archives and Records Administration. Special contributions were made by Charles E. Parrish, Historian, Louisville District; Robert Maslowski, of the Huntington District; Richard E. McCoy, Jr., Mechanical Engineer, Huntington District; David Rieger and Conrad E. Weiser of the Pittsburgh District; Martin E. Reuss, Senior Historian, Office of History; and the staff of the Cartographic and Architectural Unit, National Archives, College Park, Maryland.

Ron Carlisle wishes to acknowledge the cooperation of Mr. James McCarville and Mr. Mike Brinza of the Port of Pittsburgh Commission for their assistance and the information they provided during an interview conducted by the author on July 27, 2000.

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INTRODUCTION

The Ohio River Main Stem Navigation System consists of 20 lock and dam structures and the Louisville and Portland Canal. These structures stand along the 981-mile length of the Ohio River through or along six states from Pittsburgh, Pennsylvania, to Cario, Illinois. The Louisville and Portland Canal opened in 1830 and, in bypassing the Falls of the Ohio, established the Ohio River as an important route to the West. Subsequent improvements have enhanced the system to allow reliable and cost-efficient transportation of raw materials, basic manufactured products, and consumer goods.

This study, undertaken under terms of contract number DACW59-98-D-0009 for the Pittsburgh District of the U.S. Army Corps of Engineers, seeks to document the national and regional historical context of this engineering achievement. While the historical importance of the system is obvious on its face, this study collected, organized, and analyzed historical data to assist the Corps of Engineers in complying with regulations requiring that federal agencies identify, manage, and take into account the effects of their undertakings on significant cultural resources, including Sections 106 and 110 of the National Historic Preservation Act, as amended.

A multiple property National Register of Historic Places Nomination will be prepared from the information presented herein to assist the Corps of Engineers in evaluating the significance and National Register eligibility of the individual structures and features of the system. Accordingly, the Criteria of Evaluation of the National Register of Historic Places provided an important framework for this study. The Criteria of Evaluation state:

> The quality of significance in American history, architecture, archaeology, engineering, and culture is present in districts, sites, buildings, structures, and objects that possess integrity of location, design, setting, materials, workmanship, feeling and association, and:
>
> A. that are associated with events that have made a significant contribution to the broad patterns of our history; or
>
> B. that are associated with the lives of persons significant in our past; or
>
> C. that embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic value, or that represent a significant and distinguishable entity whose components may lack individual distinction; or
>
> D. that have yielded, or may be likely to yield, information important in prehistory or history (36 CFR 60.6).

This study was undertaken to support National Register eligibility evaluation under Criteria A, B, and C.

In designing this study, five areas of research were identified as research foci. They are summarized in the following sets of questions included in the Task Order for this study:

> A. In what ways does the navigation system reflect social, economic, and political change? Which national or regional engineers, politicians, and commercial/industrial

leaders are closely associated with the system or individual structures? In what ways?

B. Did the locks and dams make a significant contribution to regional industries, their patterns of development and productivity? To what extent were these industries dependent upon the navigation system? To what extent is the regional and national significance of these industries linked to the presence of the navigation system?

C. In what ways did the presence of navigation structures and pools influence population development, the growth of cities and villages, and agriculture? Consider, in particular, the development of Pittsburgh, Huntington, Louisville, and Cincinnati.

D. Did the navigation system play a significant role in the war efforts of World War I, World War II, and the Korean War? If so, explain how.

E. Discuss the technological significance of the Ohio River lock and dam system and the navigation industry that evolved with it. What new technologies (including new building materials and construction techniques) were introduced in this system? Explain the development of these technologies. How did these technologies affect later river improvements elsewhere in the United States or in other nations? Were innovations in ship building technology attributed to the system?

In researching these topics, it became clear that while all were interrelated, several were so closely related that it was not really possible to meaningfully separate them. Accordingly, the three essays presented here address in turn: 1) the engineering of the system, 2) political factors and military influences, and 3) community and economic development. Each of these essays builds upon the rich literature on the history of the Ohio River and offers new insights from extensive primary source research completed as part of this study. We hope that a better future can be built from this better understanding of the past.

CHAPTER I

HISTORIC ENGINEERING EVALUATION

by

Douglas C. McVarish
John Milner & Associates, Inc.
535 North Church Street
West Chester, PA 19380

CHAPTER I

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DEVELOPMENT OF THE OHIO RIVER NAVIGATION SYSTEM

Early Improvements

Before the beginning of navigation improvements, snags, rocks and gravel and sandbars obstructed the Ohio River, rendering navigation difficult and hazardous. Channel depths varied considerably from a minimum of one foot between Pittsburgh and Cincinnati to two feet between Cincinnati and the river mouth (Jones 1929:2).

Legislative efforts aimed at funding the removal of Ohio River obstructions began in 1803. In that year, the Kentucky Legislature passed a resolution inviting the State of Ohio to join it in providing funds to pay for the removal of obstructions to navigation. Citing financial considerations, the Ohio Legislature declined to participate. In 1806, in response to a second request, the State of Ohio appointed commissioners "for the purpose of exploring the rapids of the River Ohio." During the following decade, states launched additional multi-state efforts to improve the Ohio River culminating in a four-state report that mapped all sandbars and proposed two routes for a canal at the falls of the Ohio (Kreisle 1971:47).

Early on, the improvement of Ohio River navigation became a stated national priority. Secretary of the Treasury Albert Gallatin wrote of the necessity of improving inland navigation in a report on roads and canals submitted to the U.S. Senate in 1808. In this report, he advocated the construction of a canal to provide passage around the Falls of the Ohio (Gallatin 1808:27).

Waterway historian Leland Johnson attributes much of the initial push for Ohio River navigation improvements to the inter-city rivalry between Pittsburgh and Wheeling and the droughts of 1818-1819. Long a leading trade center because of its location at the head of the Ohio River, Pittsburgh faced losing this role when the National Road bypassed it to the south and met the Ohio River at Wheeling. Extended droughts in 1818 and 1819 rendered the navigation of the Upper Ohio very difficult. Reports indicated that more than $3 million worth of commodities rotted on Pittsburgh's wharves while awaiting shipment. Pittsburgh's civic leaders solicited donations for the purpose of removing rocks in the channel that hindered navigation.

At the same time a joint state commission appointed to survey the river and plan its improvement for navigation passed through Pittsburgh enroute to Louisville. During their survey of the drought-plagued river they saw more than 30 boats that had run aground in the channel. The commissioners recommended that each state bordering the river appropriate $10,000 to remove the boulders, snags, rock ledges, and gravel bars that obstructed navigation (Johnson 1991:186).

Only Pennsylvania responded to the call. The state's legislature appropriated $15,000 in 1821. Laborers blasted rocks, cleared snags and boulders, and with teams of oxen pulling plows and scrapers, dredged channels through gravel bars. Returning each dry season until funds were exhausted, the laborers maintained a low water channel deep enough to permit small boats to travel the Ohio River as far as Wheeling (Johnson 1991:186).

Federal involvement in the improvement of the Ohio River began on April 14, 1820 when Congress appropriated $5,000 for the "survey of the Ohio and Mississippi Rivers from the Rapids at Louisville, to the Balize for the purpose of facilitating and ascertaining the most practicable mode of improving the navigation of those rivers" (Bernard and Totten 1822:2). In October 1821,

Brigadier General Simon Bernard and Brevet Lieutenant Colonel Joseph G. Totten, accompanied by two other officers, left Louisville to begin the survey (Reuss 1982:x).

In 1822, the Board of Engineers presented Bernard and Totten's completed report to President James Monroe. The surveyors found two major types of navigational hazards on the Ohio River, the Falls of the Ohio at Louisville and shoals of gravel and sand. In describing the former, the authors wrote:

> Amongst the great number of obstacles which the Ohio River presents to navigation, the falls at Louisville are certainly the first in importance, for, if boats, coming from above and bound for the Mississippi, do not arrive at Louisville at the period when the superior and inferior waters are on a level, or nearly so, from floods, they are either obliged to pass the falls at great risk, or they are detained and transport it in vessels constructed below the falls. All the country, therefore, connected with the Ohio, above Louisville, is deeply interested in opening a passage round the falls, which shall be practicable at all seasons when the river is so (Bernard and Totten 1822:13).

The surveyors identified 21 shoals of sand or gravel that posed hindrances to navigation. The bars allowed sufficient water passage for keel and flat bottom boats, but prevented navigation by steamboats, with their greater drafts, for five or six months every year (Bernard and Totten 1822: 15).

To address these hazards, the surveyors proposed the construction of dikes which, by narrowing the channel, would cause it to be deepened. The authors briefly described dike construction in the report:

> These dykes [dikes] across the river are ordinarily formed by rows of piles, driven with force into the bed, and strongly wattled together, the spaced between the rows being filled with such rough stones, or large paving stones, as the neighborhood can supply (Bernard and Totten 1822:20).

Bernard and Totten suggested that such dikes initially be used on bars that had less than three feet of water flowing over them. The board expressed caution concerning the efficacy of this remedy:

> It is certain that, by the dykes and narrow passages, the water may be deepened at any required point; but it is to be feared that in some places at least the localities may be such that the very materials thus carried off by the rapid waters may be deposited when they become comparatively quiescent in such a way as very soon to form a new bar below (Bernard and Totten 1822:21).

As their response to the report, the United States Congress passed legislation on May 24, 1824 appropriating $75,000 for clearing sand and debris from the Ohio River and the Mississippi below St. Louis, generally in accordance with the Bernard-Totten plan. An additional $40,000 was provided for pier improvements on the two rivers (Shallat 1994:127). To direct the initial experimental research on wing dams called for in the report, the Army's Chief Engineer dispatched Major Stephen H. Long to the Ohio. In 1824-1825, he supervised construction of the first navigation dam on the river near Henderson, Kentucky. In this experiment, he drove parallel rows of wooden pilings in the riverbed, filled the space between them with stone, and experimented with differing lengths, widths, and heights until he developed an efficient design.

The resultant 402 yard long wing dam extended from one bank toward the channel at a 45 degree angle downstream to confine river flow at low-water stages and to erode the obstructing gravel bar. Sediment gathered against the dam and anchored it to the riverbed. The total cost of construction was $3,378.93.

The second major project funded by the appropriation was snag removal. To secure a machine capable of removing snags, the Chief Engineer offered engineers and scientists a $1,000 prize for the best design. The winning design, submitted by Captain John W. Bruce of Vanceburg, Kentucky, consisted of a twin-hulled boat with a windlass between the two hulls. Attaching a cable from the windlass to a snag, workers turned the windlass to raise the snag from the river for disposal (Johnson 1991:188).

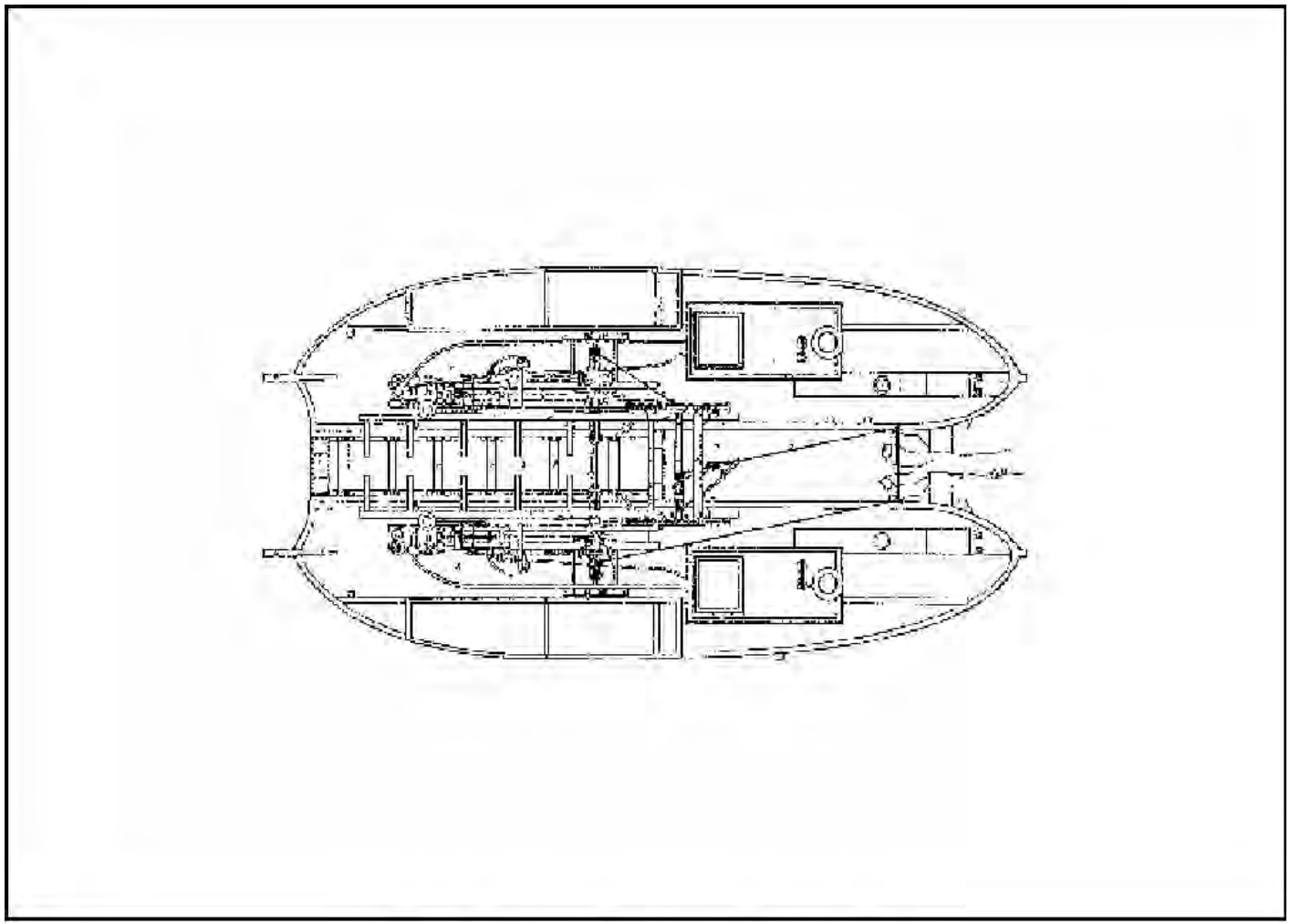
Bruce began work at Pittsburgh in 1824 and continued downriver in 1825. However, he made no attempt to clear the Ohio for steamboats. Finding a loophole in the contract, a phrase that referred to trees that blocked navigation "at the lowest stage of the water," Bruce removed only the logs in the low-water channel during the driest months. His contract was suspended. As a subsequent report indicated, "however well this invention recommended itself in theory, it was, in practice, found to be utterly useless" (U.S. House 1830:3).

After the failure of this snagboat, Henry M. Shreve, described as an "old and practical navigator of the western waters," was appointed to continue snag removal. His efforts were funded by a $30,000 Congressional appropriation on March 3, 1827. On March 3, 1827, Congress appropriated $30,000 for continued snag removal. In November 1827, Henry Shreve reported that he had succeeded in removing the obstructions off the bars and island chutes for a distance of 300 miles upstream from the mouth of the river (U.S. House 1828:3).

Shreve advocated the construction of a steamboat for improved snag removal, noting that it could operate at any stage of river when snags could be seen. With the permission of the U.S. Department of War, he was authorized to apply a portion of the Mississippi River funding to the construction of this boat. The craft, dubbed *Heliopolis*, a double-hulled steamboat joined by a platform with a windlass geared to the engine (Figure 1-1). Shreve described the boat in his patent application:

> It consists of a double or twin boat…connected by two tiers of beams: the upper tier running from the midships or centers of the boats to the stern…, decked over on the tops of the upper beams; the lower tier running from midships towards the stern, about half the distance of the upper tier, and sealed, sheathed, or planked, under said lower tier of beams, and secured by diagonal timbers…running on the top of the lower tier of beams, framed on to each beam, and secured by a bolt passing through the beam. The front or forward end of the two sets of beams are connected by a strong bulkhead,…fixed in an inclined position, and sheathed with sheet iron, about one-fourth of an inch thick, the lower side of the bulkhead being thirty inches forward of the upper side, forming an inclined plane, by which the end of a snag is conducted on deck by the impetus of the boat, when the snag comes in contact with said bulkhead (U.S. House 1843:3, 9).

Figure 1-1. Plan of Henry Shreve's snag boat (from Shallat 1994).



Despite these initial expenditures, Ohio River crafts continued to be lost as a result of striking snags. A number of Kentucky residents sent a petition to Congress requesting further appropriations to clear additional snags:

> …all are compelled to send the effects of their labor down the Ohio and Mississippi rivers to market, in the various craft that usually navigate those streams; that these great and navigable rivers are in many places, obstructed with trees, stumps, and roots of trees…whereby the navigation of them is retarded and rendered very hazardous; and by them, many of the various craft on the rivers, with valuable cargoes, are annually lost, to the great injury and distress of the adventurers, who frequently embark on board of them, with the effects of their year's labor, and often their all, as well as endangering the lives of the men sailing said craft (U.S. House 1828:1-2).

The petitioners noted that during the previous few years 19 steamboats had been totally lost together with cargoes, and the lives of crew and passengers. In addition, other steamboats suffered damage estimated at $125,000. An average of 30 flat boats were also lost every year (U.S. House 1828:2).

After Long's first successful experiment with the use of wing dams, the Corps of Engineers planned additional structures to eliminate obstructions. In 1831, Congress appropriated $150,000 for the construction of additional dikes on the Ohio. Dikes were begun at Scuffletown and Sisters Islands in 1831, and at French and Cumberland Islands in 1832. All of these locations were downriver from Owensboro, Kentucky. The wing dams generally assured a minimum channel depth of three feet. As a result of the success of these first structures, a large number of wing dikes and back channel dams were built between Pittsburgh and Cincinnati (USACE-ORD 1979:11; Office of History 1998:42; Johnson 1975:80).

These structures were built almost entirely of large rough stones deposited in the stream at the site of the works with little attempt at systematic arrangement. By 1840, the system had begun to deteriorate with some dams breaking and others causing sand to be deposited around them. By the latter part of the nineteenth century, these rough stone dams and dikes were replaced by more substantial timber structures, ballasted with stone or furnace slag and roughly paved on their upper surfaces with stone (Arras 1908:244; Kreisle 1971:77).

The Louisville and Portland Canal

The earliest major navigational improvements on the Ohio River occurred at the Falls of the Ohio at the present city of Louisville, Kentucky. The falls, actually a series of rapids formed by ledges of limestone rock, extend two miles along the river, dropping 26 feet at low water. Three main passages extended through the rapids. Indiana Chute, the longest, had a relatively uniform slope along its three-mile length. During low water, it was subdivided by the center rock into two with the better channel being sixteen feet wide and sixteen inches draft at low water. Middle Chute, a passage between Goose Island and Rock Island, extended approximately 2 1/16 miles and dropped 22 feet within the last 500 yards. Kentucky Chute branched off Middle Chute at Rock Island and dropped 26 feet within the last 185 yards. Middle and Kentucky chutes were navigable to descending traffic only during times of high water. Indiana Chute was navigable for the careful boatsman for ten months in the average year, but upstream traffic was limited to approximately two months (Bernard and Totten 1822:13-14). Boat traffic through the falls was restricted to craft

up to 14 feet wide, because the Indiana Chute had two projecting rocks that narrowed the channel (ACS 1988:20).

Because of the dangers inherent in shooting these rapids, most boats stopped above the falls. Goods and passengers were transported two and one-half miles overland to Shippingport, Kentucky, below the falls. The break in navigation was an important factor in the early growth of Louisville (Kreisle 1971:29).

A canal around the falls was initially proposed as early as 1804. In that year, the Legislature of Kentucky incorporated the Ohio Canal Company. Competing proposals were developed by proponents of a canal on the Kentucky side of the river and those proposing a canal on the Indiana side. Kentucky and Indiana each chartered a canal company in 1805. The act incorporating the Ohio Canal Company specified that construction had to begin within three years and be completed by January 1, 1812. A lottery was authorized to permit the company to raise as much as $15,000 for canal construction. No construction took place.

In 1818, the two states again chartered rival companies. The Kentucky enterprise, known as the Kentucky-Ohio Canal Company failed to begin construction. The Indiana company began preliminary excavations, damming Cone Creek and cutting a new channel for it along the line of the canal, but a financial panic doomed this enterprise (Walker 1932:21-23; Trescott 1958:687; ACS 1988:20).

The Board of Engineers on the Ohio and Mississippi Rivers prepared a report on the need for the canal in 1821. Noting that “amongst the great number of obstacles which the Ohio river presents to navigation, the falls at Louisville are certainly the first in importance,” the authors noted that several canal proposals had been developed. One proposal was to leave the river a half mile below Bear Grass Creek and rejoin it just below Shippingport. A second proposed canal would have left the river between Corn Island and the Kentucky shore and have its outlet between Shippingport and Rock Island, a total of two miles. A third canal was proposed for the Indiana side, leaving the river at Jeffersonville and following two ravines to an outlet at Clarksville (Monroe 1823).

Construction of the canal was successfully undertaken by a private stock company, the Louisville and Portland Canal Company, chartered in Kentucky in 1825 with an authorized capitalization of $600,000 divided into $100 shares (Walker 1932:25). Canvass White served as canal engineer (Roberts 1857:26). From the beginning, nearly 40 percent of the stock was owned by the United States government, a total of 2,335 shares, costing $233,500 (Humphreys 1868:5). The federal government’s share gradually increased. By 1855, the government had acquired effective control of the enterprise.

The Louisville and Portland Canal bypassed the falls (Plate 1-1). It was opened in 1830. Upon completion, the canal was 1.9 miles long and 64 feet wide in the clear. It included three lift locks in series at the foot of the canal (Plate 1-2). Each lock had a lift of slightly over eight feet, chamber length between miters of 198 feet and usable length of 170 feet, and a width of 50 feet (Plate 1-3). This canal, whose total construction cost was slightly more than $1 million, was the first successfully major improvement to the great central river system of the United States (Oakes 1914:564; Trescott 1958:694).

Plate 1-1. Plan of the Louisville & Portland Canal and vicinity. From Filson Club collection, Louisville.

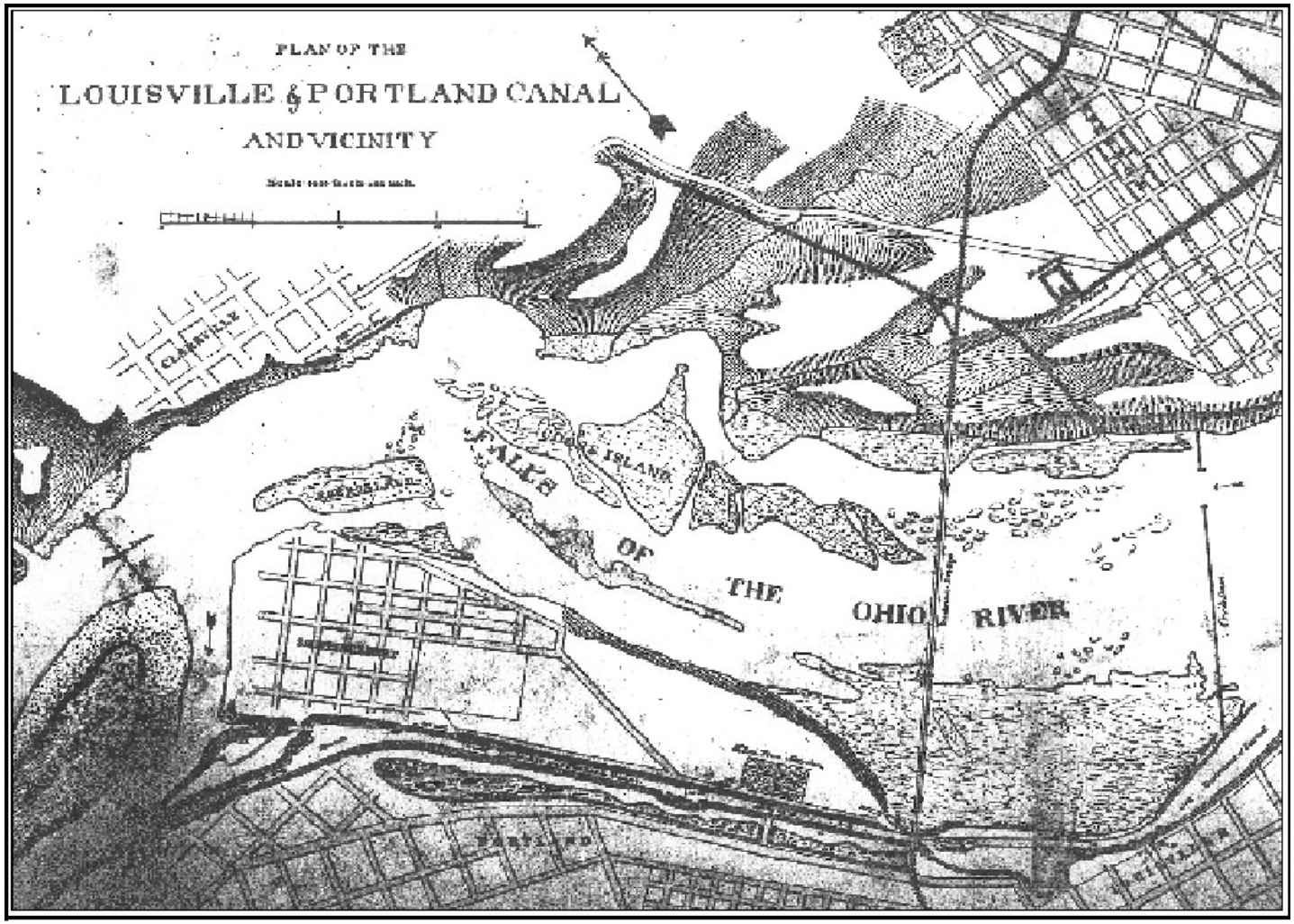
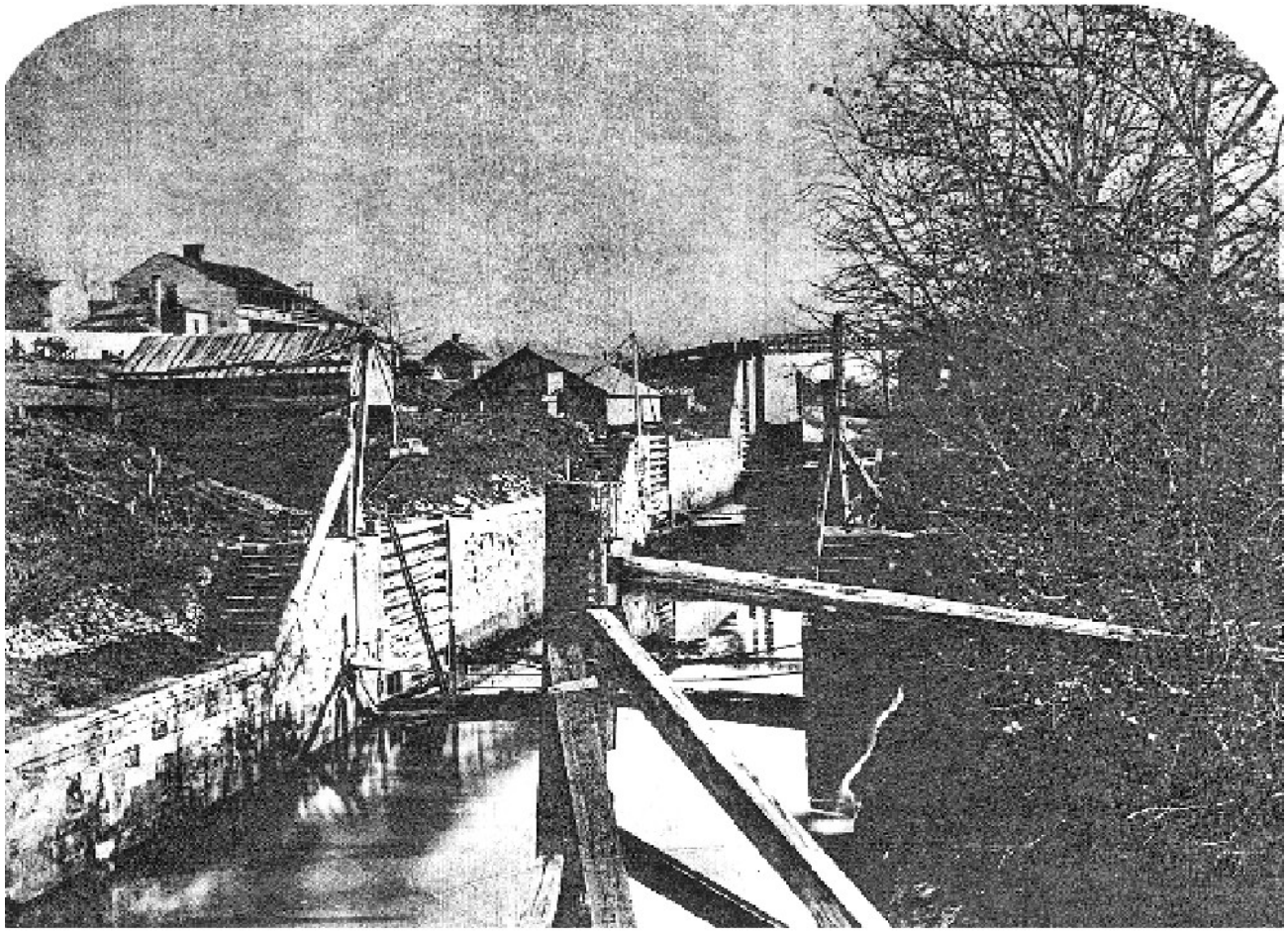


Plate 1-2. Louisville and Portland Canal. Original three stage lock (E. Klauber n.d.). From Filson Club collection, Louisville.



Flatboats passed through the canal beginning in early December 1830, and the first steamboat, *Uncas*, locked through on December 21st. During the first twelve months of operation, 406 steamboats and 375 flatboats, with an aggregate tonnage of 76,323 tons traversed the canal (Vance 1908:140).

Business was slow during the first few years of canal operation, in part because the canal was not fully completed until 1833. The company discovered that the initial toll rate of twenty cents per ton could not provide the profits permitted in the charter, so the toll was raised to forty cents in 1832 and sixty cents in 1837. By 1839, annual toll revenues had reached $180,000 and annual traffic grew to 1,666 steamboats and 578 keelboats with an aggregate tonnage of over 300,000. High tolls were a source of continuing concern to boatsmen and shippers, and petitions were regularly presented to Congress urging that the government buy out the remaining private stockholders (Trescott 1958:695; Walker 1932:27).

The lock chambers were built for the river vessels of the 1820s and accommodated a maximum hull dimension of 183 feet long by 49 ½ foot beam. In the 1840s, many new boats were too large to pass through the canal, while others suffered delays and risked damage due to the narrowness and shallowness of the waterway (Trescott 1958:699). By 1853, more than 40 percent of the steamboats plying the Ohio were too large to pass through the canal.

In 1843, Congress authorized a survey of the best method to improve navigation of the Falls of the Ohio. This survey was completed by Captain Thomas Cram and Assistant Engineers Allan Campbell and Henry Clay Long. The engineers recommended that the United States purchase the canal, enlarge it, and construct a second canal on the Indiana bank to allow two-way traffic. At the same time, other engineers advocated the construction of a dam and lock on the Ohio River below the falls to submerge them (Johnson 1975:100) calling the existing canal “the greatest obstacle to and impediment in the way of navigation between Cincinnati and the mouth of the Ohio” (U.S. Senate 1855:7).

The engineer board recommended construction of a single lift-lock of 80 foot width equipped with three gates. These gates would permit the length of the chamber to be 220, 320 or 420 feet long depending on gate configuration. The lock was to be filled and emptied by side culverts. The canal itself was proposed to be 200 feet wide to permit craft to pass one another and have a depth to permit a maximum draft of 11 feet (U.S. Senate 1855:8-9). This proposal was not approved by Congress (Johnson 1975:100).

In 1857, the Louisville and Portland Canal Company paid for a survey by Colonel Stephen H. Long. He proposed the construction of a larger lock with dimensions adequate for the largest Ohio River steamboat (Johnson 1975:100).

In 1859, hydraulic engineer Theodore R. Scowden outlined proposed improvements to the canal in a letter to the chairman of the United States House Committee on Railroads and Canals. His plans consisted of widening the canal from 64 to 100 feet, lining both sides with 17-foot high stone walls, fixing the lowest stage of canal water at six feet over the miter sill, replacing an abrupt turn in the original canal with a shallower curve, and constructing a timber and stone crib at the head of the canal to prevent boats entering it from being swept down the falls. The new locks were proposed to be 1,500 feet downstream from the old locks and connected by a 2,600 foot long branch canal (Kreisle 1971:89-90).

The following year, Congress passed a joint resolution authorizing the company directors to construct a branch canal provided that the credit of the United States not be used to fund it. Scowden was hired to prepare detailed plans for the improvements. The enlargement was begun in 1860 and stopped in 1866 after $1,825,403 had been expended (Weitzel 1868:5; Plates 1-4 and 1-5). Two years later, Congress passed a joint resolution that authorized and directed the Secretary of War:

> To cause surveys, with plans and estimates of cost, to be made by an officer of engineers for a ship canal around the falls of the Ohio, on the Indiana side thereof, of suitable location and dimensions for military, naval, and commercial purposes; and also to cause said officer to estimate the expense of completing the Louisville and Portland canal, on the Kentucky side of said falls, according to the plan on which the canal company is now progressing with said work… (Humphreys 1868:2).

After receipt of the report from Brevet Major General Godfrey Weitzel of the United States Army, Congress voted to continue with improvements to the existing canal rather than building a new canal on the Indiana side.

In his study of the Louisville and Portland Canal, Major J.C. Oakes described the improvements:

> The work was completed practically as designed by Mr. Scowden and provided: a depth of 6 feet in the canal by means of excavation and a guiding dike and cross dam at the head of the canal….; a width of canal 86 ½ feet between vertical walls 15 to 17 feet high; two locks in series, each 372 feet between quoins or 348 feet available length by 80 feet width… (Oakes 1914:565).

Both locks were equipped with wooden mitering gates. The lock chambers were filled and emptied through butterfly valve controlled openings in the gates (Oakes 1914:568).

The most substantial modifications to Scowden's plans for the canal occurred at the dam located at the head of the falls. As early as 1868, General Godfrey Weitzel of the Corps of Engineers recommended the construction of a dike and cross dam to raise the lower water depth in the canal to 6 feet, and by 1879, the structures had been completed. These structures were built of timber cribs (Oakes 1914:572). Completion of these structures had been delayed by a series of delays including shortages of funds, high water levels, and an October 1875 collision of the barge *Citizen* with the cofferdam (USACE-ChE 1876:747-748).

The new locks were opened to traffic on February 26, 1872 (Plate 1-6) as reported in the *Louisville Courier and Journal:*

> When the locks were completed they were the largest locks in the world, 80 feet in width and 350 feet long with a lift of 26 feet. The stone for the locks and bridges was all cut at a sand quarry one hundred and twenty miles down the river from full-sized diagrams furnished by Mr. Scowden. Neither mallet nor chisel was ever used on the works and all the face stone on the works were set to their places by the instruments of the engineer (as cited in Kreisle 1971:94).

Plate 1-3. Louisville and Portland Canal. Original canal walls (E. Klauber n.d.). From Filson Club collection, Louisville.

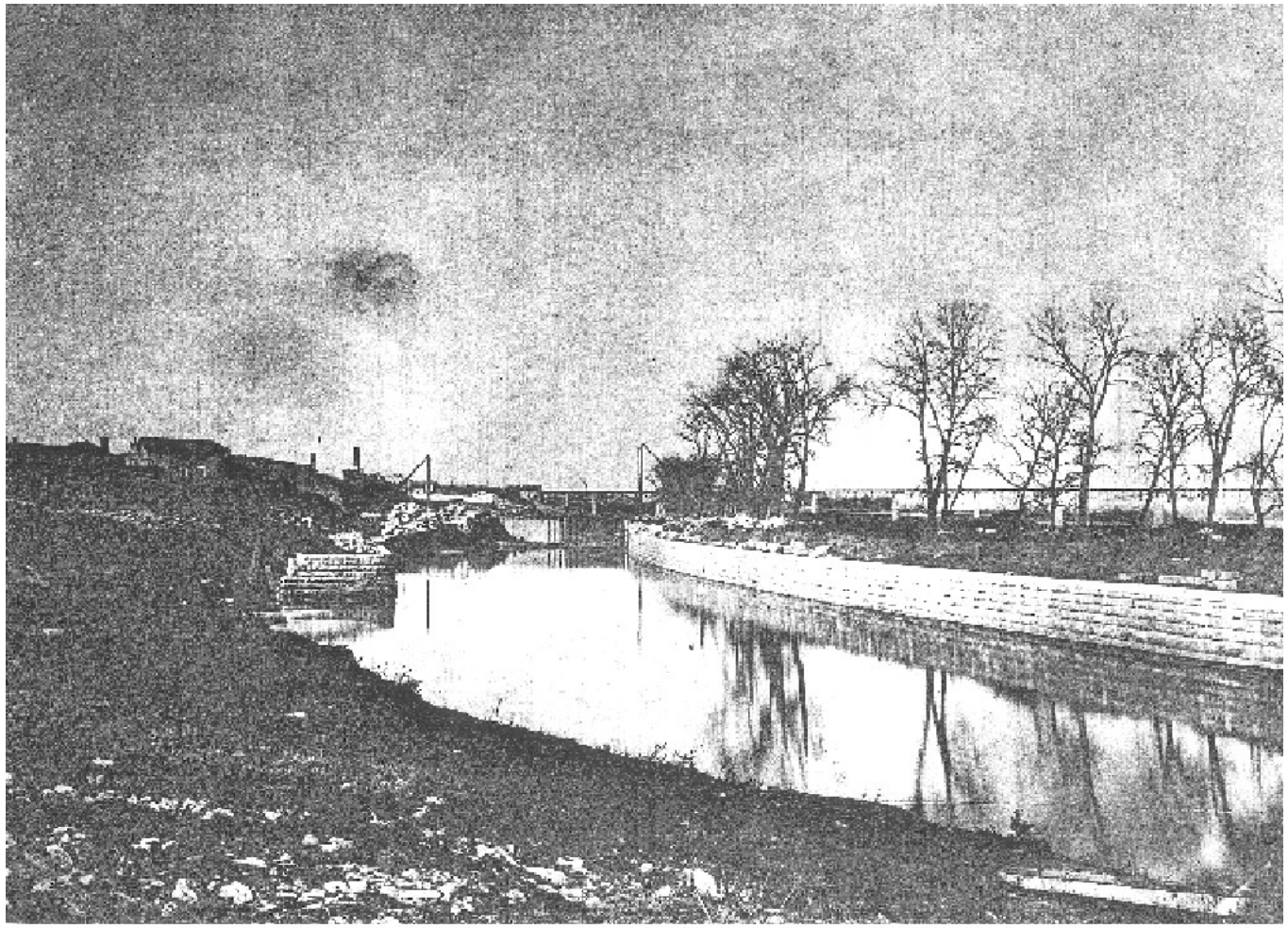


Plate 1-4. Louisville and Portland Canal. View of new side walls and head of new locks, looking southwest. From Filson Club collection, Louisville.

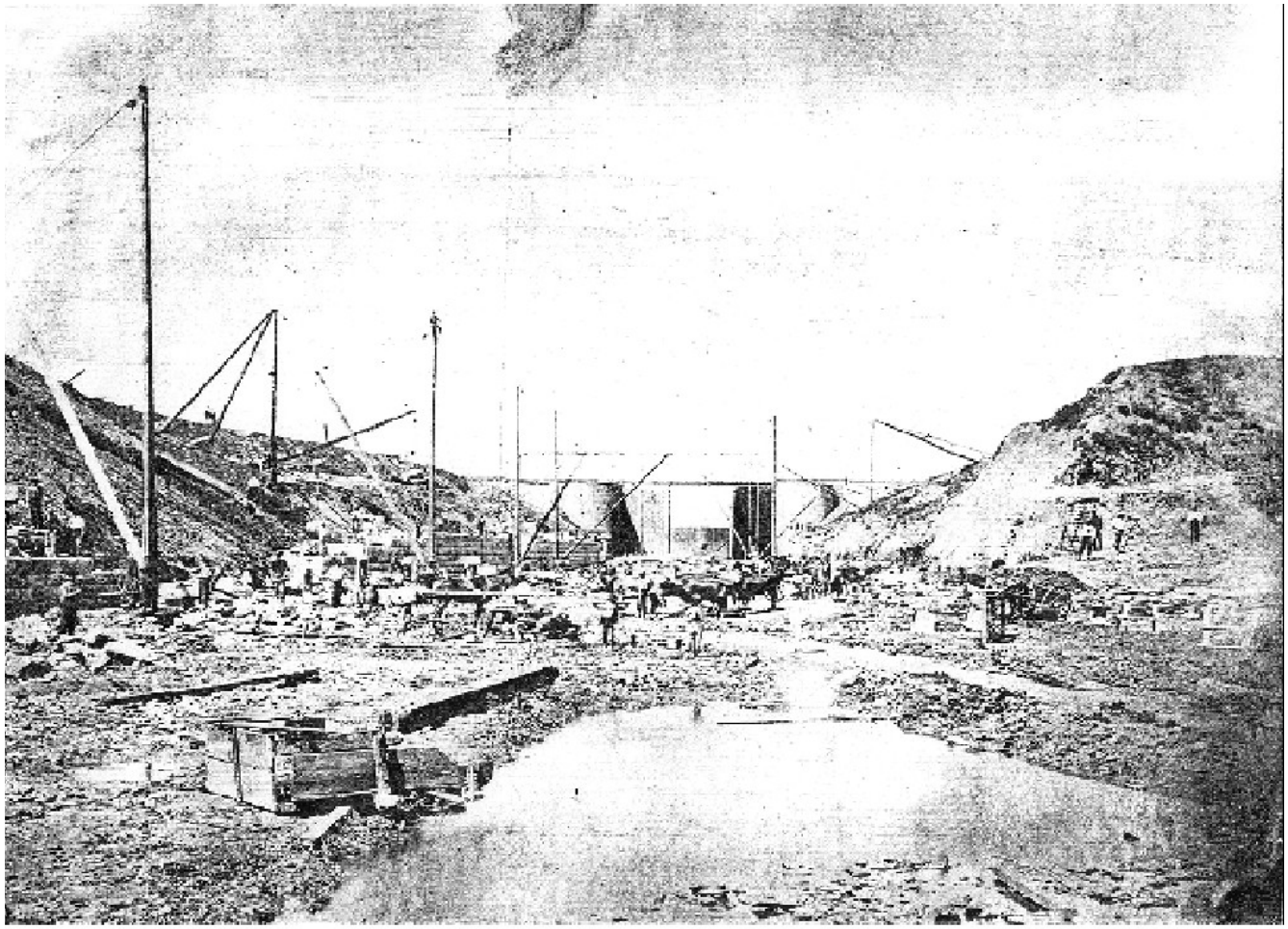


Plate 1-5. Louisville and Portland Canal. New locks under construction, looking northeast (E. Klauber n.d.). From Filson Club collection, Louisville.

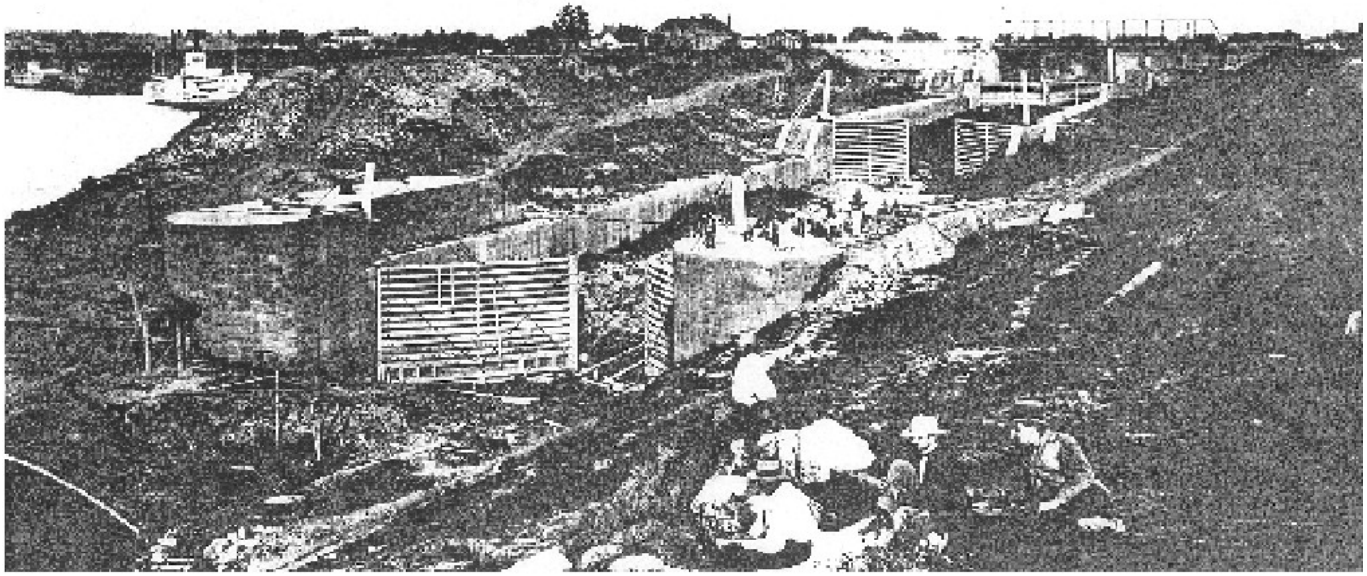
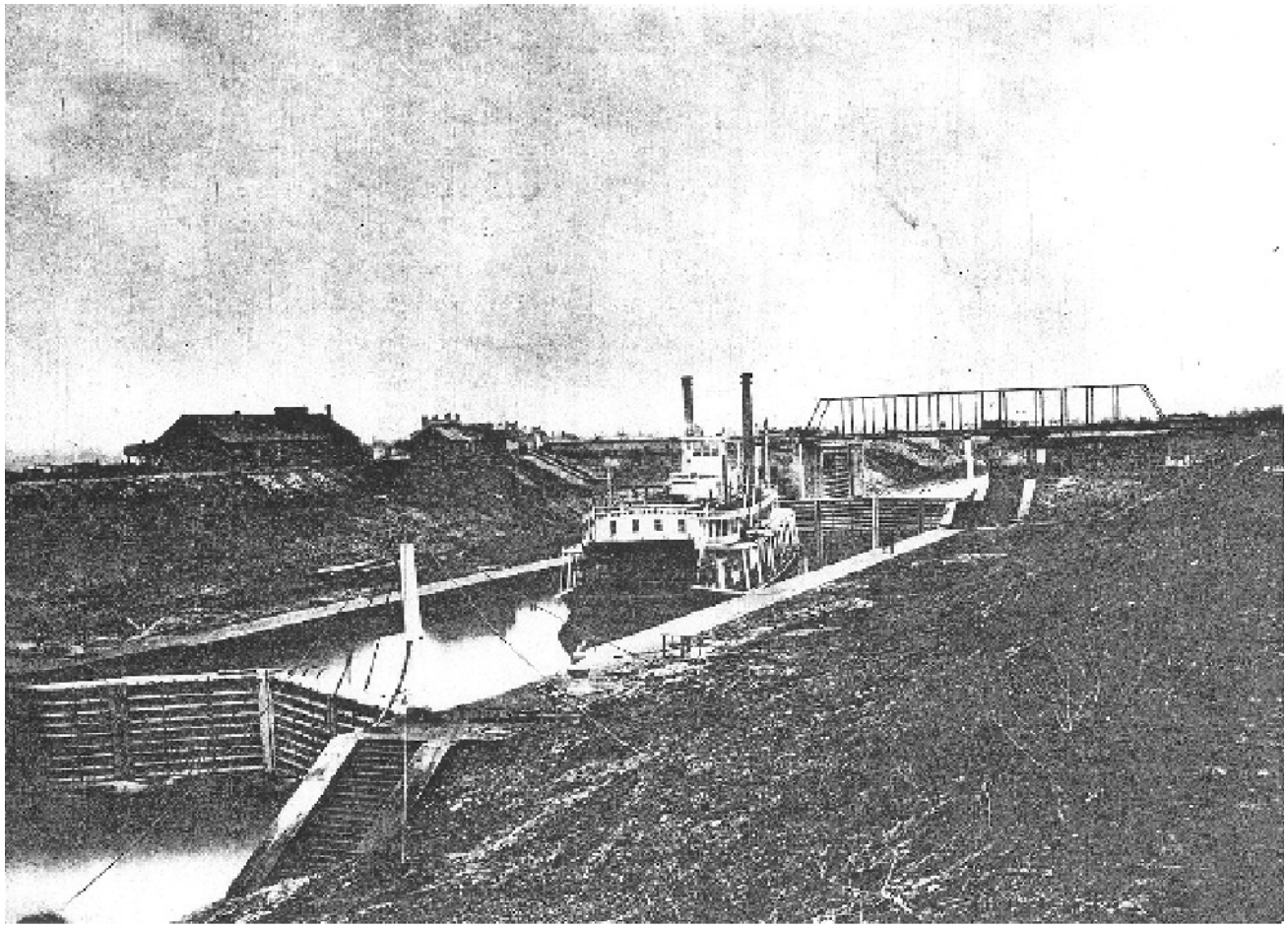


Plate 1-6. Louisville and Portland Canal. Completed new locks, looking northeast (E. Klauber n.d.). From Filson Club collection, Louisville.



Captain Alexander Mackenzie reported on the condition of the new locks in December 1875:

> With exception of the guard-gates all parts of the new locks are in a serviceable condition. The coping of the walls is of soft stone, and has been injured in several places. The water has found its way under the miter-sills, washing out the concrete, thereby causing some of the stones to settle, but they will probably remain secure for several years. In time new sills, built of harder stone, and sunk to the solid rock, will be necessary.
>
> The lift-gates are moved with difficulty on account of their great weight and the sediment continually being deposited in front of them. No plans have yet been perfected for moving these gates by steam or water power; and the trial of horse-power has not been made (USACE-ChE 1876:757).

During the fiscal year ended June 30, 1876, a total of 982 steamboats passed through the canal, as well as 526 model barges, 1,623 square barges, and 102 small boats. Toll receipts for the year amounted to $76,669.14 (USACE-ChE 1876:753).

In 1881, the Corps of Engineers completed a timber crib dam at Louisville. This dam raised the canal pool by about three feet. From 1881 to 1901, 135,630 boats carrying cargo weighing over 37 million tons locked through the Louisville and Portland Canal. The average annual traffic was 6,780 boats carrying over 1.8 million of cargo. About 75 percent of this tonnage was coal. Lesser amounts of lumber, steel and iron products, sugar and molasses, salt and agricultural produce were also carried. Congestion proved a major problem. For example on July 6, 1902, towboats pushing 461 barges arrived at the canal. The last of these barges were not cleared until July 17th. In 1909, a movable weir dam was built to provide a minimum channel depth of nine feet from Louisville to Madison, Indiana (USAED-L 1995). This dam consisted of eleven sections of Boulé gates, Chanoine wickets, and masonry weirs (Johnson 1975:175).

Further improvements, beginning in 1913, were undertaken as part of the larger scheme of Ohio River improvements and will be discussed later in the report.

Additional River Improvement Projects and Proposals

Because Shreve's snagboats were too large to pass through the Louisville and Portland Canal, in 1835, the Corps of Engineers removed the Upper Ohio from Shreve's jurisdiction. Captain John Sanders of the U.S. Army Corps of Engineers was appointed as superintendent of the Upper Ohio project. The project consisted of three different but related types of activities: removing snags and similar obstructions, blasting away rocks to clear channels, and constructing stone riprap dikes to concentrate water flow over bars and scour away accumulated sand and gravel deposits (Johnson 1975:74). Sanders built smaller snagboats to clear the Upper Ohio along with dredges to cut through gravel bars. Shreve strove to achieve a minimum channel depth of 36 inches on the Lower Ohio, while Sanders attempted to open a channel at least 30 inches deep at low water on the Upper Ohio (Johnson1991:190).

Between 1826 and 1838, regular appropriations were made for Ohio River improvements. In 1830, work began on removal of rocks at Grand Chain. During the Van Buren administration, appropriations were terminated and existing projects were suspended. No funds were appropriated between July 1838 and August 1842. During the years of suspension, 136

steamboats sank on the Ohio River, an estimated loss of a million dollars annually (Johnson 1991:190).

When President John Tyler signed the River and Harbor Act of 1842, snag clearance resumed on the Ohio River. Captain Sanders resumed work. The Corps replaced Henry Shreve with Captain John Russell who put Shreve's snagboats to work and built more to clear the Lower Ohio and other rivers. Snag clearance lasted only three years until President James K. Polk took office and vetoed waterways appropriations on constitutional grounds (Johnson 1991:191).

Between 1845 and 1866, only two additional appropriations were made, the larger amounting to $95,000. Channel clearance began again in 1852 when President Millard Fillmore approved a new River and Harbor Act. Using funds from this appropriation, Colonel Long and Captain Russell built new snagboats and a dredge, began renewed snag clearance, and repaired wing dams. Long requested an additional $600,000 to finish channel clearance projects citing the 124 lives lost in 85 steamboat wrecks in 1854. Both the Franklin Pierce and James Buchanan administrations refused to appropriate the requested funds (Johnson 1991:191).

New appropriations for Ohio River navigation improvements began in 1866. The Chief of Engineers sent William Milnor Roberts, U.S. Civil Engineer, to Pittsburgh and General Godfrey Weitzel to Louisville to resume the work. Roberts secured workboats, cleared snags, and rebuilt wing dams, and Weitzel oversaw the enlargement of the Louisville and Portland Canal (Johnson 1991:191). Between 1825 and 1866, river improvements included construction of 111 wing and training dikes and 47 dams in back channels (Johnson 1975:86, 93).

Following the end of the Civil War, Corps officers became increasingly skeptical about the efficacy of the wing dams. Brevet Major General Gouveneur K. Warren wrote in 1867:

> I do not believe the country will ever stand such a heavy continuous outlay as the wing-dam system of the Ohio has caused, and I believe that the extravagant and useless expenditure there, in the palmy days of western river improvements between 1830 and 1844, did more than anything else to bring the whole subject into disrepute (Office of History 1998:42).

While the method of improving the navigable channel of the river by dikes and cut-off dams generally proved successful in maintaining a navigable depth of three feet, engineers recognized that such measures were inadequate to provide for the accommodation of coal fleets and other deeper draft vessels (Taft 1908:10).

By the mid-nineteenth century, more ambitious schemes began to be developed to insure adequate water depth on the Ohio River. One proposal envisioned using Lake Erie as a limitless source of water supply for the upper Ohio River. Charles Ellet, Jr., a noted civil engineer, proposed a series of reservoirs for collecting water during wet times to release into the Ohio during dry periods. Such a scheme was initially proposed for employment in England in a c. 1800 essay by the noted English civil engineer Thomas Telford (Belknap 1871:25). W. Milnor Roberts described Ellet's plan in a report to Major General A.A. Humphreys, Chief of Engineers:

> His plan contemplated no work upon the river itself; the idea being to accumulate large quantities of water in reservoirs upon the headwaters, or on the main streams above the head of the Ohio, to be drawn off and allowed to flow when needed to maintain the proper depth in the main river (Belknap 1871:4).

This scheme was elaborated upon by engineer Ellwood Morris in an article in an 1857 issue of the *Journal of the Franklin Institute* (Morris 1857). In 1855, General Herman Haupt proposed construction of a series of canals or channels, 200 to 300 feet wide and a succession of open dams six to ten feet in height, which would connect each pool on the upper Ohio. This project would have included 400 miles of dikes and 100 low dams (Roberts 1857:25). Almost 25 years later, Haupt revisited his original plan and proposed a 100 foot wide channel which might incorporate a system of floating lock gates (Haupt 1880).

A scheme supported by rivermen and developed by government surveyor Alonzo Livermore, included a combination of dams and open chutes through the dams. These chutes were arranged to retard the flow and lessen the velocity of water from the upper to the lower pool without interfering with the free passage of boats through the chutes. For a chute of 100 feet or less in width, the natural low water flow of the river was deemed sufficient without reliance on artificial reservoirs (Belknap 1871:5).

A final proposal called for a slackwater system, a series of dams and locks similar to that under construction on the Monongahela River in Pennsylvania. In August 1866, W. Milnor Roberts, who had served as engineer for the Monongahela Navigation Company between 1837 and 1840, was appointed by General A. A. Humphreys, Chief of Engineers, as superintending engineer of the Ohio River. After studying existing improvements, Roberts reported that the 47 back channel dams and 111 dikes had shown some success but the maximum depth over shoals in low water was 2 ½ feet, insufficient for the growing commercial traffic on the river (Mueller 1952:179).

In the fall of 1866, Roberts organized a new survey of the entire river to map all its pools, ripples, shoals, island and track the river slope. Following receipt of the survey, Roberts prepared a detailed report titled *Practical Views on the Proposed Improvement of the Ohio River.*

In this report, he alluded to the needs of the new coal towboats and noted that:

> A constant, reliable navigation, which should never be less than five feet at extreme low-water periods, which could usually be six feet or more, and which should afford, in times of freshets, a navigation as good as we have now in similar freshets, is the great desideratum (Belknap 1871:6).

Roberts concluded that the most efficient means of radical improvement of the river was by the construction of locks and dams providing slackwater pools with the dams navigable at times of high water. He estimated that the entire river would require about 66 locks and dams, averaging about six feet lift each. The average length of the dam on the Upper Ohio would be 1,300 feet, while on the Lower Ohio, the length would be 2,200 feet. Roberts estimated the total cost of these improvements to be about 23.7 million dollars (Belknap 1871:8, 11).

In 1870, Major William E. Merrill succeeded Roberts in charge of Ohio River improvements. After reviewing all the proposals for navigation improvements, Merrill concurred that the slackwater system was the most efficient way to insure river navigation. He dismissed the proposal to divert water from Lake Erie noting that the Ohio does not descend to the level of the lake until it reaches Parkersburg, West Virginia. Haupt's plan was viewed as too costly and requiring too much maintenance. The scheme for large reservoirs would require six reservoirs, each 25 miles long with dams 100 feet high. Merrill argued that there were not six such sites available in the Ohio Valley. He concluded that low dams would inundate little bottomland, the

engineering involved was well understood, and the dams could establish harbors for riverside cities (Johnson 1991:192).

In 1872, a board of engineer officers reported to the Chief of Engineers on options for movable hydraulic gates and dams on the Ohio. This report engendered substantial discussion including several proposals for movable dams by Pittsburgh engineer Felix R. Brunot in an article in the *Journal of the Franklin Institute* (Brunot 1874). Merrill recommended the construction of 13 locks and movable dams with Chanoine wickets, one of the dam types studied, between Pittsburgh and Wheeling. In 1875, Merrill expressed his opinion that the locks and dam system should be extended throughout the entire river (Taft 1908:10).

Representatives of river interests criticized Merrill's decision in favor of a slackwater system. Coal shippers and towboatsmen argued that dams would obstruct channels and require time-consuming breaking of tows to enter each of the locks. The difficulty posed by breaking tows was described in an 1874 report:

> Coal-fleets are so large and ponderous that they require a wide river for maneuvering; and besides, the barges must be bound together in every direction in the firmest possible manner by cables and screw-clamps. It is very tedious and difficult to make up a coal-fleet and somewhat hazardous; and it is almost indispensable when the boats are once firmly connected they should remain so until the whole fleet is landed at its destination. For this reason the passage of a lock after the fleet has started is most objectionable, and would cause insupportable delay and danger (Belknap 1874:3).

These critics also argued that the proposed improvements would raise flood heights, create stagnant slackwater pools, and eventually lead to the silting of river channels. Pittsburgh's rivermen organized a torchlight parade to protest Merrill's plan (Robinson 1983:25).

In a response to the opposition, Merrill wrote:

> The truth is, that if the Ohio River were provided with a perpetual 6-ft. navigation, there would be no need for the huge fleets that can only run during a few months in the year, and at other times are tied to the banks. The traffic in coal would become regular and constant. I am far from desiring to do anything that will injure the coal trade, and my record will show that I have worked faithfully to improve the river, and especially its upper portion, so that coal tows might run with more ease and safety; but I recognize the fact that the shipment of coal is not the only nor even the chief commerce on the Ohio River, that, however valuable in its effect on other industries, the total annual value of the coal that descends the Ohio is but $6,000,000, as compared with a general river commerce of about $200,000,000 (as cited in Anonymous 1905).

Support for the canalization proposal grew when a drought hit the Pittsburgh area. In May 1871, the river fell below boating stage not to rise again until the following winter. Barges laden with coal waited above Monongahela River dams for an Ohio River rise to permit them to descend to Cincinnati, Louisville and other ports, cities that faced fuel shortages. Because coal barges could not leave the Monongahela to travel up the Allegheny River to Pittsburgh's north sides, wagons hauled coal across downtown causing traffic jams and damaging roads. A *Pittsburgh Daily Gazette* editor supported the construction of a dam on the Ohio to allow a more dependable water

supply: “Let us no longer depend on the rain from Heaven for conducting our chief employment” (Johnson 1991:193).

Proponents of the slackwater system still had to address the issue of how to conserve the upper pool yet permit navigation over the dam at high river flow times. To remedy this problem, means to keep the chute closed during low water had to be developed.

To placate opponents, Merrill began investigating movable dams that could be lowered during high water to pass tows through without locking. In 1872, Major Merrill and Major Godfrey Weitzel were appointed to study hydraulic gates for possible use in the slackwater system dams. This charge led to a comprehensive study of all existing types of chutes, weirs, and movable dams, including structures in use in Belgium, France, Russia, Germany, and India.

During the course of this study, Major Merrill learned that the French Corps of Engineers was building movable dams that could be lowered to the river bottom at high river stages, allowing navigation over the dam. Major General Craighill, William R. Hutton, and Addison Scott traveled to France to inspect examples of the 124 movable dams the French engineers had in operation (Johnson 1977:83). The results of this investigation were presented in two reports issued by the Secretary of War in 1874 and 1875 (Belknap 1874, 1875).

Their French counterparts noted that the movable dams used on French rivers had evolved from a dam constructed on Pennsylvania’s Lehigh River by Josiah White of the Lehigh Navigation Company in 1818. This dam, called a “beartrap” had been used to create artificial rises on the Lehigh to permit navigation. The beartrap was constructed of two overlapping leaves, fitted tightly in a chute formed by two guidewalls. The leaves of the trap rested in a recess in the sill of the chute. When water pressure was shut off, the leaves were lowered by gravity, opening the chute (Johnson 1977:83).

French engineers built beartraps at Neuville au Pont on the Marne River in 1840. They improved the technology by constructing buoyant leaves to assist in the raising operation. This design proved unfeasible because the current passing through the gate was too strong for ascending navigation. Subsequent French experiments and modifications led to the movable dams that American Army engineers studied on the French rivers in the 1870s.

The Americans were particularly impressed by the movable dams in use on the Seine River near Paris. This type of dam was invented in 1852 by Jacques Chanoine, Chief Engineer of the French Corps. Similar dams were also in use on the Yonne, Marne, Meuse, and Moselle rivers (USACE-Pittsburgh n.d.:15). The Chanoine dam is described in Leland Johnson’s study of the Huntington District, U.S. Army Corps of Engineers:

> Chanoine dams consisted of a masonry foundation level with the riverbottom, to which long boards known as wickets were hinged. When the wickets were down, lying flat on the foundation, boats passed over them through an open channel called a navigable pass. When the river began to drop, threatening to stop navigation, men at the dam dropped a grapple into the river to catch the handle at the top of each wicket and pull it up. As each wicket was raised, a prop attached to its backside slid up a slot in the foundation and when the wicket was released the prop held it in a near vertical position. Wickets were raised one by one until a row of them, resembling a line of ironing boards on end, closed the channel and backed up water to form a slackwater pool. While the river was low, boats

> traveled the slackwater pools and were moved from pool to pool through locks. When the river began to rise, the wickets were dropped simultaneously by a tripping bar operated from the lockwall, which pushed the wickets' props to the side and allowed them to drop harmlessly to the foundation, again opening the channel for river traffic (Johnson 1977:84).

Merrill recommended that a series of movable dams with Chanoine wickets be used for the canalization of the Ohio River. These dams would address the desire of the coal interests for open-channel navigation, while at the same time providing a series of navigation pools connected by locks for use at low water periods. To accommodate the large tows on the Ohio, he developed plans for 110 by 600 foot locks, the largest locks proposed to that time (Robinson 1983:26).

Merrill proposed construction of the first experimental movable dam and lock at Davis Island, five miles below Pittsburgh.

Davis Island Lock and Dam

Critics continued to protest the proposed closing of the river to open navigation but supporters of canalization also voiced their opinions. Proponents included the Ohio River Commission and the Grange. The former, whose members represented the six states through which the river flows, argued that the interests of inland navigation had been shortchanged by Congress. Appropriations had been made, instead, to benefit coastal navigation and railroads. They urged Congress to fund a comprehensive survey of the river and construction of the Davis Island Lock and Dam (Ohio River Commission 1872). The Grange, an organization of farmers, sought cheaper transportation for agricultural products by improving the position of waterways in competing with railroads (Robinson 1983:26).

During 1873 and 1874, the U.S. Senate Committee on Transportation Routes held hearings concerning Ohio River canalization. At the conclusion of the hearings, the committee reported that waterways represented the "cheapest line of transport" and recommended "improvement of the Ohio River in such a manner as to secure from Pittsburgh to Cairo a depth of 6 feet of water at all seasons" (as cited in Robinson 1983:26).

General James K. Moorhead, former United States Congressman, president of the Ohio River Commission, the Pittsburgh Chamber of Commerce, and the Monongahela Navigation Company organized a lobbying effort on behalf of immediate authorization and funding of a lock and dam at Davis Island. After being told that no funds would be available due to the ongoing economic depression, the Pittsburgh delegation went before the House Committee on Commerce in a last ditch effort to obtain funding for construction. One of the members of the delegation, John H. Ricketson, later reported General Moorhead's speech to the committee:

> Finally General Moorhead arose, and I can see him now as he stood there, still in the vigor of his powers, and in all the magnificence of his presence. Said he: "Gentlemen, I am now only an old horse turned out to grass, but for ten years I represented my district on the floor of yonder hall, and I sat perhaps in the seat now occupied by one of you. In my time an emergency arose every now and then like the one that brings me before you today, and to meet it, we had to go out of the usual order of things. We want $100,000 for the Davis Island Dam, and we want it at once. If we don't get it, not only Pittsburgh interests, but those of the Government will suffer. Now, I want you to do for me just as I would do for you

> were our situations reversed. I want you to make a unanimous recommendation in favor of this appropriation, and we will pass it by a joint resolution of the Senate and House. Where there is a will there is a way" (as cited in Johnson 1985:44).

As he requested, the Committee voted unanimously to allocate $100,000 of a $300,000 Ohio River appropriation for commencement of construction at Davis Island. On March 3, 1875, the United States Congress enacted the Rivers and Harbors Act with the $100,000 Davis Island appropriation included (Johnson 1985:44-45).

Despite the availability of funds, construction was delayed because of the necessity of the Pennsylvania Legislature to grant the federal government jurisdiction over riparian land. Coal interests lobbied against this transfer, but in 1877, the required special legislation was enacted. Construction began at Davis Island in 1878 but was not finished until 1885 due to intermittent funding and the project's innovative design (Robinson 1983:26-27). Lieut. Frederick A. Mahan, US Army Corps of Engineers was in local charge (Anonymous 1905). The total cost of the project was $910,000. Davis Island was officially dedicated on October 7, 1885 in a ceremony attended by 50,000 spectators (Johnson 1977:93). By 1895, a total of over 2.8 million tons of freight passed through the lock annually (Carr 1999:4).

Upon its completion, the 1,223 foot dam, with its Chanoine wicket navigable pass of 559 feet, was the longest in the world. The project's 110 by 600 foot lock was also un-exceeded (Plate 1-7; Figure 1-2). This lock employed rolling gates (Figure 1-3) rather than the typical miter gates to close the 110-foot wide lock, the first use of this technology (USACE-Pittsburgh 1982:2). When the lock was open, the rolling gate was housed in a recess in the landward lock wall (USACE-ORD 1979:25). A complete account of the history, construction, operation and influence of the lock and dam is contained in Leland R. Johnson's study, *The Davis Island Lock and Dam, 1870-1922* (USACE-Pittsburgh 1985).

Merrill suggested deferring the building of additional Ohio River locks and dams until experience was gained in operating this prototype. Corps engineers made several changes in design based on this monitoring. Perhaps most notably, wicket operation from a service bridge, as found in France, was eliminated. The bridge had been damaged by barges on several occasions and almost destroyed by the debris carried by the crest of the 1889 Johnstown flood. Instead, at later dams, wickets were raised and lowered by lock personnel on maneuver boats. The accumulation of debris at the dam also led to the installation in 1889 of a drift gap, controlled by beartrap gates, through which floating logs and other large debris could be flushed (USACE-ORD 1979:25).

Heavy scour below the dam was stopped by sinking barges loaded with stone, and it became standard practice to build stone riprap aprons below each Ohio River dams. The first rolling gates were built of wood and mounted on metal wheels and axles. Based on the rate of

Plate 1-7. Davis Island Lock and Dam (Postcard collection, Historical Society of Western Pennsylvania).

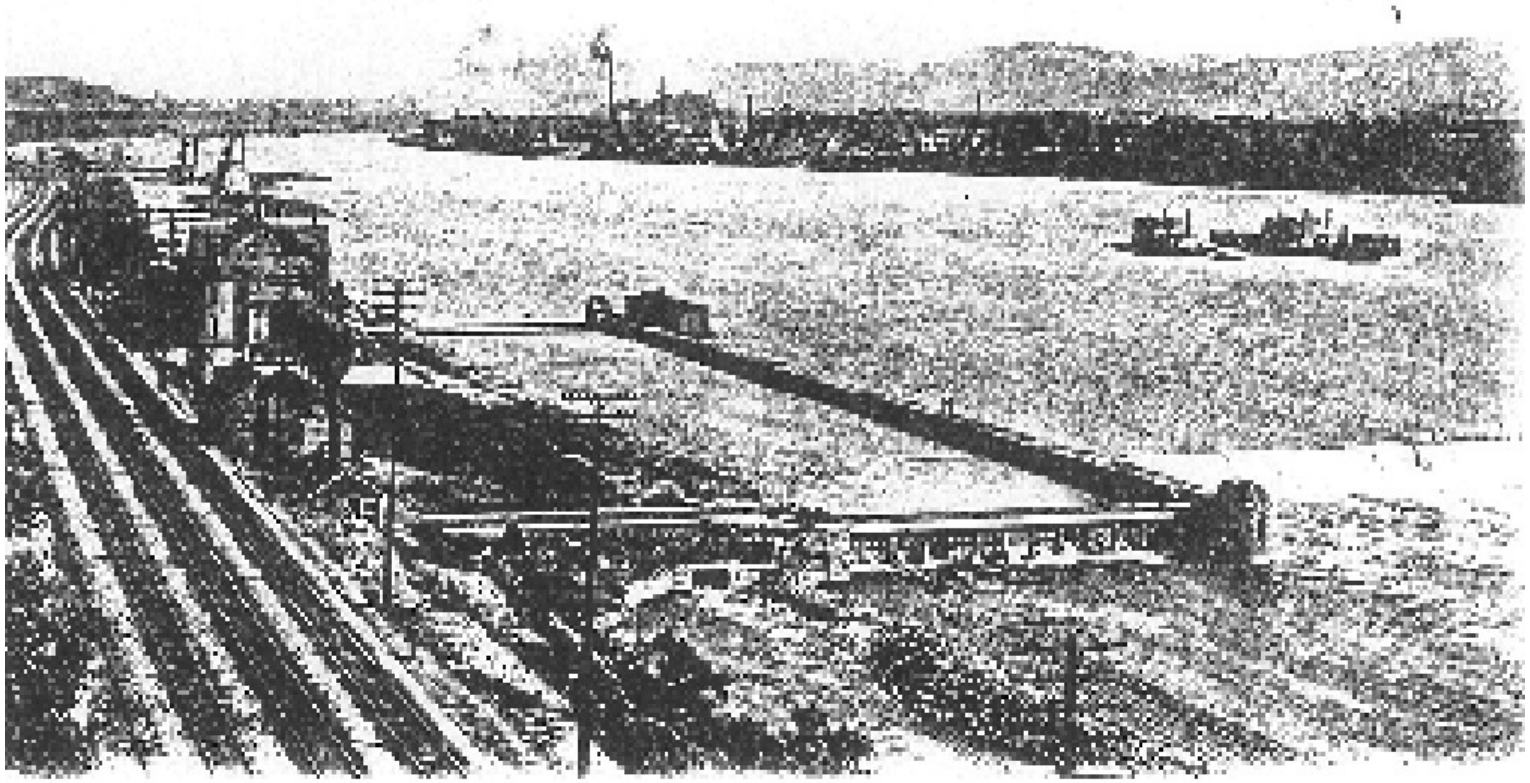


Plate 1-8. Dashields Lock. General view looking upstream (Pittsburgh District, U.S. Army Corps of Engineers 1952).

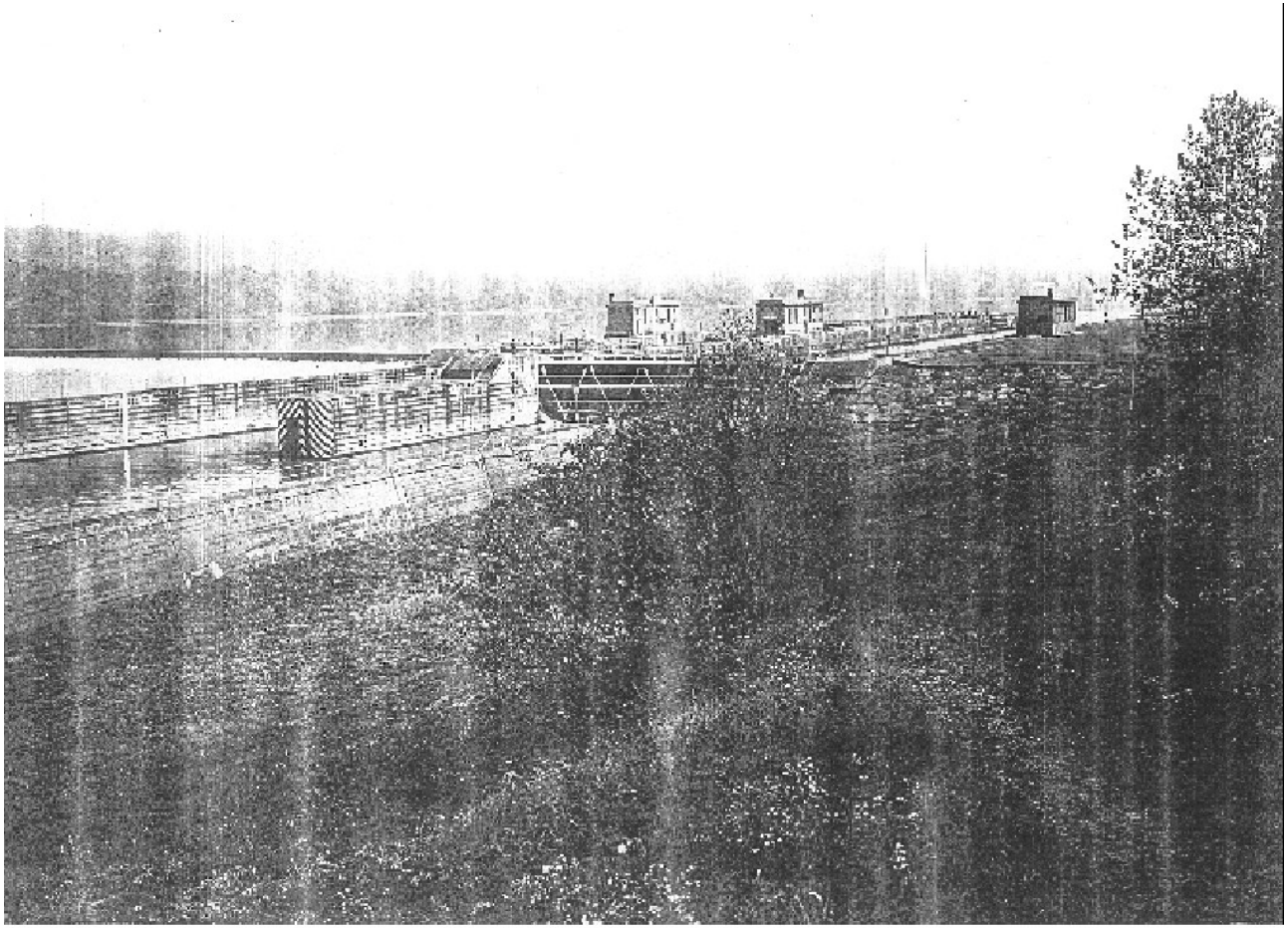


Plate 1-9. Louisville and Portland Canal. New lock. From U. of Louisville Photographic Archives.

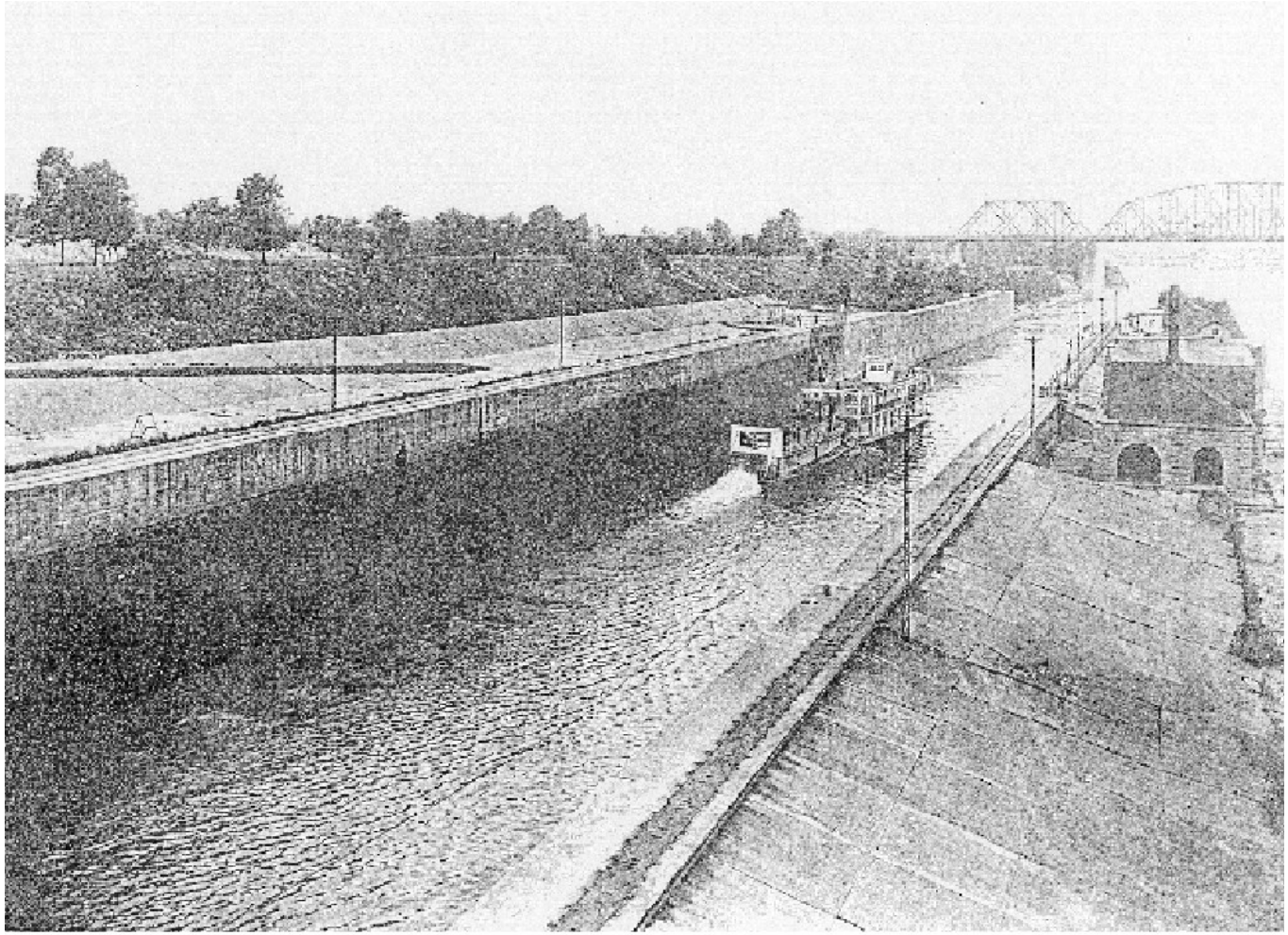


Plate 1-10. Louisville and Portland Canal. South wall, old canal (Louisville Electric Company 1926). From U. of Louisville Photographic Archives.

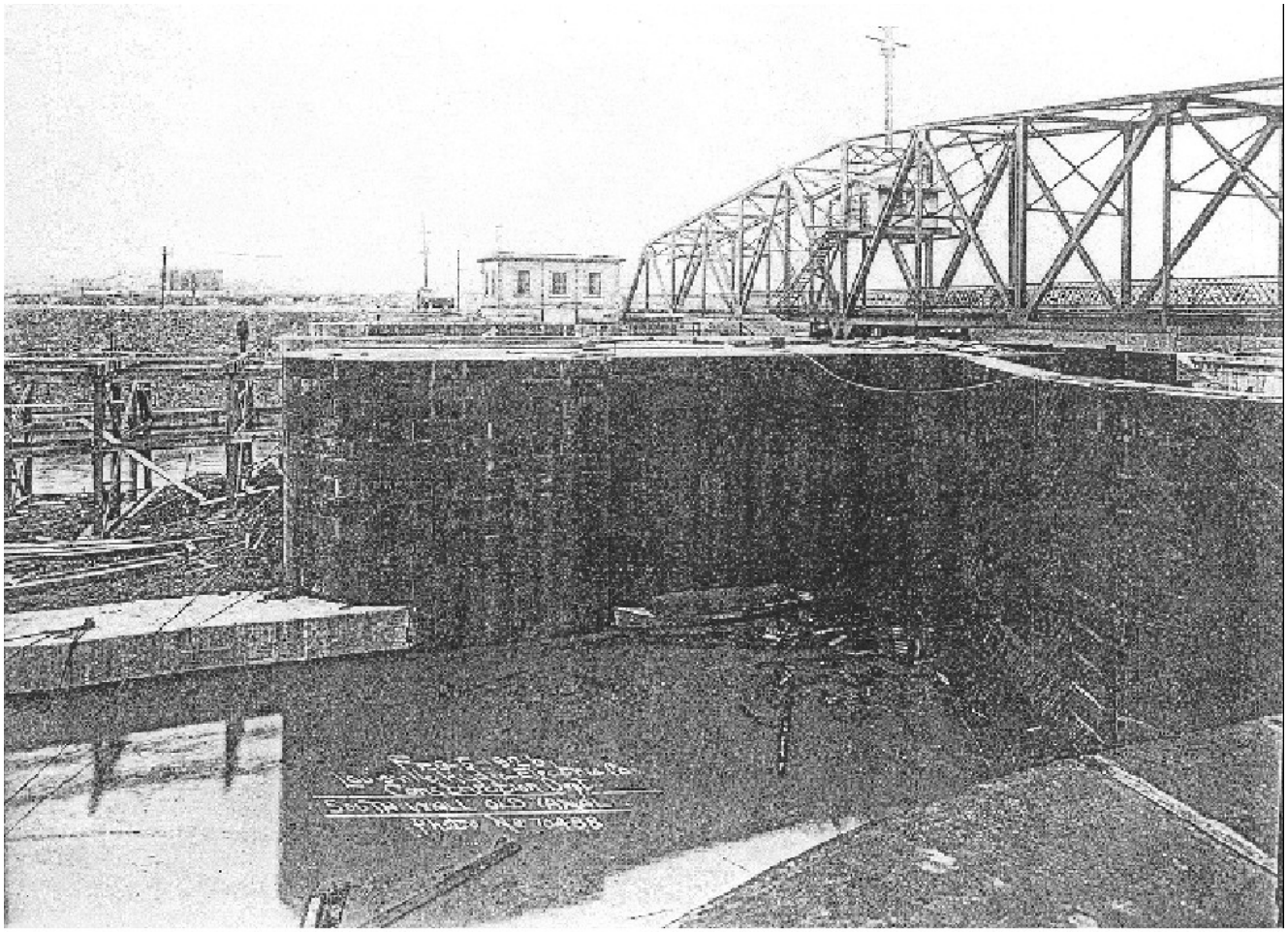


Figure 1-2. Davis Island Lock and Dam. Plan of lock (reprinted by USACE-Pittsburgh 1985).

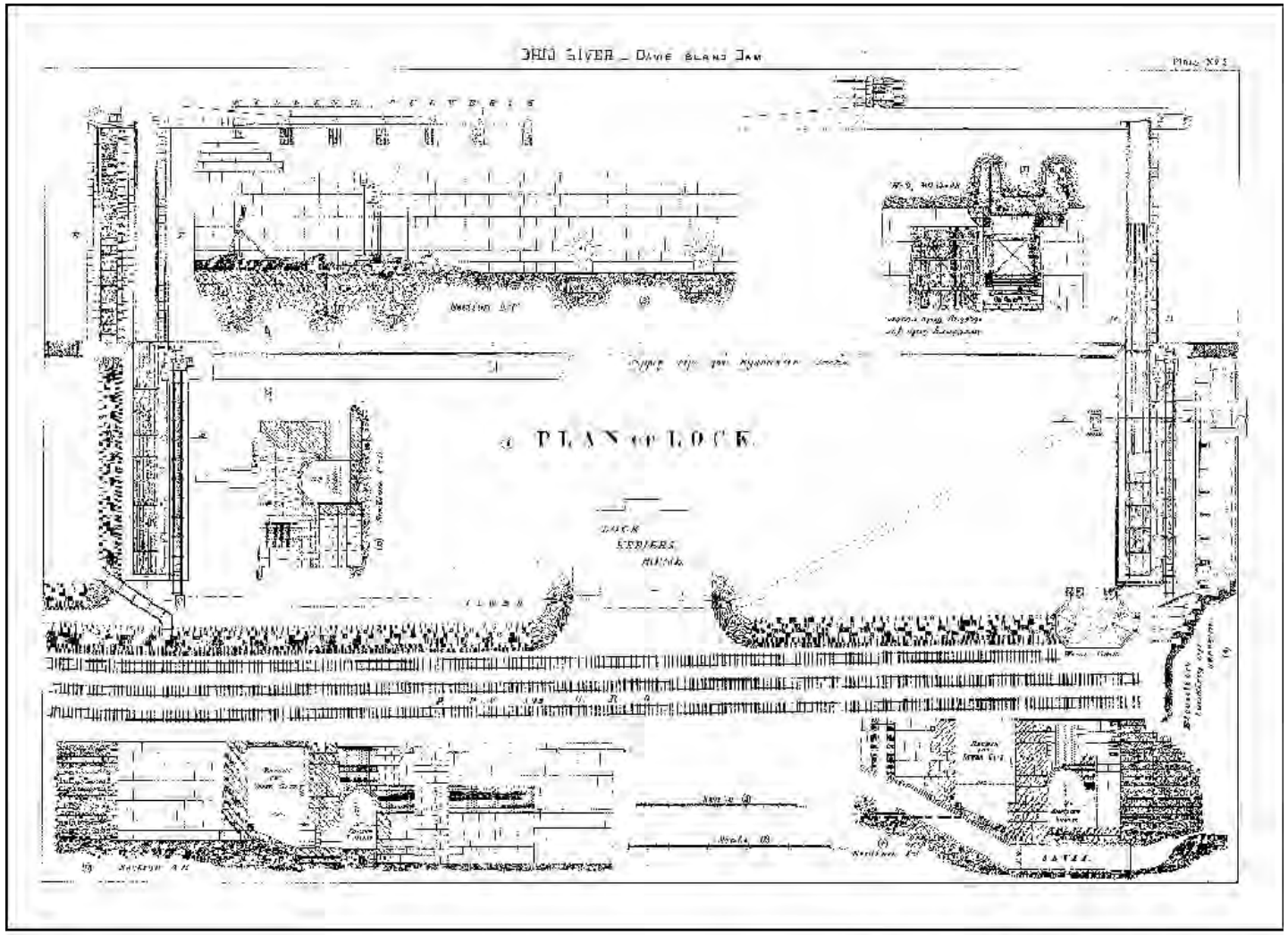
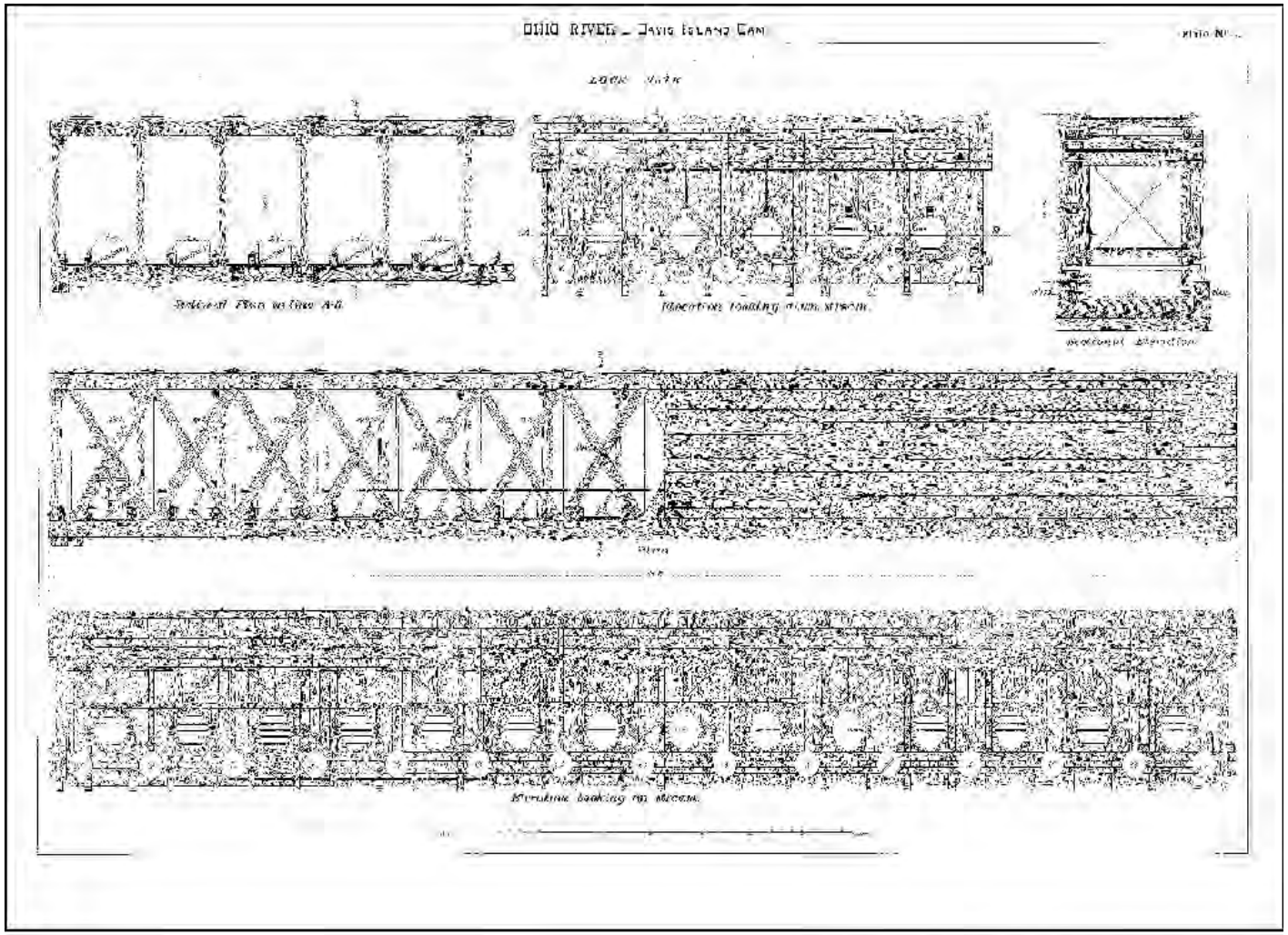


Figure 1-3. Davis Island Lock and Dam. Lock gate (reprinted by USACE Pittsburgh 1985).



deterioration of Davis Island's gates, later rolling gates were constructed of metal (Johnson 1977:94).

Continuation of Slackwater Construction

The River and Harbor Act of August 11, 1881 directed appointment of a Board of three engineer officers to examine and report on the feasibility and advisability of improving the Ohio River below Pittsburgh with movable dams. The Board recommended the construction of four dams below Davis Island, No. 5 being located just below the mouth of Beaver River (Taft 1908:10).

Sentiment of rivermen began to change to favor canalization after the Davis Island Lock was in operation. During an unexpected flood in July 1888, one hundred coal barges sank along the Ohio River, but no barge in the harbor behind Davis Island was lost. Industry located along the Davis Island pool benefited from a more reliable water supply. Fears that the pool would be stagnant and a breeding ground for disease proved unfounded. Instead, sewage and other obnoxious effluents which had formerly rotted along the shoreline during low water periods were washed away. Both rivermen and industrialists urged the extension of canalization downriver (Johnson 1977:95).

In 1888, Congress authorized a study of an extension of the 6-foot minimum river depth down the upper Ohio River. The following year, a Board of Engineers concluded that it was "practicable, feasible, and advisable to improve the Ohio River from Pittsburgh to a point just below the mouth of the Beaver River…by the construction of movable dams" (as cited in USACE-ChE 1892:2534). Drawing upon Lt. Colonel William E. Merrill's 1891 survey, the location of the five additional locks and dams were selected as Merriman's Bar, the Trap. Logstown Bar, just below the Beaver River, and below Raccoon Rapids (USACE-ChE 1892:2534-2535). Lock and Dam No. 6, named the Merrill Dam in honor of the late engineer, was constructed first. First appropriations for its construction were made in 1890, but small annual appropriations delayed the project's completion until 1906 (Robinson 1983:27).

The high cost of the locks and dams, approximately $1 million for each complex on the upper Ohio, made Congress reluctant to appropriate additional construction funds. To lobby for funding, rivermen and shippers from Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and Virginia organized the Ohio Valley Improvement Association (OVIA) in 1895. Colonel John L. Vance of Gallipolis, Ohio was named its first president (Ambler 1932:409; Mueller 1952:180). The Association sponsored river trips for members of Congress, dramatizing the Ohio River valley's need for improved waterways (Johnson 1977:96). The first appropriations for locks and dams 2 through 5 were made in 1896.

Army Engineers completed a survey of the river from the mouth of the Beaver River to Marietta, Ohio in 1898. The following year, they recommended the construction of twelve more locks and dams (7 to 18) that were authorized in 1899. The Army also made the decision to build the first structures below major riverports and the mouths of large tributary streams, rather than in downstream order. Dam No. 13 at Wheeling and No. 18 at Marietta were to be built first followed by those in between (Johnson 1977:96).

By 1900, coal barge tows had increased in number and draft. Merrill's successor in charge of the river's canalization, urged that the minimum channel depth be increased to nine feet. That depth, he reported stood "a fairly good chance of given all the draft that can go through the Mississippi

River during the life of the present generation and perhaps during the present century" (Johnson 1991:195).

The Corps continued the river survey from Marietta to Cincinnati in 1900. The following year, the building of twenty additional locks and dams was recommended (Nos. 19 to 38) with the dams below Parkersburg and the Little Kanawha River, Gallipolis and the Kanawha River, Ashland and the Big Sandy River, Portsmouth and the Scioto River, and Cincinnati and the Miami River to be constructed first. By the end of 1901, Davis Island had been completed, Nos. 2 through 6 were under construction and 32 more complexes had been authorized (Johnson 1977:96).

While plans proceeding for the continuation of canalization, representatives of river interests pointed out that large barge tows then in operation often drew more than six feet of water. These interests, led by the OVIA, asked Congress to consider creating a nine-foot minimum depth for the entire Ohio River channel. In the River and Harbor Act approved March 3, 1905, Congress authorized an analysis of the feasibility of extending the slackwater system to the mouth of the Ohio. The Chief of Engineers appointed a board of officers to conduct this study. Named the Lockwood Board after its chairman Lieut. Col. D.W. Lockwood, the board included Lieut. Col. Ernest H. Ruffner, Lieut. Col. Clinton B. Sears, Major George A. Zinn, and Major William L. Sibert (Taft 1908:1-2).

The board estimated that completion of a 6-foot project the length of the Ohio River, including the construction of 45 locks with movable dams, would cost $50,962,266, while the 9-foot project would require the construction of 54 dams and associated locks at the cost of $63,731,488. The board noted that the latter alternative would result in greatly increased economic benefits by encouraging the development of bulk traffic volumes and urged its approval (Robinson 1983:28; Taft 1908:2-3).

The continuing canalization project was not without its critics. One wrote that the project was doomed to become a disastrous "monument to the folly of man" as river traffic would never justify the expense incurred in building it (Johnson 1977:98).

The River and Harbor Act of March 3, 1909, provided $160,000 for the cost of surveying the location of Locks and Dams 9 to 29 and preparing plans and estimates for the locks and dams. This survey was conducted by Captain Lytle Brown of the Corps of Engineers. The report, issued by Congress in 1912, included a thorough discussion of the engineering aspects of the proposed lock and dam complexes (Stimson 1912).

In the River and Harbor Act of 1910, Congress authorized construction of the 9-foot channel project. A total of $1,150,000 was appropriated to be used for the purchase of sites for eighteen locks and dams, numbered 9, 10, 12, 14, 15, 16, 17, 20, 21, 22, 23, 24, 25, 27, 28, 29, 41, and 48, and toward the construction of locks and dams 7, 9, 10, 12, 19, 20, 29, 41, and 48 (USACE-ORD 1979:28).

At Louisville, the complex was designated Locks and Dam No. 41 in 1914. The existing 100 by 600 foot lock was completed in 1921, and the old two-flight lock was replaced in 1930 by the existing 56 by 360 foot lock. Between 1925 and 1927, a movable weir dam with a navigable pass was built in conjunction with a hydroelectric power project of the Louisville Gas and Electric Company (USAED-L 1995).

Even as construction of the slackwater system continued, river traffic declined. In 1917, cargo carried on the river reached a low of about 4.6 million tons, a nadir caused largely by the abrupt halt of coal shipments from Pittsburgh to New Orleans. The turning point for the slackwater system was during World War I. Wartime shipping overburdened the country's land transportation system and by 1920, cargo volume on the Ohio River had risen to almost 9.4 million tons, a total that increased further 10.8 million tons in 1924 (Froggett 1926a), 16 million tons by 1925 (Froggett 1926b), and 22.3 million tons by 1930 (Robinson 1983:28-29; USACE-ORD 1979:22). Where traffic once consisted primarily of coal and steel products moving downstream, new products were being added as the century progressed. Freight soon included petroleum and its products, iron and steel, dry and liquid chemicals, grain, cement, and a variety of other items (Gaum 1970:487), and upstream traffic substantially increased in volume.

By 1926, the 9-foot slackwater system had been completed as far as Cincinnati. Construction continued rapidly downriver and was officially completed in 1929. As completed, the system included 51 movable (wicket) dams, each with a 110 by 600 foot lock chamber. Of the 54 structures originally contemplated, numbers 40, 42 and 54 were eliminated through modification of other projects (Robinson 1983:29; USACE-ORD 1979:29). The total cost of the project was $125 million, one-third of the cost of the Panama Canal (Johnson 1977:131).

President Herbert Hoover, an engineer himself, put the project in historical perspective at a dedication ceremony in Cincinnati in October 1929:

> While I am proud to be the President who witnesses the apparent completion of its improvement, I have the belief that some day new inventions and new pressures of population will require its further development. In some generations to come, they will perhaps look back at our triumph in building a channel nine feet in depth in the same way that we look at the triumph of our forefathers when, having cleared snags and bars, they announced that a boat drawing two feet of water could pass safely from Pittsburgh to New Orleans. Yet for their times and means they, too, accomplished a great task. It is the river that is permanent; it is one of God's gifts to man, and with each succeeding generation we will advance in our appreciation and our use of it. And with each generation it will grow in the history and tradition of our Nation (as cited in Johnson 1977:132-133).

Even as the original slackwater system was under construction, the Corps began planning Hoover's predicted improvements on the portions of the river closest to Pittsburgh.

Replacement of the Original Locks and Dams

Movable dams in the upper part of the river proved unsatisfactory. The river was so variable in flow that frequent manipulation of the dams was necessary. In addition, the steepness of the bottom slope made it extremely difficult to maintain a constant depth of nine feet (Kutz 1930:437). A 1916 report indicated that Dams No. 1 and No. 2 were in poor condition and would require reconstruction in the near future (Baker 1916:2). Plans began to be developed to replace the movable dams with fixed crest dams in the section of the Ohio River nearest Pittsburgh.

The Baker report cited additional reasons for the replacement of the Upper Ohio movable dams with fixed dams:

> Following the construction of Dams 2, 3, 4, etc., the coal men and vessel interests have found it advantageous at times to assemble their tows farther downstream than formerly, for this could be done without any appreciable increase of cost, owing to the fact that the vessels were always in commission and operating charges continuous. The distance downstream thus secured was that much gained in the fleet's run, and a further advantage was that much of the former congestion in pool No. 1 was avoided. As a result of this experience the sentiment has been growing among those interested in this traffic that the establishment of permanent pools by fixed dams upon this portion of the river would be a gain to the commerce originating in the vicinity of Pittsburgh. The construction of permanent, or fixed, dams would also permit the establishment of factories and large industrial plants requiring great quantities of water along the upper Ohio… (Baker 1916:6).

The report included the following recommendations:

> (a) That the Secretary of War be given authority…to cause fixed dams to be built in the Ohio River wherever such fixed dams would be more advantageous than movable dams, and that such authority be secured by the first bill in Congress to which its enactment would be germane.
>
> (b) That a fixed dam at or near Emsworth, Pa., be built at an early date to take the place of existing Dams 1 and 2 (as cited in USACE-ORD 1979:29).

In 1917, President Wilson signed the bill appropriating the funds necessary for the construction of the first and longest fixed dam on the Ohio River at Emsworth, Pennsylvania (USACE-Pittsburgh n.d.:22).

Dams 1 and 2, the structures closest to Pittsburgh, were replaced in 1921 by the non-navigable, fixed concrete Emsworth Locks and Dam at Mile 6.2 of the Ohio River. Dashields Lock and Dam, similar in construction to Emsworth, was placed in the system at Mile 13.3, taking the place of Lock and Dam 3 (USACE-ORD 1979:30).

The site selected for Emsworth was at Neville Island, where the existence of channels on either side of the island necessitated the building of dams on both channels. Because traffic could not be passed through the dam should the lock be closed in an emergency, two locks were built, one with the Ohio River standard 110 by 600 foot dimensions and the other with the standard 56 by 360 foot Monongahela River dimensions. These locks opened for navigation on September 1, 1921 and were the first double locks on the river (USACE-ORD 1979:31).

Construction of Dashields Locks and Dam at Deadman's Island (Plate 1-8) was approved by the Chief of Engineers in 1926. The complex was named for pioneer area resident David A. Shields. The dam is 1,585 feet long and it served to submerge a stretch of rapids that had become hazardous when the wickets of former Dam No. 3 were down. The locks marked the first use of cast steel armoring for exposed vertical corners of lock walls, a feature that later became standard on all inland waterways (USACE-ORD 1979:31).

In 1921, an Ohio River standard 110 by 600 foot lock was opened at Locks and Dam No. 41 in Louisville (Plate 1-9). In 1930, a 56 by 360 foot auxiliary chamber was completed to replace the old two-flight lock structure (USACE-ORD 1979:35). The auxiliary lock was built on the lower

part of the old, two-flight lock chamber. Part of the walls of these old chambers were used as the upper guide walls into the new lock (Plate 1-10) (Rhett 1971:VI-2).

During the 1930s, two additional replacement projects were begun: the high-lift Montgomery and Gallipolis locks and dams. Construction of Montgomery Locks and Dam (Plate 1-11), located at river mile 31.7, commenced in 1932. The structure was opened for use in June 1936, replacing locks and dams 4, 5, and 6. The dam, 1,379 feet in length, includes ten 100-foot vertical-lift gated spillway sections. The main lock has usable dimensions of 110 by 600 feet, while the auxiliary lock has usable dimensions of 56 by 360 feet (USACE-ORD 1979:33).

The Gallipolis Locks and Dam was placed in operation in 1937 at river mile 279.2, 14 miles downstream from the mouth of the Kanawha River. It replaced three dams on the Ohio River and three on the Kanawha River. The dam is 1,116 feet long and is equipped with eight roller gates, each 125.5 feet long, separated by nine piers (Plate 1-12; Figure 1-4). These are the only roller gates used on Ohio River dams. The two locks, as originally built, were 110 feet wide. The larger chamber measured the Ohio River standard 600 feet long, while the auxiliary chamber measured 360 feet long (Figure 1-5) (USACE-ORD 1979:33-34).

In addition to the new complex construction, the Emsworth Dam was rebuilt in 1936-1937 (Plate 1-13). The original dam was cut down and functions as the apron and baffle for the replacement structure (USACE-Pittsburgh 1971:5). The movable crest dam with vertical lift gates raised the upper pool by seven feet and allowed the elimination of the first locks and dams on both the Monongahela and Allegheny rivers. The main channel dam, measuring 967 feet long, includes eight 100-foot long vertical lift gates. The back channel dam has a length of 750 feet and includes five vertical lift gates and one movable trunnion Sidney gate (Plate 1-14) (USACE-ORD 1979:35).

Further improvements to the Ohio River Navigation System were driven by changes in tow size. As an economy measure, 1,000 foot tows had come into use, and these tows had to be broken up to pass through the 600-foot lock chambers of the Ohio River. Among the most serious bottlenecks on the river was at Louisville. There, the narrow two-mile canal approach, the high lift of 37 feet, and the slow lock filling and emptying characteristics combined to limit the physical annual capacity of the Louisville locks to about 19 million ton (Bruce et al. 1957:1239-3).

Ohio River Division studies indicated that lock dimensions of 110 by 1,200 feet, double the length of the old locks, could handle the largest tows operating efficiently on the river. The Division adopted these dimensions for the main lock at each new dam. An auxiliary lock, 110 by 600 feet, would provide additional capacity and serve traffic when the larger lock needed repairs. While the old locks had lifts of 7 to 8 feet, the new locks would have lifts ranging from 12 to 37 feet. An improved valve and culvert system would permit filling of these new, larger, locks in as little as eight minutes. The new dams were equipped with tainter gates that could be pivoted up and down to control the pool (Johnson 1991:202).

Plate 1-11. Montgomery Lock and Dam (Postcard collection of Craig D. Cicconi, U.S. Army Corps of Engineers, Pittsburgh District).

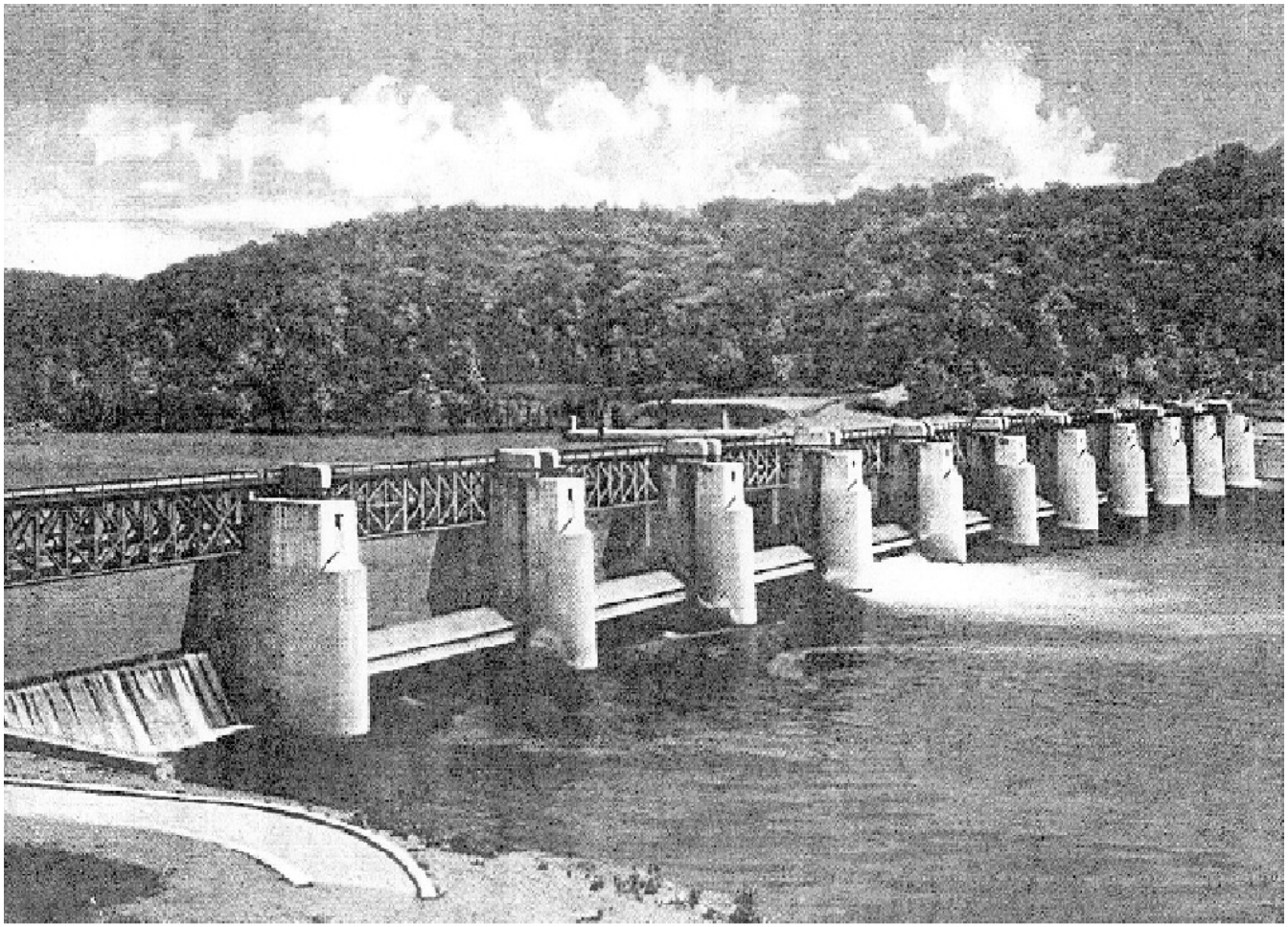


Plate 1-12. Gallipolis Dam (U.S. Engineer Office, Huntington 1937). (From Kemp 1993).

Plate 1-13. Emsworth Locks and Dam. General view of complex looking upstream (U.S. Engineer Office, Pittsburgh 1938). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

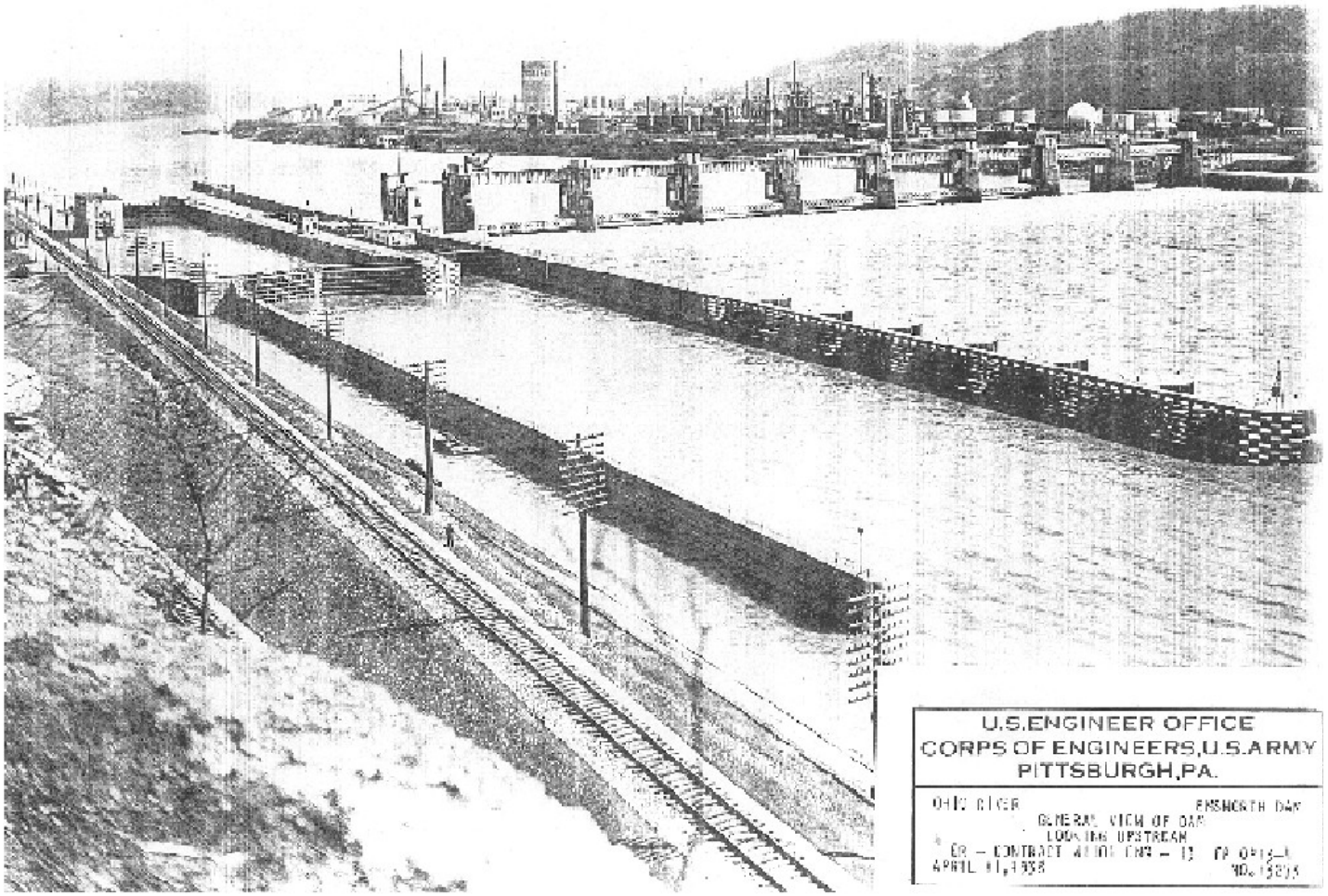


Plate 1-14. Emsworth Dam. Back channel. Sidney gate shown open and rotated about two-thirds rotation limit (U.S. Engineer Office, Pittsburgh 1940). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

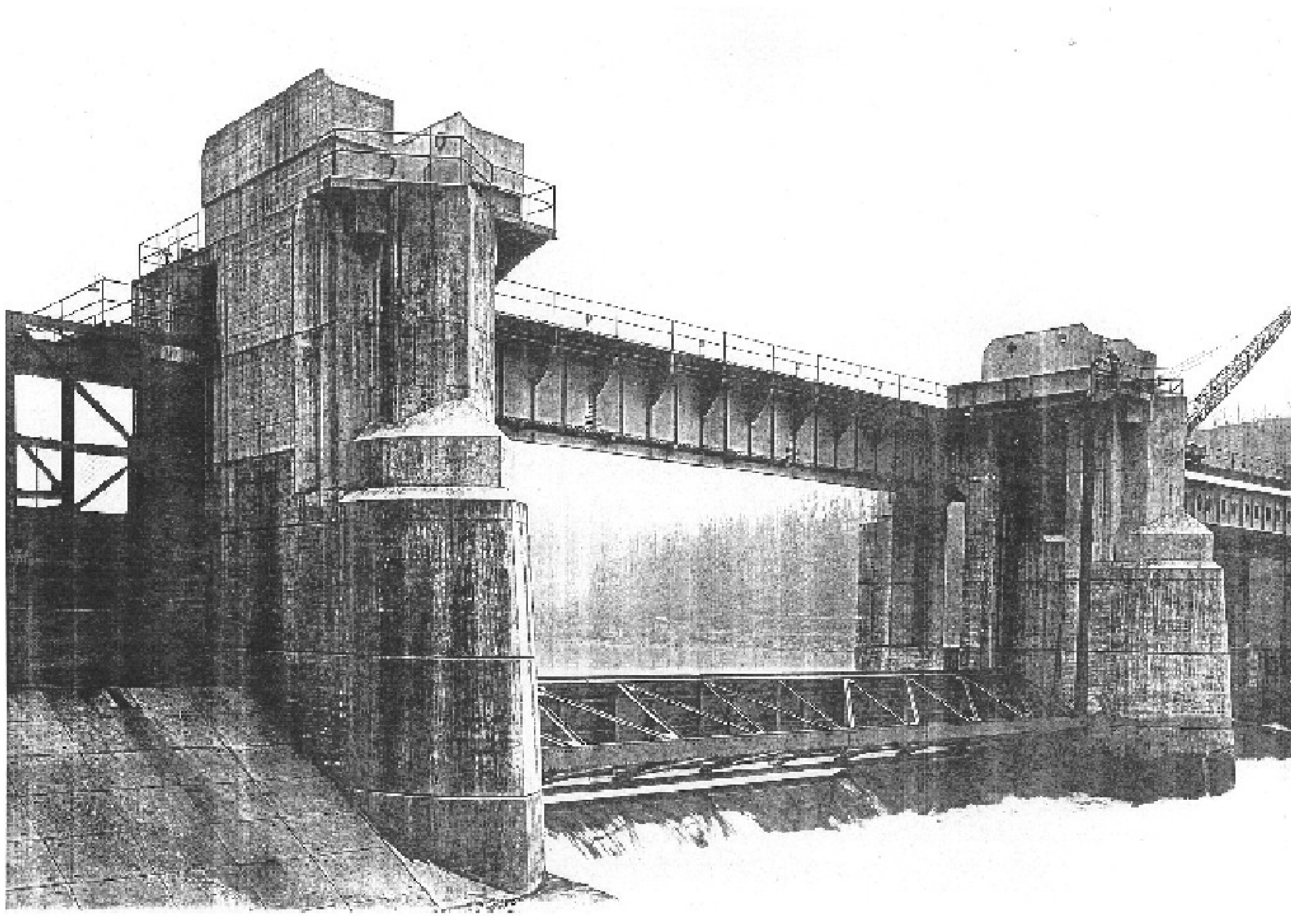


Figure 1-4. Gallipolis Locks and Dam. Dam. General plan (U.S. Engineer Office, Huntington 1938). (From USACE-Huntington 1970).

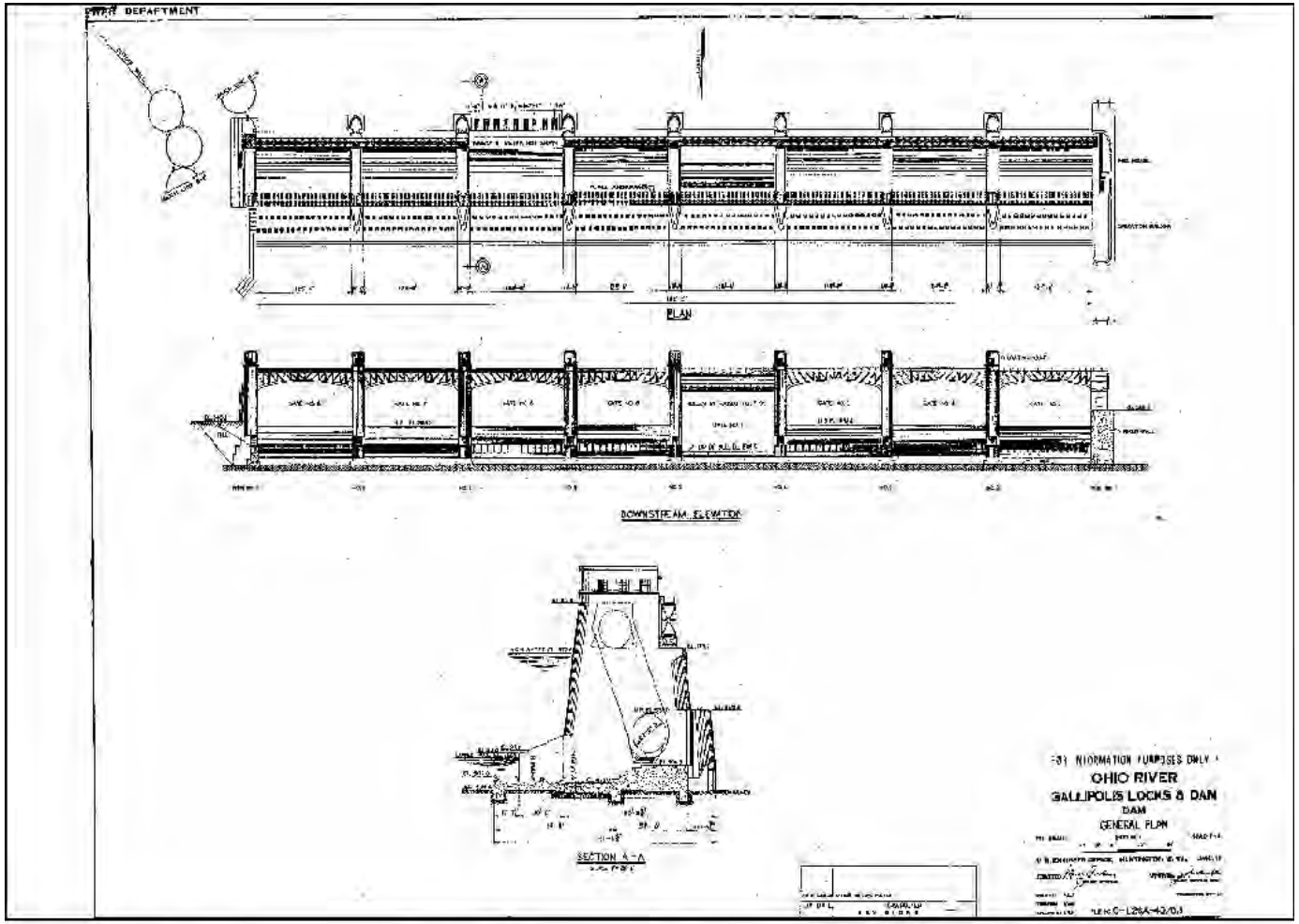
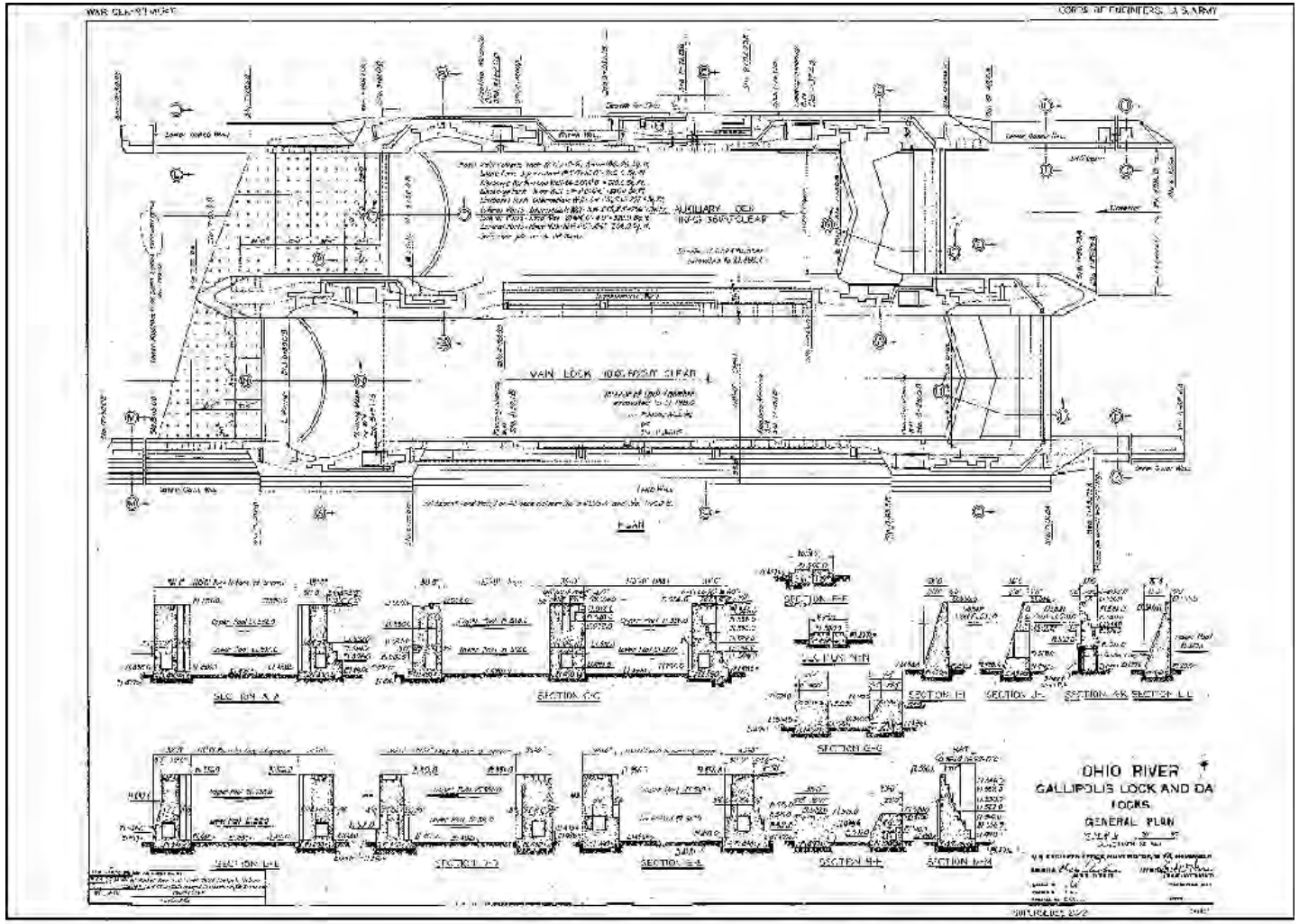


Figure 1-5. Gallipolis Locks and Dam. Locks. General Plan (U.S. Engineer Office, Huntington 1934). (From USACE-Huntington 1970).



In March 1953, a full-scale modernization program of the Ohio River Navigation System was approved. Several factors drove the modernization program. Fewer locks and dams with locks of adequate size would reduce travel costs. Deeper pools impounded by higher dams would also reduce cost through the reduction of resistance to propulsion in deeper water. The preponderance of downbound loaded tows was a thing of the past. Riverside terminals and industries became increasingly dependent on uniform water supplies.

High-lift dams created longer, deeper pools, and the gates could be opened at high-river stages to pass river discharge without affecting flood levels (Robinson 1983:39). The wicket dam's provision of an open river at high water was no longer the advantage that it had been (Bruce et al. 1957:1239-5).

The designs of these projects called for non-navigable dams with fixed sills, equipped with tainter gates to regulate water flow. The gates are designed so that in times of flood they may be raised completely out of the water and leave clearance for the highest flood of record (Gaum 1970:491). The improved conduit and valve system **uses** reverse tainter valves in place of the older butterfly valves (USACE-ORD 1979:37).

The modernization program commenced with work on the Greenup Locks and Dam in 1954. By 1980, the program included the construction of 13 new high-lift lock and dam structures to replace 39 low-lift lock and dam structures. The thirteen new dams have lifts ranging from 16 to 35 feet. In addition, a new 1,200 foot lock was added at Louisville (McAlpine Lock) (USACE-ORD 1979:38). Other improvements at Louisville included rehabilitation of the existing locks and widening of the canal from 200 to 500 feet (USACE-Louisville 1995).

Greenup Locks and Dam were authorized to replace locks and dams 27, 28, 29 and 30 on the Ohio River and No. 1 on the Big Sandy River. Construction began in October 1954. The locks were placed in operation in November 1959, and the pool was raised to its full height in June 1962. New Cumberland Locks and Dam were authorized to replace locks and dams 7, 8, and 9. The locks opened for traffic in November 1959. Markland Locks and Dam, located at river mile 531.5, were approved by the Secretary of the Army on March 11, 1953. Construction of the complex began in March 1956. The locks were completed in May 1959, while the dam was completed in June 1964. Captain Anthony Meldahl Locks and Dam were authorized as a replacement for locks and dams 31, 32, 33 and 34. Construction began in April 1958. The locks were placed in operation in November 1962, while the dam was placed in operation on December 22, 1964. Pike Island Locks and Dams were authorized to replace locks and dams 10 and 11. Construction began in 1959, and the locks were opened in November 1963. John T. Myers Locks and Dam were authorized as a replacement for locks and dams 47, 48, and 49 in September 1958. Construction commenced in June 1965, and the project was completed in April 1985. The Cannelton Locks and Dam, located at river mile 720.8, were approved as replacements for locks and dams 43, 44 and 45 on January 27, 1960. Construction began in May 1962 and was completed in December 1983. Belleville Locks and Dam were approved as a replacement for locks and dams 17, 18, 19, and 20 on the Ohio River, Dam No. 1 on the Little Kanawha River and Dam No. 1 on the Muskingum River. Construction began in May 1962. The locks were placed in operation on October 12, 1965, while the dam pool was raised to full height on November 1, 1968. Racine Locks and Dam, located at river mile 237.5 replaced locks and dams 21, 22, and 23. Construction began in May 1964. The locks were placed in operation in December 1967, and the pool was raised to full height in August 1971. Newburgh Locks and Dam, located at river mile 776.1 were authorized as a replacement for locks and dams 46 and 47 in April 1962. The project began in April 1965 and was completed in October 1986. Willow

Island Locks and Dam replaced locks and dams 15, 16, and 17. Construction began in January 1967. The locks were placed in operation in January 1972, while the dam construction was completed in 1976. Hannibal Locks and Dam were authorized to replace locks and dams 12, 13, and 14. Construction began in 1967, and the locks were opened to river traffic in 1972. Smithland Locks and Dam, located at river mile 918.5, were authorized in December 1965 as a replacement for locks and dams 50 and 51. Project construction began in 1970 and was completed in November 1980. Smithland was the first Ohio River project to be built with twin 110 foot by 1,200 foot locks.

Construction on replacement locks at Gallipolis (present Robert C. Byrd Locks and Dam) began in late 1987. The new 110 x 1200 and 110 x 600 foot locks were opened in January 1993. Rehabilitation of the dam began in August 1992.

Construction has begun for a 1,200 by 110 foot concrete lock to replace the 600 foot and 360 foot locks at McAlpine locks in Louisville. The project will also involve replacement of an existing access bridge with a fixed, concrete and steel arch bridge spanning both the existing and new lock. Completion of this project is scheduled for 2006-2007 (USACE-Louisville 1999a).

Construction of the Olmsted Locks and Dam, a project that will replace the last of the numbered locks, #52 (Plate 1-15) and #53, began in 1992. This complex, when completed, will consist of twin 110-foot wide by 1,200 foot long lock chambers, and a dam with a 2,200 foot navigable pass and 425 feet of fixed weir. Completion of the entire project is scheduled for 2006 (USACE-Louisville 1999b).

Lock Sizes and Riverboat Technology

Prior to 1811, no powered vessels plied the inland rivers of the United States (Dyer 1956:1122). Flatboats and keelboats constituted the principal means of transportation on the Ohio River. Flatboats floated with the current with control limited to steering, while keelboats were the only sizable craft capable of moving cargo upstream (USACE-ORD 1979:6). Coal was shipped down the Ohio as early as 1793 by the Army Quartermaster Department to supply garrisons at forts on the frontier (USACE-ORD 1979:19).

Commercial coal shipments began on the Ohio in 1814 when the first coal from the Monongahela was floated down the Ohio River. Early shipments were transported in roughly framed and planked coalboats that were sold along with the coal at their destination. These boats measured about 80 feet long by 18 feet wide and drew 40 inches. Later boats were built with a length of 175 feet and a width of 26 feet. These vessels drew 8 feet when fully loaded with 24,000 bushels of coal. The boats were generally lashed together in pairs and floated downriver at high water stages (USACE-ORD 1979:19).

According to river historian Frederick Way, Jr., steam power was introduced on the Ohio and Mississippi rivers in 1811, when the first river steamboat, the *New Orleans*, was built in Pittsburgh, Pennsylvania (Way 1990:xi) and descended the Ohio River. Measuring 138 feet long and of 300 ton burden, its hull design made it impractical to operate in shallow water. Within a few years, steam-powered flatboats first appeared on the river. The first documented steam flatboat, the *G. Washington*, traveled the river in 1816. Entrepreneurs soon started packet boat lines to serve growing river towns. By 1819, 63 steamboats were in use on the Ohio River and connecting waterways (Loveland and Bailey 1949:171; Pence 1929:17).

Steamboat and flatboat traffic grew dramatically in the 1820s. Steamboat tonnage on the Ohio and Mississippi River systems totaled 25,700 tons in 1827, and about 7,000 flatboats navigated the rivers in the same year. A total of approximately 537,000 tons of freight valued at over $50 million was transported on the rivers in that year (Johnson 1975:74).

Leland Johnson summarized the importance of the steamboat to the economy of the nineteenth century Ohio Valley:

> Nearly 6,000 steamboats were built along the inland rivers between 1820 and 1880, and, from first to last, about three-fourths were built in the Ohio valley. The steamboat construction boom gave an enormous boost to Ohio valley industrial development, and the speedy, economical transportation the steamboats furnished accelerated commercial growth and ended the frontier isolation of the region (as cited in USACE-ORD 1979:9).

The Ohio River steamboat was a flat-bottomed vessel with a long and slender hull and ends modeled for ease of entry and run. The steamboat hull measured six to nine times as long as deep. To stiffen the flexible and lightly built wooden craft, the hogchain system of bracing was developed. Hogchains were wrought iron rods firmly fitted at the forward and aft ends of the hull led up over tall timber braces. The main deck was open with all space not occupied by boilers and machinery used for stowing freight (USACE-ORD 1979:9).

During much of the nineteenth century, commerce and industry were largely dependent on water transportation for the movement of both raw materials and finished products, as well as passengers. Steam packets moved most of the cotton from the South, timber and lumber from the forests and sawmills, and much of the coal from mines to market (Dyer 1956:1122-3).

With the growth of the railroad during the nineteenth century, commodity shipment began to shift to land-based transportation. A 1908 report chronicled this shift:

> From the beginning the railroad was a reliable system of transportation, and this reliability caused a gradual transfer to it from the intermittently navigable streams of the shipment of the more expensive grades of commodities—commodities that could stand a high freight rate and which demanded sure delivery in a reasonable time.
>
> As the railroad, paralleling the intermittently navigable stream, increased in efficiency, it continued to take from that stream the transportation of articles of less and less value, until finally there was generally left to the stream only the handling of the cheaper, bulkier commodities, like coal, the original cost of which was small and the loss consequent upon holding same in boats until the river reached a navigable stage was small (Taft 1908:16).

W. Milnor Roberts wrote in 1866 that one-way coalboats were gradually being superseded by steamboats towing fleets of coal barges downriver and returning the empty barges upriver for reuse. By the 1840s, it became common practice to place barges ahead of steamboats and push them downriver. Coal shipments down the Ohio River in the mid-1860s amounted to about 40 million bushels (or 1.5 million tons). At least 90 steam towboats were engaged in coal hauling (USACE-ORD 1979:19). By 1870, fleets of barges became common, and oil and coal provided much of the barge tonnage (Dyer 1956:1122-3).

To accommodate these barges, engineers planned 110 by 600 foot locks on the Ohio River. Ralph Bloor, in his pioneering study of inland waterway lock sizes, cited the reasons for this decision:

> In 1874 the engineers reported that locks should be large enough to pass a coal fleet of ten barges 24 ft by 130 ft., one fuel flat 22 ft by 100 ft, and one steamboat 48 ft by 230 ft. Two barges abreast would require locks 50 ft wide, but this would be too narrow for some of the steamboats then in use. If the barges were four abreast, a width of 100 ft would be needed, and it was doubted that a mitering lock gate could be designed for this width. Therefore, a lock 75 ft wide seemed desirable and the corresponding length needed was about 600 ft. To the coal carriers, accustomed to open-river operation, a lock 75 ft wide seemed hopelessly restrictive. In an effort to reach a satisfactory solution the engineers designed a rolling type of lock gate which they considered usable on locks wider than 100 ft, and in 1878 recommended a lock size 110 ft wide by 600 ft long. Thus was originated the largest commonly used lock size in the United States (Bloor 1951:878).

The 110 by 600 foot locks that were the original Ohio River standard were capable of passing an ordinary Ohio River towboat, ten barges and two flats in one locking. When loaded with coal, the barges had the capacity of 140,000 bushels or approximately 112 railcar loads (Anonymous 1905).

By the beginning of the twentieth century, the demand for speed in passenger transportation lessened the demand for packet boats. In many cases, rail lines offered more convenient and faster transport. In addition, the barge gradually replaced packet boats as the preferred means of freight transport on the river (Loveland and Bailey 1949:172).

In the early twentieth century, great fleets of wooden coal barges were assembled in the Upper Ohio Valley and towed as far as New Orleans. For example, in February 1907, the steamer *Sprague* took a tow from Louisville to New Orleans composed of 62 coal barges with a gross weight of nearly 70,000 tons (Dyer 1956:1122-3).

A 1908 study of the Ohio River included a description of the large towboats used on the river at that time:

> The larger sternwheel towboats on the Ohio River are equipped with from three to five balanced rudders. These rudders are from 20 to 30 feet long, shaped to the bottom of the boat, extend forward of the rudder post and project to the rear several feet beneath the stern-wheel. When the stern-wheel is reversed a strong current is deflected against the long rudder blades, thus facilitating steering….

A stern-wheel steamboat of about 1,000 horsepower will ordinarily leave the headwaters of the Ohio on suitable stages of water for southwestern points with a tow consisting of about 12 coal

Figure 1-6. Towboat "Exporter" and tow, Pittsburg[h] to Bellaire, Ohio (Taft 1908).

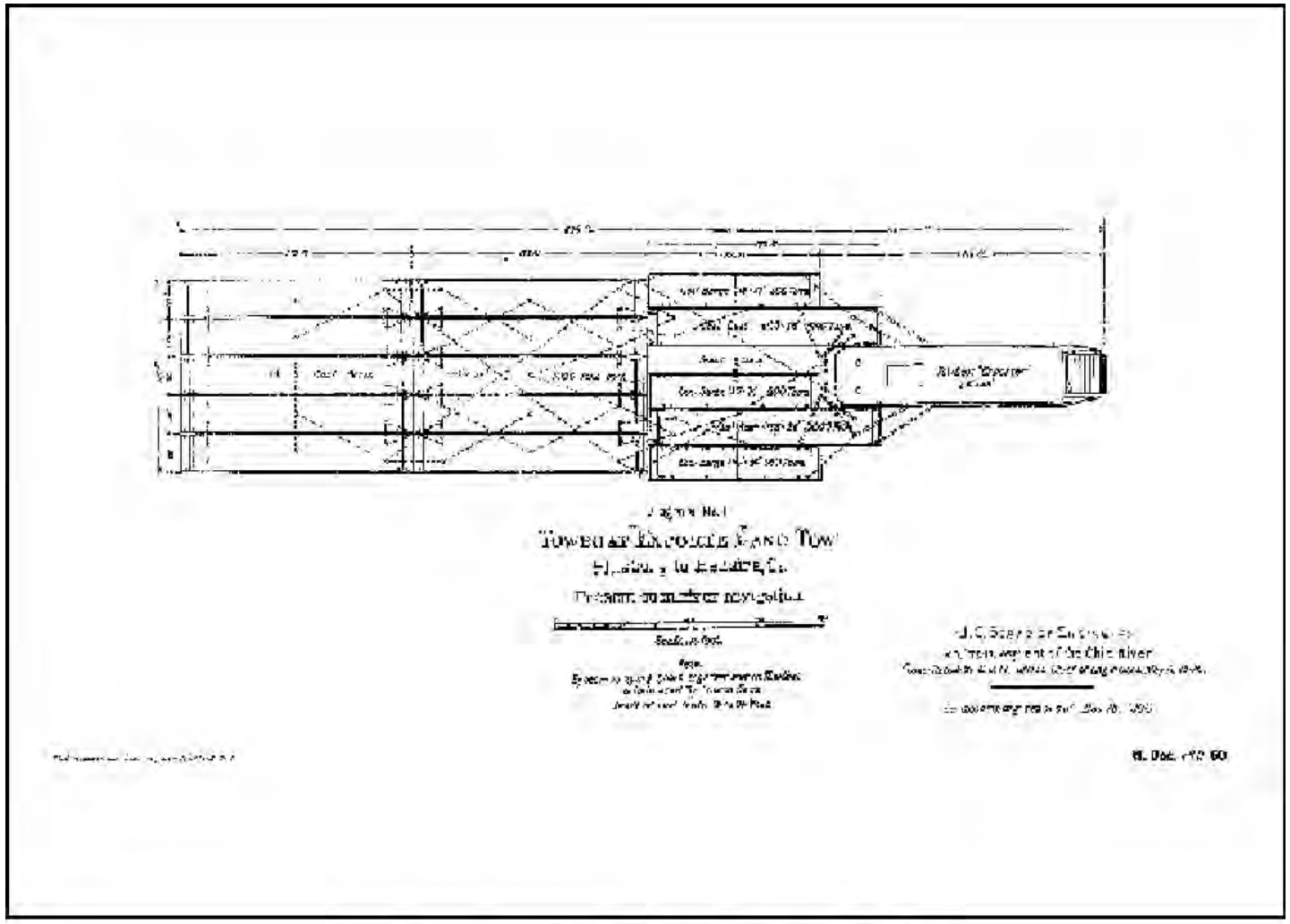
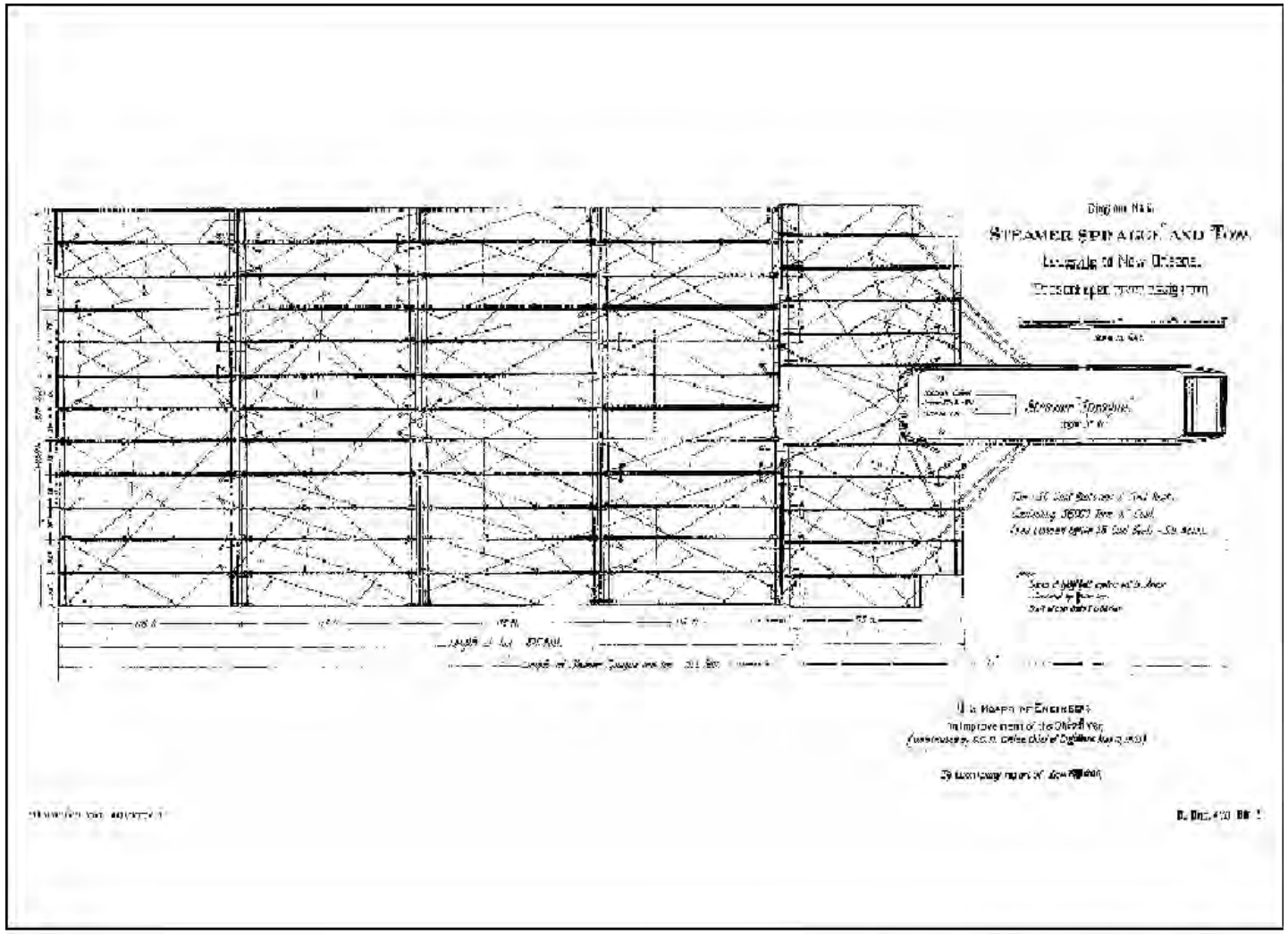


Figure 1-7. Steamer "Sprague" and tow, Louisville to New Orleans (Taft 1908).



> boats and 3 barges [Figure 1-6]…After passing the Bellaire bridge, 96 miles below Pittsburg[h], 5 more coal boats will ordinarily be added to this tow, making a total of 17 coal boats and 3 barges, the cargo of which will be about 18,500 tons. Ordinarily this boat will proceed with the above tow to Louisville, Ky., and, after passing through the canal, will deliver its tow to a larger boat. From the canal at Louisville to New Orleans a boat of the most powerful class will tow from 30 to 60 coal boats, each boat being loaded with about 1,000 tons of coal or other similar commodities [Figure 1-7] (Taft 1908:19).

Two types of barges were then in use on the Ohio River, one drawing about six feet, while the other drew about eight feet (Taft 1908:33). Before many years passed, steel barges began to replace wood barges. By the late 1920s, more than 500 steel barges were launched each year (Deisler 1929:69).

By 1930, packet freight amounted to only 330,000 tons (1.6 percent) of total Ohio River cargo. Most of the cargo was carried in fleets of barges pushed by stern-wheel towboats.The barges were generally constructed of steel with a capacity of 800 to 1,000 tons each. Most were of the open type, with a small percentage specially constructed tank barges. Steam power still dominated in towboats, although diesel-powered boats were rapidly increasing in number. During low water season, tows were generally limited by the size of the locks, and cargoes ran between 8,000 and 10,000 tons. Larger tows, 12,000 to 14,000 tons, were not infrequent and had to be broken in two to pass through the locks (Kutz 1930:440). As towboat and barge technology improved and the demands for bulk shipment increased, barge dimensions also increased. The 24 foot wide barge grew in size to 35 feet, and the width of the tow grew to a maximum of 108 feet, allowing very little room for error in a 110 foot wide lock (Davis 1970:455).

Loveland and Bailey characterized river traffic in the immediate post-World War II era:

> The major portion of the present commerce on the river is handled in barge tows consisting of a towboat and one or more barges. Tows range up to 105 feet in width and 1,200 feet in length or larger. Tow from 600 to 1,200 feet in length require two trips for passing through locks of standard dimensions, 110 by 600 feet. Tows of sufficient size to require two trips (double lockage) are of common occurrence. Extremely large tows requiring triple lockages occur at rare intervals (Loveland and Bailey 1949:172-173).

Post war towbats used underwater screw propellers and often had a draft of seven to eight feet. Loveland and Bailey illustrated the evolution of the towboat by comparison of the *Sprague*, a steam-powered sternwheeler, and the *Esso Louisiana*, the diesel-powered boat that replaced her:

> The *Sprague* was constructed in 1902 and is 276 feet (315 feet overall) by 62 feet by 7.4 feet in depth, with double expansion steam engines 28-inch diameter (high pressure), 63-inch diameter (low pressure) by 12-foot stroke, developing 2,709 horsepower. The sternwheel on the *Sprague* is 38 feet in diameter by 40 feet wide. The *Esso Louisiana* is 166 feet by 36 feet by 10.5 feet in depth, with two diesel engines turning two underwater propellers and developing a total of 2,000 h.p. Although the *Sprague* is 110 feet longer and 26 feet wider, the *Esso Louisiana* is expected to out-perform her (Loveland and Bailey 1949:175).

In 1950, commerce on the river reached an all-time high. Over 48.5 million tons were carried over 8.8 billion ton-miles. Much of the increase in commerce can be attributed to increases in coal and coke shipments (Mueller 1952:183).

Major changes occurred in the design of barges following war's end. The old "Pittsburgh standard" barges had capacities of about 1,000 tons. By the late 1970s, four types of barges were employed on the Ohio River: 1) open hopper, 2) covered hopper, 3) deck, and 4) tank. Open hopper barges, used to transport bulk solid cargo dominate. Open hopper barges are built in three sizes, the standard, which measures 175 feet in length and 26 feet in width with a capacity of 1,000 tons; the jumbo, which measures 195 feet in length and 35 feet in width and has a capacity of 1,500 tons; and the super jumbo, which measures between 250 and 290 feet in length, from 40 to 52 feet in width, and has a capacity of 2,500 to 3,000 tons (USACE-ORD 1979:56).

Post World War II lock sizes were proposed by Ralph L. Bloor in a 1951 study. Bloor noted that, in 1945, the predominant width of Ohio River bulk cargo barges was either 26 or 27 feet width a lesser number 35 feet wide. The predominant width of tank barges was 35 feet with a lesser number 26 feet wide. He noted that a lock of 110 ft by 600 ft had been established as a kind of standard because it is wide enough to accept either the 26 ft barge or the 35 ft barge without wasting space. He concluded that for the larger river a lock length of 1,200 ft must be considered since tows of that length had already been operated to a limited extent by the early 1950s and future increases in traffic would make them more common (Bloor 1951:887).

By the late 1970s, downriver from Huntington, West Virginia, about two-thirds of the barges in use were jumbos, about one quarter were integrated chemical and petroleum barges (150 to 300 feet long, 50 to 54 feet wide, with capacities of 1,900 to 3,000 tons), and most of the remainder were standard barges. Upriver from Huntington, jumbos accounted for about half the total number, standards for about 30 percent, and integrated for most of the remainder. The average number of barges per tow was about eight. Coal tows of 20 to 24 standard barges or 15 jumbo barges were frequently seen (USACE-ORD 1979:57). The total amount of waterborne commerce on the Ohio River in 1977 amounted to over 151 million tons of which over half was coal and coke (USACE-ORD 1979:22).

Clearance in the 1,200 foot locks for some tows was as little as a foot on the sides and twenty feet in length. According to John Davis, tows carrying as much as 20,000 to 25,000 tons of flammable liquids were being used on the Ohio River that had lengths of 1,180 feet and widths of 108 feet (Davis 1970:457).

Traffic on the Ohio River grew 60 percent between 1983 and 1997. In 1997, over 271 million tons of commodities moved on the waterways of the Ohio River Basin of which, almost 240 million tons traveled on the Ohio River. The value of these commodities was almost $31.3 billion. Over 58 percent of the tonnage was coal, while aggregates accounted for almost 18 percent (Palmer 1999:3; USACE 1998).

OHIO RIVER NAVIGATION SYSTEM TECHNOLOGY

Locks

Lock Construction

The walls of Louisville and Portland Canal locks were constructed of cut stone masonry. Stone for these walls was quarried a few miles below the site and transported upriver. Later, limestone taken from the lock pits was used in the production of cement for use as a mortar to bind the masonry in the lock walls together (USACE-ORD 1979:17).

The first two locks constructed on the Ohio River (Davis Island and Lock #6 (Merrill)) also had walls of cut stone masonry. The next two locks constructed had walls of natural cement concrete faced with Portland cement, except in the lock chamber, where the walls were faced with timber. All later locks have walls constructed of concrete (Kutz 1930:434).

To prevent scouring and gouging of lock walls, those locks constructed beginning in the late 1920s had part of the lock wall faces protected against abrasion by horizontal lines of cast-steel fenders imbedded in the concrete (Kutz 1930:434). These cast-steel fenders were first used on the Ohio River.

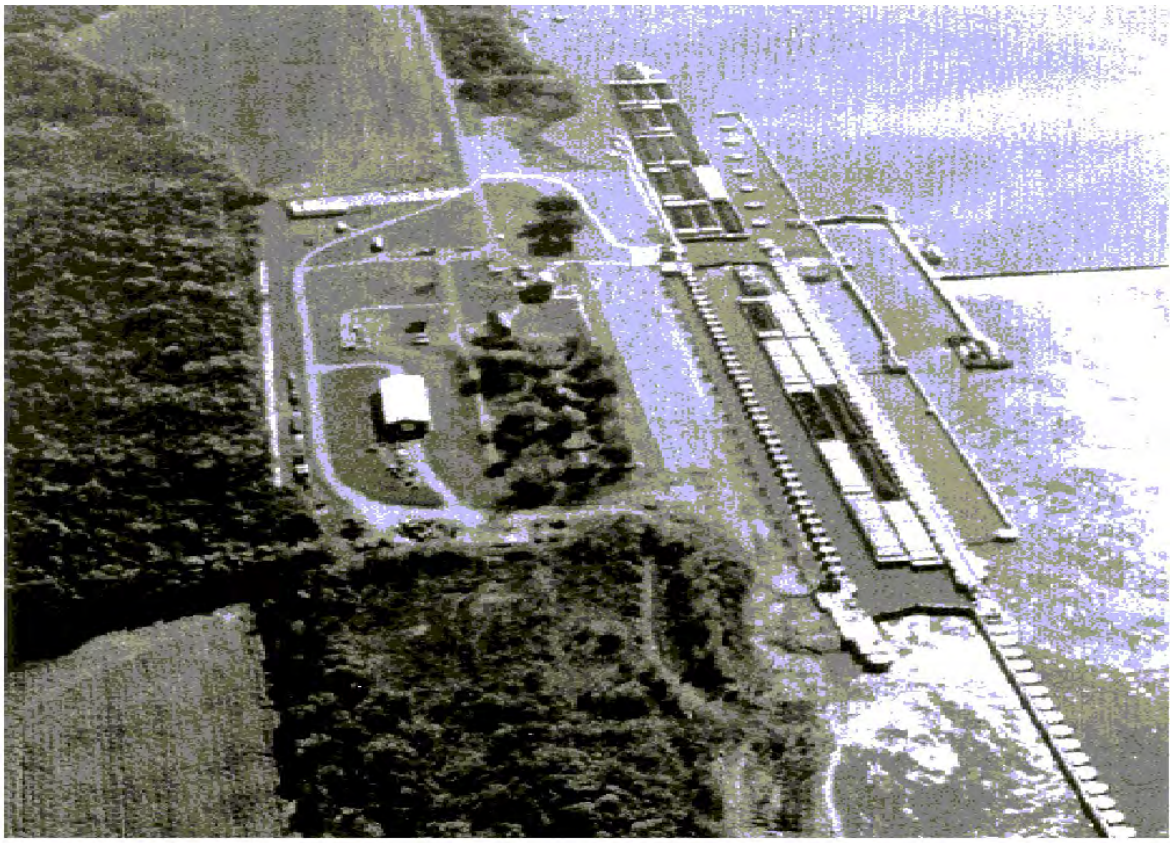
All the modern locks have concrete gravity lock walls. For example, at Meldahl locks, the land wall has a base width of 62 feet, the middle wall a base width of 67 feet and the river wall, a base width of 61 feet. Top widths range from 5 to 52 feet (Houck 1960:19).

In recent years, the Corps employed innovative techniques to construct a temporary 1,200 foot lock chamber at Locks 52 (See Plate 1-15). This long chamber was needed to alleviate congestion on the lower Ohio River. The construction involved the use of circular steel cells, not to serve as a cofferdam, but to serve as walls of the 1,200 foot lock chamber itself. The same technology was later used in a temporary 720 foot lock chamber at Monongahela River Locks No. 3. Leland Johnson described the technology in his history of the Louisville District:

> With lines of steel cells forming the walls, the lock could not be filled and emptied through the usual culverts inside concrete lock walls; the design therefore included an open flume down one side of the new lock walls with gates at each end controlling the flow of water through the flume (Johnson 1975:35).

The lock chamber was constructed with three lines of circular cells, two serving as lock walls and the third as one side of the flume and the retaining wall of the riverbank. Steel piling driven in a circle formed each cell. Each cell was filled with sand and capped with concrete. At the ends of the lock chamber, concrete monoliths provided anchorage for the lock gates and the gates controlling flow through the flume. The flume pit was floored with broken stone and the lock chamber was floored with pre-cast concrete blocks. The entire job required only 38 months from conception of the design to completion. It was recognized by the Chief of Engineers with his National Design Award of 1970 for the “innovative common sense” approach to a “unique engineering challenge” (Johnson 1975:35).

Plate 1-15. Aerial view of Locks and Dam No. 52. Note circular cells used in land lock. No date. From Louisville District, U.S. Army Corps of Engineers.



In the early numbered locks, guide and guard walls were originally constructed of timber cribs filled with stone. At Davis Island, these walls were eventually reconstructed in concrete and lengthened (Johnson 1985:73). Later numbered locks had concrete guide and guard walls.

The approach walls of some of the first replacement locks, such as Montgomery, were constructed of concrete founded on wood bearing piles. The approach walls at Deadman Island Lock were founded on concrete piers spaced 20 feet center to center and ranging from 16 to 27 feet high. Montgomery's approach walls were later extended. The upper guide wall extension is a concrete cap supported on steel sheet pile cells and diaphragms. The upper guard wall extension is a series of six individual circular, sheet pile cells filled with granular material and capped with concrete. The cells are tied together with a timber fender system (USACE-Pittsburgh 1972b:2; Casey 1929:444-445). The guard and guide walls at Dashields locks were constructed using a concrete cap on concrete piers (USACE-Pittsburgh 1972a:1).

At Hannibal locks, the upper guard wall is founded on isolated steel sheet piling cells providing ports beneath the walls. Later permanent steel sheet pile bulkheads were installed in the eight port openings immediately upstream of the river wall. The lower guard wall is founded on continuous diaphragm-type steel sheet pile cells. The approach walls are protected by wall armor of continuous bands of rolled structural steel (USACE-Pittsburgh 1973:6).

Modern locks such as Captain Anthony Meldahl used circular interlocking sheet steel piling guard and guide walls (Houck 1960:17). Another recently added feature of locks are floating mooring bits. For example at Smithland, sixteen floating mooring bitts are provided in each lock, eight in each wall. The bitts are similar to those installed at the Cannelton, Barkley, Hannibal and Opekiska locks (USACE-Louisville:Smithfield:E1).

Lock Gates

Rolling Gates

The first locks constructed on the Ohio River Navigation System used rolling gates (Figure 1-8). These gates were developed to span the unprecedented width of the Davis Island lock chamber. A rolling gate is a massive steel frame, sheathed on one side and running on ten pairs of flanged car wheels which rolls on a steel track carrying the gate from a recess in back of the land wall across the lock chamber. On most of the rolling gates, the wheels were constructed of cast iron, revolving on fixed axles. This mounting permitted ready replacement in case of breakage but caused more wear on the gate tracks than wheels rigidly connected to revolving axles. The gates were opened or closed by a chain or cable connected to a winding drum which, in turn, was gear-connected to a reciprocating engine actuated by compressed air (Kutz 1930:434).

In a report submitted in 1878, Major William E. Merrill discussed the reasons for his development of the rolling lock gate:

> The plan for a lock which was presented to the board in April 1875…contemplated a width in the clear of 78 feet and an available length of 630 feet. It was expected to accommodate a fleet of nine coal barges, in three ranks of three in a rank, a towboat in rear of the fleet, and a small fuel flat. It was known even then that coal fleets are not usually made up in this manner, but the lock proposed was believed to be as wide as it was practicable to make it with miter gates of such limited height.
>
> The coal trade objected strenuously to this arrangement of lock, and meanwhile, the officer in charge, recognizing the force of the objections to the lock as approved, endeavored to overcome them by an increase in width. After long investigation he decided to recommend a gate somewhat resembling a railroad car, which, when out of use, is housed in a recess in the bank, and when needed is run across the lock, thus shutting it up and acting as a gate (Stimson 1912:54).

The rolling lock gates consisted of three main parts: 1) a top truss which served to carry a portion of the water pressure to the lock walls; 2) a vertical water screen which served to close the lock and transferred one-third of the pressure to the top truss and two-thirds to the track; and 3) the truck and wheels.

William L. Sibert described the original Davis Island gates in a paper presented to the American Society of Civil Engineers:

> The original gates at the Davis Island Lock were made of pine timber. The top truss was of the Howe type, supported on posts so as to lie above the normal level of the upper pool. The posts extended below the level of the track, and their

> lower ends served as flanges for the wheels which were of the plain-tread type, traveling on a flat-rail track, the gauge of which was 11 ft. 6 in. … The gate was moved back and forth by two chains, each chain being fastened at one end to an end of the gate and wound around a chain drum at the entrance to the recess. The chains were rigidly attached to the gate, and this mode of fastening was found to give much trouble. If a gate struck a submerged snag or rock on the track, it stopped moving instantly, and something broke before the engine could be stopped (Sibert 1908:1192).

After being in use for twelve years, the original wooden gates at Davis Island were replaced by steel gates. These gates had a Pratt type top truss, flanged wheels, and lateral movement of the gate was provided by hanging the framework upon each axle by eye-bar hangers. The new gates used rectangular valves instead of the circular butterfly valves of the original gates (Sibert 1908:1192-93).

Other early Ohio River locks used gates similar to the steel gates of Davis Island. The water screen consisted of horizontal white oak planks bolted to vertical, 15-in I-beams, which rested at top and bottom against horizontal members. Gate valves were placed in the bottom of the gate, 18 in each gate. The valves were rectangular, horizontal axis butterfly valves approximately 3 feet by 4 feet in size. These valves were operated by hand from the top of the gate using racks and pinions. These gate valves functioned only when the wall valves were not operational or for flushing debris out of the lock chamber and tail bay (Sibert 1908:1193).

Corps engineers made improvements to the operating mechanism of later rolling lock gates. The operating chains were 1 ¼ inch crane chains fastened at each end of the gate to a tug-lever arranged with a spring control. This spring control diminished the shock due to starting and stopping the gate (Figure 1-9). To prevent chain breakage, the connections to the tug-levers were made by shackles and pins of a size that the pins would break before the chain. Power for the gates was provided by a horizontal, double cylinder, 10 by 12 inch engine operated by compressed air (Sibert 1908:1193-1194). Horizontally pivoting valves were placed in the lower sector of the lock gates (Figure 1-10).

Because drift collected in the gate recesses at Davis Island, a drift chute was installed in Locks 2 through 6. The drift chute consisted of a tunnel that ran from the rear of the upper gate recess down past the rear of the lower gate recess and emptied into the tail-bay of the lock. The entrances to the drift chutes were provided with movable doors (Sibert 1908:1195).

All Ohio River locks built before 1914 had rolling gates housed in recesses in the lock landwall (Plates 1-16, 1-17, 1-18 and 1-19). According to Leland Johnson, these rolling gates worked well on the upper Ohio River where the riverbed consisted primarily of coarse gravel and floods were of relatively short duration. The chief difficulties with these gates were broken wheels or worn out tracks. Below Huntington, the Merrill gate recesses filled with sand and mud from the soft, shifting banks after every floods. Because of this difficulty, the rolling gates were replaced in locks begun after 1914 with structural-steel, swinging mitering gates (Johnson 1977:130; Kutz 1930:434).

Figure 1-8. Ohio River Lock No. 6. General plan of upper gate (Craighill 1903). From Cartographic Branch, National Archives.

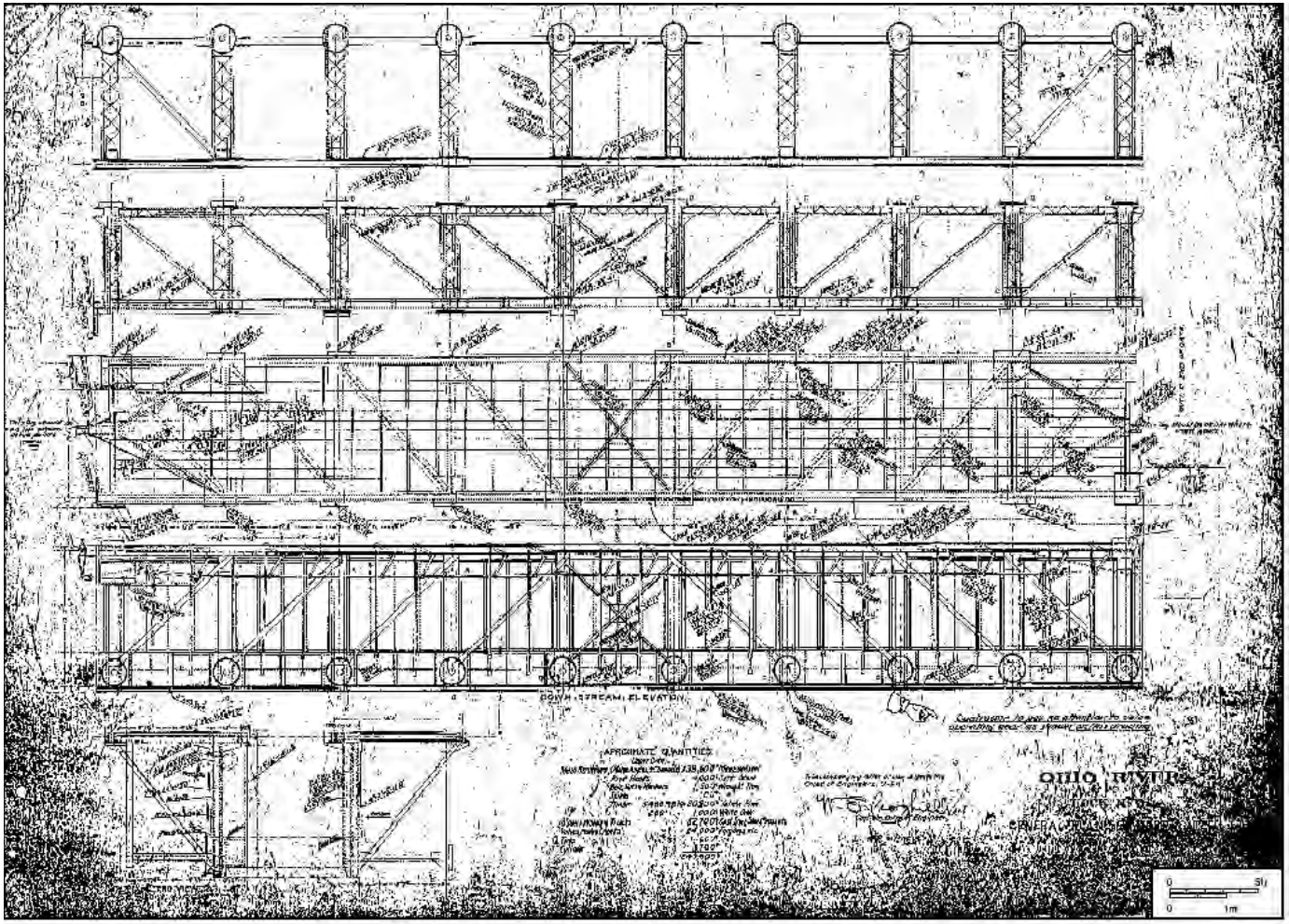
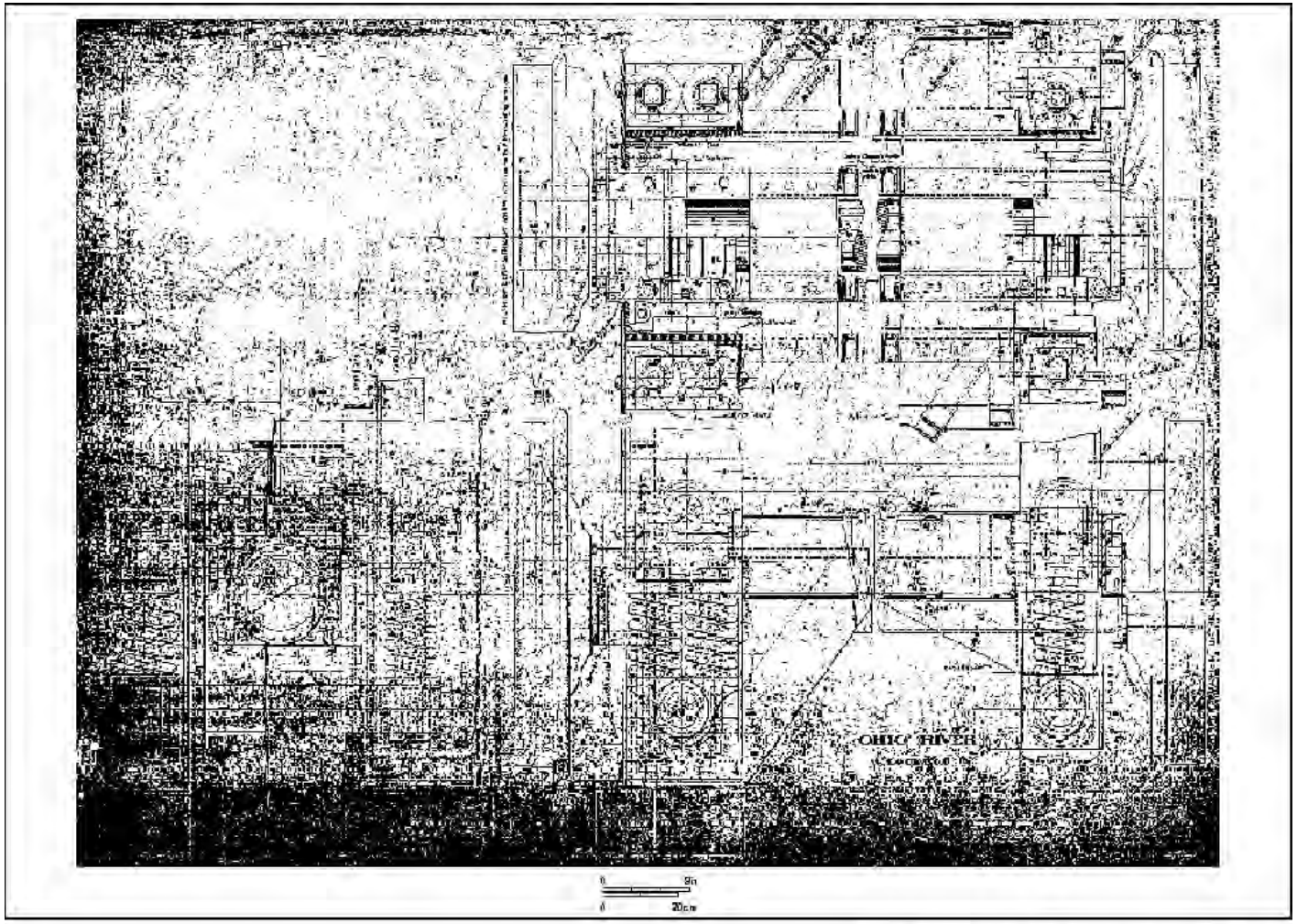


Figure 1-9. Ohio River Lock No. 6. Wheel arrangement for gates (Craighill 1903). From Cartographic Branch, National Archives.



A typical rolling lock gate on the Ohio River measured about 116 feet in length, 12 feet in width, and 20 to 24 feet in height. The upper gate weighed about 120 tons, while the lower gate weighed about 160 tons. Springs were fitted to the axle bearings and carried the weight of the gate. Posts, horizontals, and bracing carried a system of steel framing. A wooden bulkhead attached to the downstream side of the gate, took the water pressure. A horizontal water seal rail extended along the downstream side of the gate for its entire length, and a vertical water seal was placed on the downstream side of each end of the gate (Hall 1934:25).[1]

As of 1929, the following locks on the Ohio River used miter gates: Emsworth, Deadman Island, #16, #17, #21, #22, #23, #25, #27, #33, #36, #38, #39, #41, #43, #44, #45, #46, #47, #49, #50, #51, #52, #53. The following locks on the Ohio River used rolling gates: #5, #6, #7, #8, #9, #10, #11, #12, #13, #14, #15, #18, #19, #20, #24, #26, #28, #29, #30, #31, #32, #34, #35, #37, and #48 (Jones 1929). Rolling gates were also installed on the Bruges, Belgium Ship Canal; at the tidal lock on the Charles River in Boston; and on the Nile River, among other waterways (Thomas and Watt 1913:II:453).

Most rolling gates on the Ohio River remained in satisfactory working order until the lock was closed. In one case, at Lock 37, it was necessary to replace the lock gates due to extensive rust and corrosion (Hall 1934). In other cases, such as Lock No. 4, the rolling gate tracks were found to be badly worn and bent and needed to be replaced. In the case of Lock 4, the track was replaced by one constructed of high carbon steel with rivets countersunk an extra ½ inch over standard (Bain 1929).

Miter Gates

More navigation locks in the United States use miter gates than any other gate type. Each gate consists of two leaves of equal size and is hinged at the top by means of a gudgeon pin, a fixed part of the leaf which seats in a gudgeon or eye connected to the wall by adjustable anchorage bars. Directly below the gudgeon pin, on the bottom of the gate leaf, is a socket called the pintle shoe. This shoe bears upon and semi-encloses the pintle, a carefully finished hemispherical member fixed to a base on the shelf in the lock wall. The gate is suspended in position by the gudgeon and the pintle, and pivots about these points when in motion. When the miter gate is opened the leaves are swung into recesses in the walls so that the downstream faces are flush with the wall surfaces (Engineer School 1940:57).

The miter gates used at Ohio River locks, operated by a hydraulic oil cylinder and piston, were designed in the Louisville District in 1913. To span the wide openings of Ohio River lock chambers, the engineers combined an interior bracing frame, surrounded by steel-skin plates, with the traditional flat leaf miter gates form. These gates opened and closed with a single stroke of the piston, required less time and less power to operate than the rolling gates (Johnson 1975:185; O'Brien et al. 1992:87).

[1] The Hall article cited in the references describes the replacement of the lock gates at Lock 37 on the Ohio River.

Plate 1-16. Upper rolling gate recess. Lock 12. Wheeling, West Virginia. September 19, 1910 (Stimson 1912).

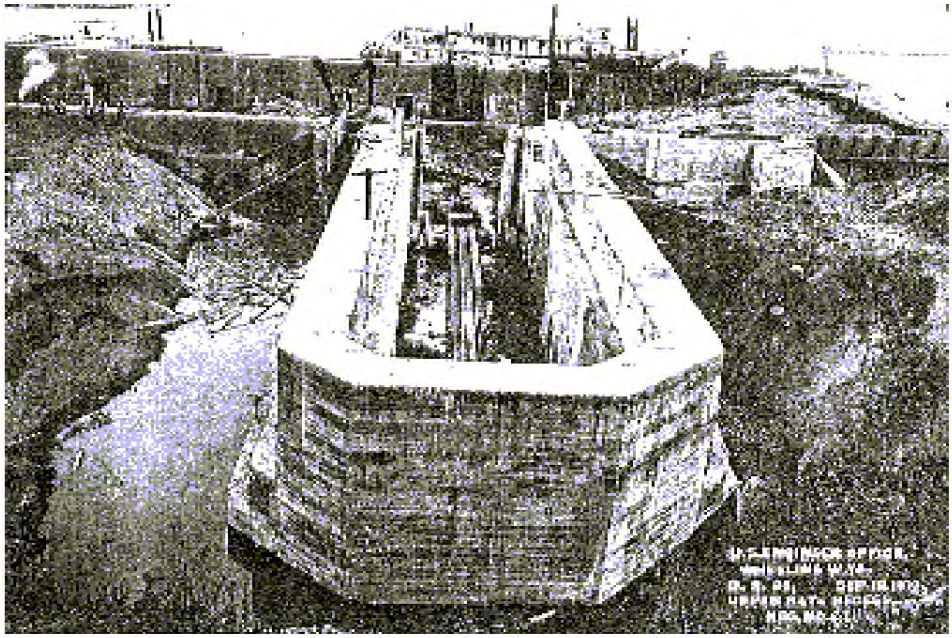


Plate 1-17. Lower rolling lock gate. Lock 12. Wheeling, West Virginia. October 31, 1908 (Stimson 1912).

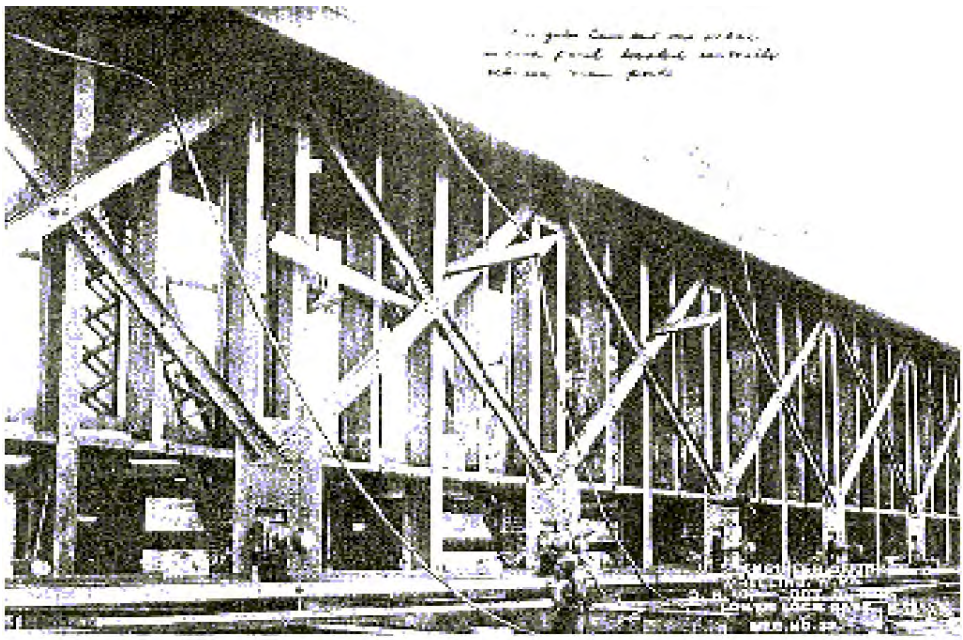


Plate 1-18. Ohio River Lock #48. General view showing downstream side of lower rolling gate from land end. November 7, 1945. From the files of the Louisville District, U.S. Army Corps of Engineers.

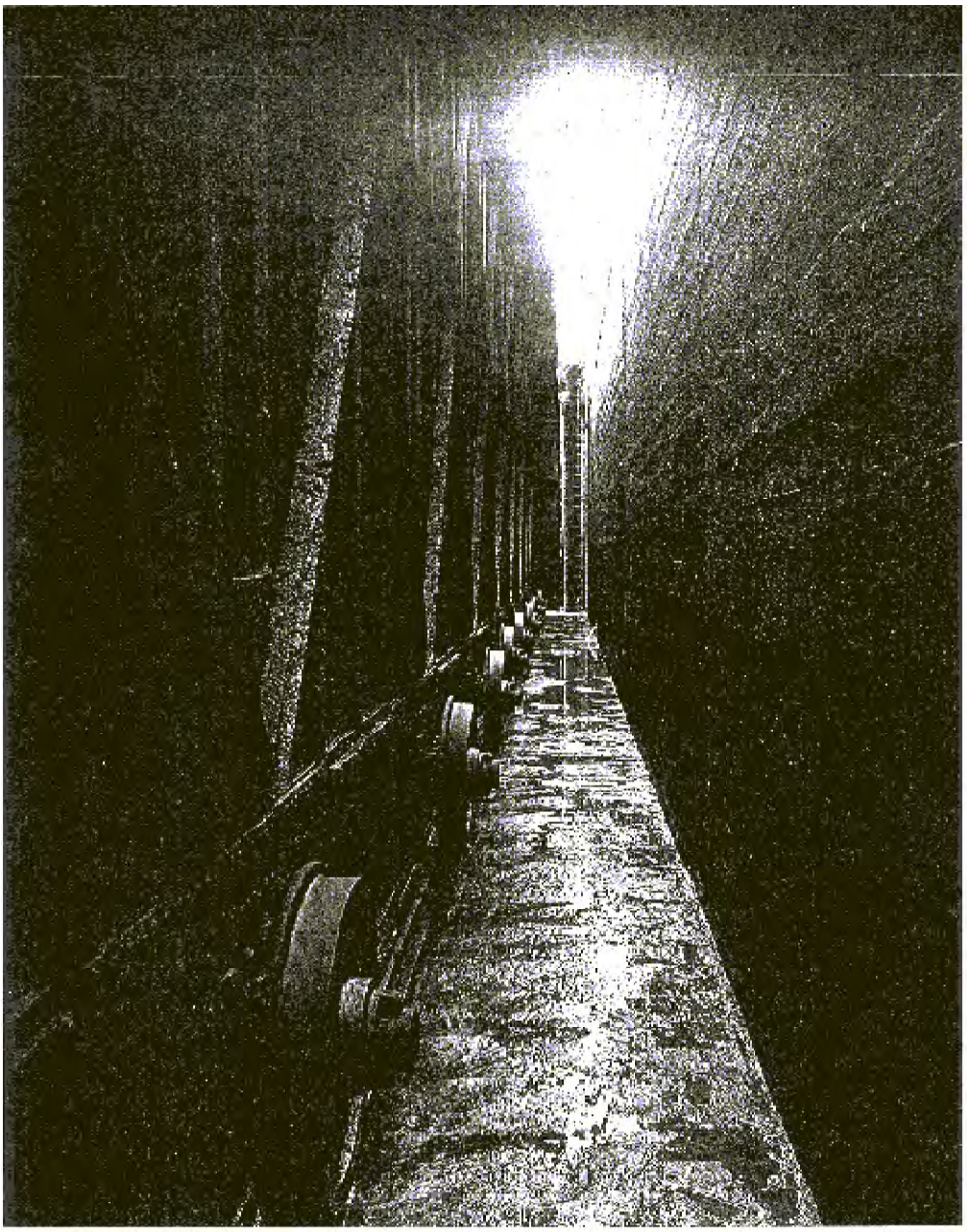


Plate 1-19. Ohio River Lock #48. Repairs to rolling lock gate. General view at lower gate, looking landward; gate in recess. June 18, 1938. From the files of the Louisville District, U.S. Army Corps of Engineers.

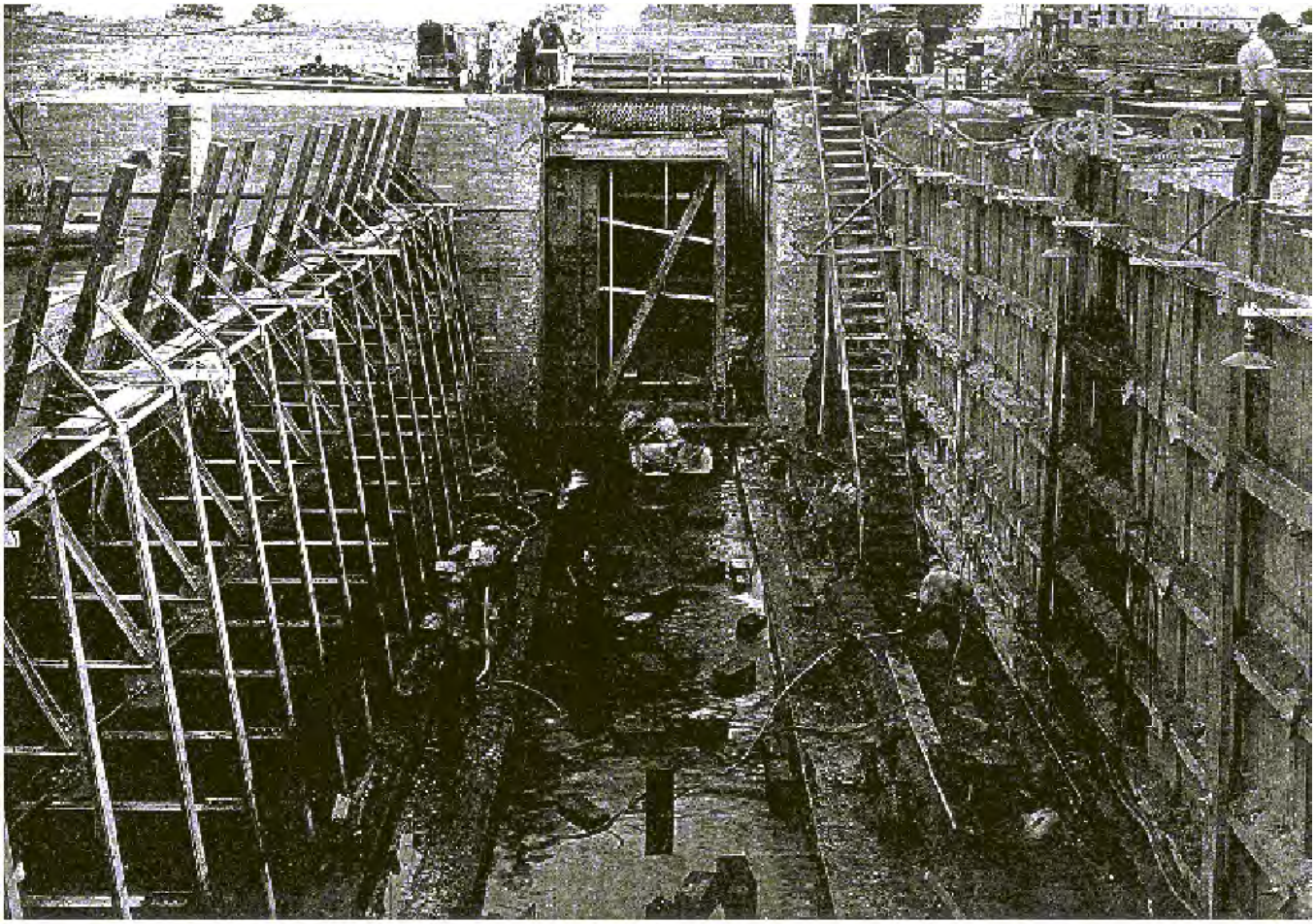
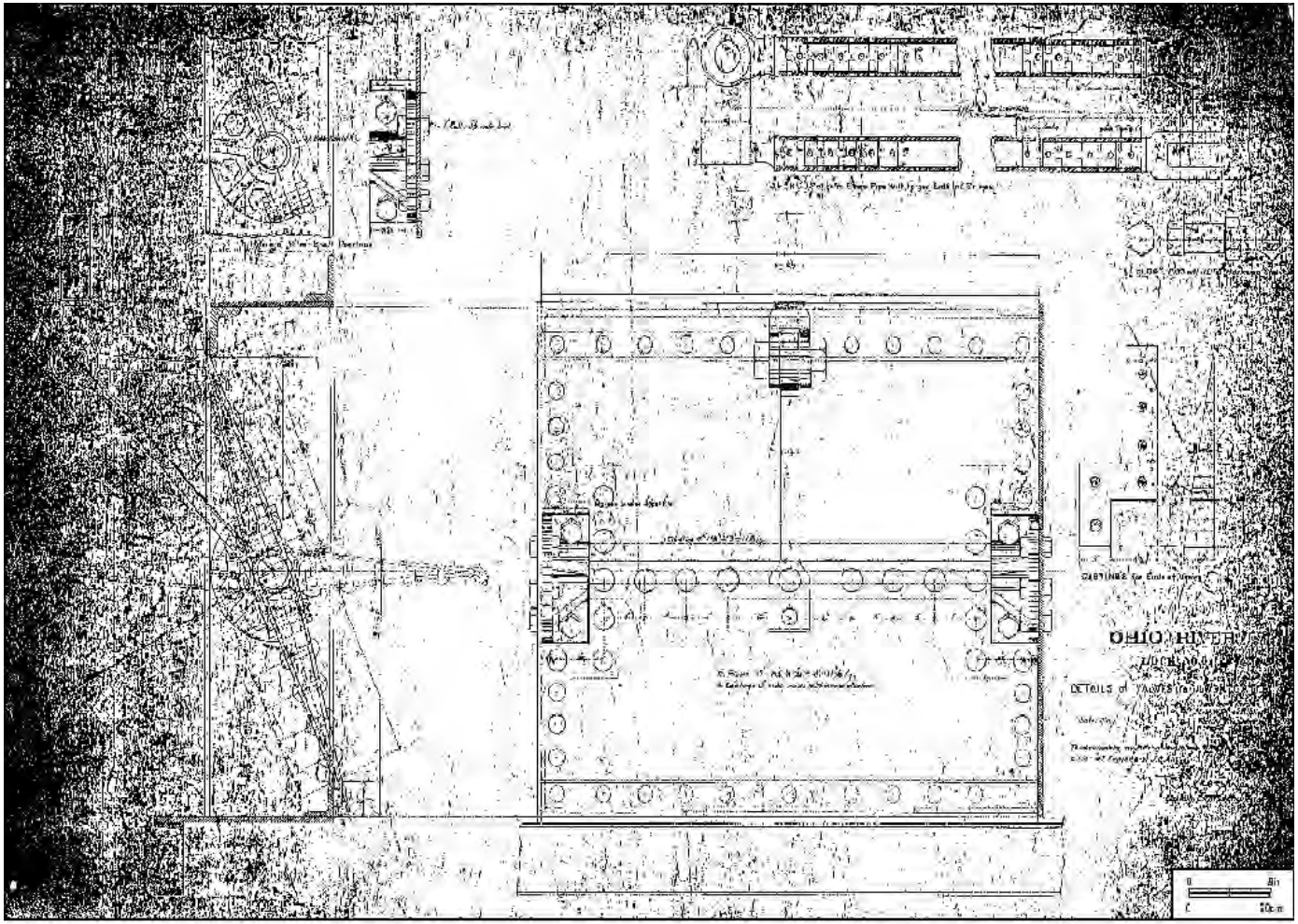


Figure 1-10. Ohio River Lock No. 6. Details of valves for lock gates (Craighill 1902). From Cartographic Branch, National Archives.



Miter gates are either horizontally or vertically framed, distinguished by whether the main load-supporting members run horizontally or vertically. Engineer Malcolm Elliott described the differences between the two gate types:

> A horizontally framed gate is one which resists the water pressure by means of a series of *horizontal* members more or less uniformly distributed from the bottom of the gate to the top. Each horizontal member receives the load on its own portion of the gate and is supported at one end by a corresponding member of the opposite gate leaf and at the other end by the lock wall.
>
> In [the vertical lock gate] the loads are carried by a series of *vertical* girders more or less uniformly distributed throughout the length of the gate. These vertical girders are supported at the bottom by a sill anchored into the floor of the lock, and at the top by a horizontal member which is in turn supported in the same way as are the horizontal members of a horizontally framed gate (Elliott 1915:405).

Vertical framed miter gates were initially thought to be better suited to the wide dimensions of Ohio River locks. In 1915, it was reported that the vertical frame mitering type had been approved for all Ohio River locks that were to be built in the future (Elliott 1915:415). High narrow gates are generally best framed horizontally while wide, low gates are best framed vertically (Engineer School 1940:58-59).

For example, the original smaller lock gates at Deadman Island Lock and Dam [present Dashields] were horizontally framed. The horizontal members were 24-inch, 80-pound I-beams framed to vertical quoin and miter beams of similar section. A diagonal eyebar extended from the upper end of the quoin beam to the lower end of the miter beam. The gates for the larger lock were vertically framed. Two vertical 48-inch quoin and miter girders divided the gate into three sections, each of which was strengthened by a pair of diagonal tension bars and three additional vertical 24-inch I-beams at 4 feet 10 inches, center to center spacing (Casey 1929:445).

The present miter gates on the Ohio River are all similar. The gates are of welded steel construction and the skin plate, girders, and framing are of structural steel with the eye-bars for the diagonals of high strength steel. The skin plate is on the upstream side of the gate, while the adjustable eye-bar diagonals are on the downstream side of the gate (USACE-Huntington 1971:3).

Modern Ohio River miter gates are operated by struts. The struts are connected to the top girder of the gate upstream from the pintle, pushing the gates closed and pulling them open. Ohio River miter gates are operated using the Ohio River design of strut, sector arm and sector (Figure 1-11). The angle of travel of the sector in the Ohio River type is less than 180 degrees, and the line of the strut does not quite pass through the axis of the sector at either limiting position (Engineer School 1940:391-392). An electric-hydraulic system provides the power necessary for gate operation.

<u>Culvert System</u>

Each of the early numbered locks was equipped with a conduit that ran across under the bottom of the lock from the bottom of a well in the power house to the bottom of another well in the river wall. The pipes that supplied pressure for working the river wall valves and beartrap gates were located in these conduits (Sibert 1908:1197). Ports for emptying and filling the original numbered

locks were located in the river wall. A total of seventeen openings were placed above the dam for filling, and the same number below for emptying (Kutz 1930:434). This type of culvert system was used to fill and empty most late nineteenth and early twentieth century locks of the United States including those constructed on the Monongahela River and the Cumberland River in Tennessee and Kentucky (Griffin 1950:833).

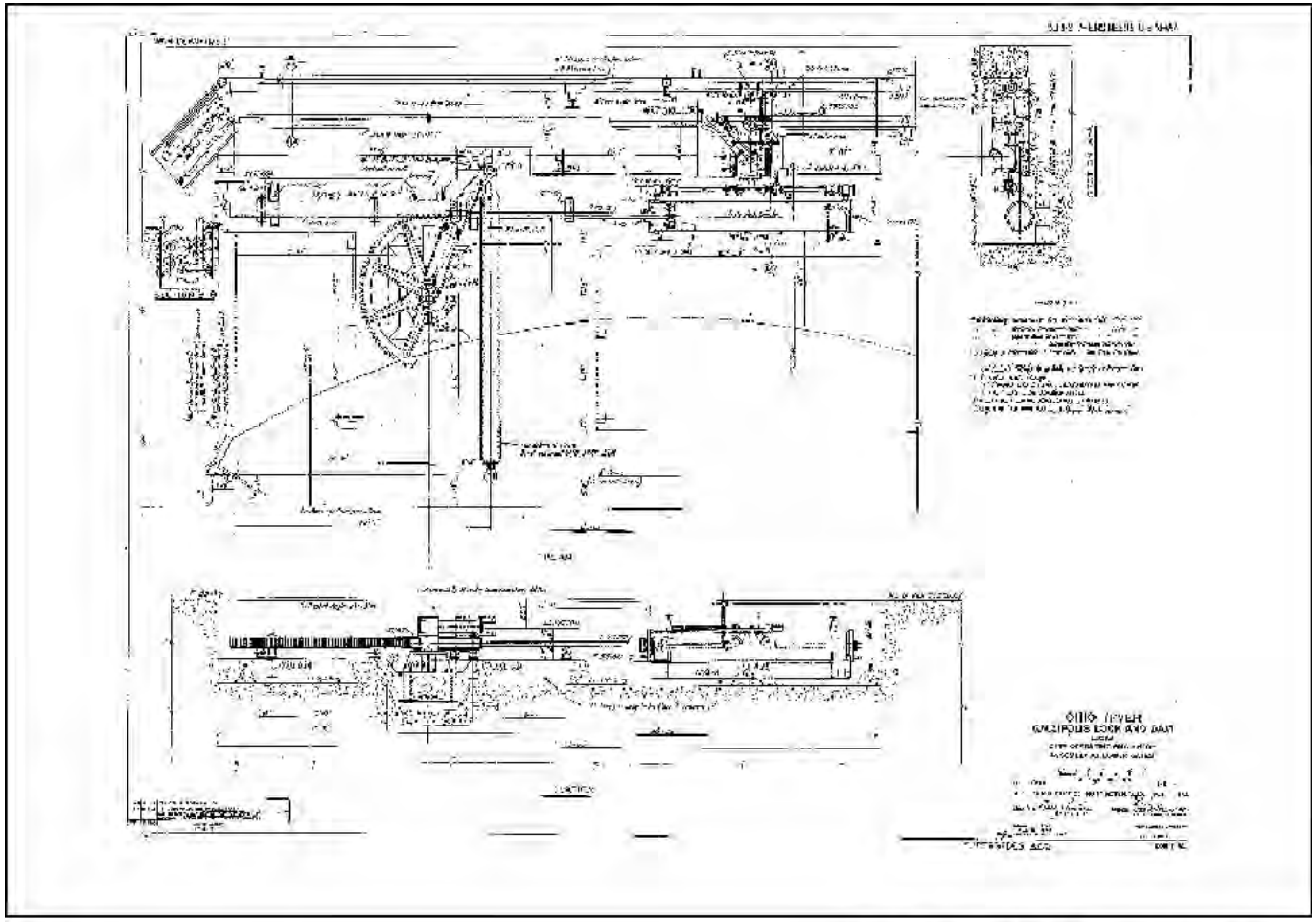
This early culvert system was described by Thomas and Watt in their landmark study of river navigation improvements:

> ….the transverse culvert has been applied to the locks of the Ohio River and to occasional ones elsewhere. On the Ohio locks a series of openings (16 for filling and 16 for emptying) is placed in the river wall…, above and below the dam. These are closed by cast-iron butterfly valves, 4 ½ feet in diameter, moving on vertical shafts. The water enters the chamber directly from the river through one set of valves placed upstream of the dam and empties directly into the river through a second set of valves placed downstream of the dam. The method has worked very satisfactorily, but it was found in the earlier examples that where the filling valves were some distance downstream of the upper end of the wall, the slope of the river in moderate stages resulted in a level in the chamber slightly lower than that above the gates, and the head had to be equalized by using valves in the gates before they could be operated easily. There is some tendency also, as with valves in the gates, to an uneven flow of water in filling the chambers (Thomas and Watt 1913:II:492-493).

A. Frederick Griffin described the use of the early culvert system in the first generation of Ohio River locks:

> Many of the locks on the Ohio River are of low lift and are filled or emptied through a series of ports in the river lock wall controlled by butterfly valves….The filling valves, in the upstream section of the wall, discharge directly from the upper pool into the lock chamber. The emptying valves, in the downstream section of the same wall, discharge directly into the lower pool. Filling time averages from about 5 min to 8 min, and emptying requires from 4 min to 6 min, depending on the head.
>
> During the filling operation, flow through the filling ports creates a turbulent eddy in the lock chamber with a downstream flow along the lock wall. Somewhat similar currents are experienced during emptying operations….The action of the currents described is ordinarily controlled by judicious opening of the filling and emptying valves…. (Griffin 1950:833-834).

Figure 1-11. Gallipolis Locks and Dam. Locks. Gate operating machinery assembly at lower gates (U.S. Engineer Office, Huntington 1933). (From USACE-Huntington 1970).



In the next generation of locks, the individual filling and emptying culverts for each valve were replaced by culverts that ran the length of the lock walls. This type of system was used in locks on the Monongahela River, the Allegheny River, the Kanawha River, the Tennessee River, the Upper Mississippi River, the Illinois Waterway, the New York State Barge Canal, the Intracoastal Waterway, and the Welland Canal (Griffin 1950:835). The Deadman Island (Dashields) Locks use this longitudinal culvert system for filling and emptying the chambers. In his article on construction of the locks and dam, Hugh J. Casey described the features of this system:

> The culverts for the operation of the 110-foot lock extend through the land and middle walls while that for operation of the small lock extends through the river wall. Through the walls at the head of each culvert is a series of screened openings 5 feet square, which taper to 4 feet square as they enter the culvert. The culvert is of sufficient size and structural shape to carry the water through the wall. A large butterfly valve near the head of the culvert below the intakes controls the inflow. A series of similar 3- by 4-foot openings, tapering out to 4 by 5 feet branch off from this culvert into the lock chamber. The culvert diminishes in size toward the center of the chamber as its flow capacity decreases. As the culvert approaches the lower end of the lock wall, it tapers out again to the same size it had at the upper entrance. Here it has a similar butterfly valve and a series of openings branching out from it into the lower lock approaches. The openings are all below draft line…This system will fill or empty the lock in five and one-half minutes (Casey 1929:446).

A similar culvert system was used in the auxiliary chamber at McAlpine Lock. An 8 by 10 foot tunnel extends the length of each wall with four intake ports measuring 4 feet by 6 feet located in the face of the upper miter gate recesses and four discharge ports measuring 4 feet by 6 feet located immediately below the lower miter gate (Rhett 1971).

The Gallipolis locks have culverts in the land, middle and river walls, each measuring 12 feet 6 inches square in section. Three intake ports, each measuring 8 feet by 10 feet in section provide water for the culverts. The water is discharged in discharge ports measuring with 5 feet by 6 feet or 7 feet by 6 feet in section.

Because of the increased size of locks installed during the post-World War II modernization program on the Ohio, more efficient means of filling and emptying the chambers were needed. The emptying system using ports in the lock walls would have created intolerable turbulence and excessive hawser stresses for tows tied in the lock chambers because of the much higher rates of filling and emptying. To prevent these problems, a new system was developed with parallel lateral culverts across the lock floor with ports in the sides of the laterals spaced alternately in adjacent laterals. This system, developed on the Ohio River, was, at the time of its introduction, unique in the United States. Bruce et al. described it in a 1957 article on the Ohio River navigation system:

> Main lock design for the new high-lift locks on the Ohio River locates one group of laterals in the center of the upstream half of the lock. This group is fed by a culvert in the upper half of the river wall. The arrangement permits the discharge outlet for the upper group of laterals to be located near the center of the lock and shortens the length of the culvert which would otherwise be required in the river wall. A second group of laterals is located in the center of the downstream half of the main lock. This group is fed by a culvert located in the intermediate wall

> between the main and auxiliary locks. The discharge outlet for the lower group is carried from the lower end of the culvert in the intermediate wall across the bottom of the main lock and through the river wall to discharge in the river. The idea for the design of the filling and emptying system, which splits the laterals into two groups, is of French origin, but the details have been worked out by exhaustive model tests made for the high-lift Ohio River locks (Bruce et al. 1957:1239-9-10).

Post World War II locks on the Ohio River use larger longitudinal culverts in their filling and emptying system. For example, at the Captain Anthony Meldahl Locks, the 1,200 foot lock fills and emptied through 16 foot wide and 18 foot high culverts in the river and middle walls, and the 600 foot lock is filled and emptied through a single 16 foot wide and 18 foot high culvert in the land wall. Intake manifolds are placed in each lock wall. (USACE-Huntington 1969:4).

Before construction, the culvert system used in the New Cumberland locks was tested using a 1:25 scale model at the Hydraulic Laboratory of the Corps of Engineers in Iowa City. A. Frederick Griffin described the proposed culvert layout and the results of these tests:

> Longitudinal culverts in the river and middle walls connected to intake manifolds in the sides of the approach walls, to lock-chamber ports in the sides of the walls, and to outlet manifolds discharging into the tail bay below the lower miter gates are proposed for the main lock. The auxiliary lock is filled and emptied by an intake manifold, a longitudinal culvert, and a discharge manifold in the land wall, the longitudinal culvert being connected to laterals with side ports in the chamber floor. Tests on the main lock have shown that modifying the lock-chamber ports so that the jets from the ports strike the floor of the lock chamber at the base of the opposite wall, instead of at the midpoint of the floor, results in a reduction of hawser stresses by an average of 50%. With an assumed 2-min time of culvert-valve operation, satisfactory filling in about 8 min and emptying in about 8.4 min was obtained. It was also found that reducing the inside area of the laterals in the auxiliary lock chamber, in steps from the first port to the end, would result in a more equal distribution of flow during filling operations (Griffin 1950:850).

In the Racine locks, the large lock is filled and emptied through culverts in the river and middle walls, while the small lock is filled and emptied through a culvert in the land wall. Intake manifolds are provided in each lock wall upstream from the emergency bulkhead sill. The main lock chamber has a series of wall ports in each lock wall, opening into the lock chamber from the wall culverts at an elevation a minimum of 28 feet below the normal lower pool. The lock culverts are emptied through outlet structures extending outside the river wall to divert the flow outside of the lower lock approaches.

At Racine, room was not available in the middle wall to accommodate two culverts and the necessary valves. Therefore, a system of bottom laterals was adopted for the filling and emptying system in the auxiliary lock. The system of bottom laterals, having openings along both sides and connecting with the culvert in the land wall only, extends across the floor of the lock chamber to distribute the flows and reduce turbulence. The Racine system is based upon model studies for Cannelton Locks (USACE-Huntington 1971:4).

The Belleville locks culvert system was based on model studies performed for the Greenup and Markland locks. The main lock is filled and emptied through 15 by 16 foot culverts in the river

and intermediate walls, and the auxiliary lock is filled and emptied through a 15 by 16 foot culvert in the land wall. Laterals, having ports on both sides and connected at one end to a wall culvert extending across the lock chamber, were adopted for dispersing flows and reducing turbulence in the chambers. Discharge outlets are used for each lock culvert to divert the entire flow outside of the lock approaches (USACE-Huntington-Belleville:5).

At Smithland locks, the ports are approximately centered in each lock chamber. These ports, each of which measures 2.75 feet wide and 3.50 feet high at the throat, are spaced on 28-foot centers. Ports in the opposing walls are staggered so that the issuing jets will not interfere with one another. These ports extend over 50 percent of the lock chamber and have triangular deflectors installed in front of the upstream one-third of the ports. These deflectors measuring 12 feet by 12 feet by 3.5 feet high are installed to reduce the high upstream longitudinal hawser stresses which occur during the filling operations. Each sidewall port manifold contains 25 ports (USACE-Louisville-Smithland E-1-2).

Hydraulic System and Machinery Operation

Typically, in modern locks, the lock's machinery is actuated by hydraulic pressure supplied from a pumping station within the operation building. For example, at Meldahl Locks, the pumping equipment consists of three main pumps and a smaller pressure-holding pump, powered by electric motors. Related equipment includes an oil storage tank, oil filters, and pressure control devices (USACE-Huntington 1969:7).

At Racine and other recently constructed locks, the hydraulic piping circuits for the lock gate operating machinery and the lock chamber filling and emptying machinery are closed pressure systems where a constant operating pressure is maintained. Separate pipe systems are provided for each lock, with interconnection at the pumps in the operation building (USACE-Huntington 1971:2).

The New Cumberland Locks are typical of modern Ohio River locks in the operation of its gates and filling and emptying valves. The main elements comprising the gate operating machinery consist of a cylinder, piston and piston rod, rack, sector gear, sector arm, and strut. The piston rod is in the extended position when the gate is closed. The cylinder is located on the downstream side of the sector gear with the rack, gear and strut in the same plane. The strut incorporates a shock absorber assembly containing a nest of ring springs to protect the operating machinery from instantaneous transmission of shock loads into the machinery (USACE-Pittsburgh 1976:5).

The main elements comprising the culvert valve operating machinery consists of a cylinder, a piston, piston rod, cross-head, cross-head guides, connecting rod, rocker and strut. The piston rod is connected to the cross head which is pin connected to one end of the connecting rod. The other end of the connecting rod is pin connected to the upper arm of the rocker and the strut is pin connected to the lower arm of the rocker. The bottom end of the strut is attached to the pickup connection on the center of the valve by means of a pin. The strut incorporates a spring assembly to insure positive seating of the culvert valve in the closed position (USACE-Pittsburgh 1976:8).

Valves

Ohio River locks have used three types of valves: butterfly, tainter, and Stoney [and cylindrical].

Butterfly valves are installed to swing on either the horizontal or vertical axis (Plate 20; Figure

12). The axial structural member is called the stem. The blade of the valve is attached to and supported by the stem. A vertical stem also usually serves as the means of opening and closing the valve, whereas a strut generally operates the horizontal stem type. The valve blades may be either circular or rectangular (Engineer School 1940:369).

Vertical butterfly valves are also used at only one lock complex in the Pittsburgh District, Emsworth. The main lock is filled by 16 valves located in the upper end of the middle wall and emptied by 16 similar valves which pass water through the lower end of the wall and under the riverward chamber into the river below the dam. The auxiliary lock is controlled by six filling and six emptying valves, located in the riverward wall.

A tainter valve is a steel plate sector of a cylinder, supported by ribs which are in turn supported by beams which carry the load to radial struts at either end (Figure 1-13). The end struts bear upon and revolve about trunnions which are at the axis of the skin plate cylinder. The first tainter valves used on the Ohio River were hydraulic operated by a cable and pulley mechanism (Figure 1-14).

When a tainter valve is installed with the trunnions upstream from the face, it is called a reverse tainter valve (Figure 1-15). Early Ohio River tainter valves were operated using a cable and cylinder mechanism. Tainter valves are either horizontally or vertically framed. Test installations of vertically framed valves indicated that this configuration reduced the variation in hydraulic forces acting on the valve (Figure 1-16).

The Stoney gate valve was developed by the Irish engineer Francis G.G. Stoney (1837-1897) who first employed it in 1875 (WVU n.d.:II:9). The Stoney gate valve resembles a thin flat box, which is raised and lowered vertically to and from its sealed closed position (Figure 1-17). The downstream side rests on a rolling train running on a metal frame set in the masonry, or fixed rollers on the gate rest directly on the supporting track frame. The valve moves in a recess in the culvert side walls, and the gate and roller train are counterweighted (Engineer School 1940:372). The only lock chamber on the Ohio River that presently uses Stoney valves is the 360 foot auxiliary chamber at McAlpine Locks. The first use of the valve in the United States was at Lock 9 on the Monongahela River. Stoney valves are presently used for empty and fill valves at Winfield, Marmet and London locks on the Kanawha River.

The numbered locks of the Ohio River all used butterfly valves. These valves were mounted on vertical axes that extended to a pit in the top of the wall in which the operating mechanism was located. C.I. Grimm, an engineer with the Cincinnati Corps office described the operation of the valves:

> The valve is rotated through an angle of approximately 75 degrees by means of a sector at the top of the stem, engaged by a rack which is moved forward or back by the piston of a small hydraulic cylinder jack. These jacks are connected to common pipe lines, the pressure in which is reversed and regulated from a central point (Grimm 1930:52).

Plate 1-20. Emsworth Locks and Dam. Large lock. Butterfly emptying valve (U.S. Engineer Office, Pittsburgh 1945). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

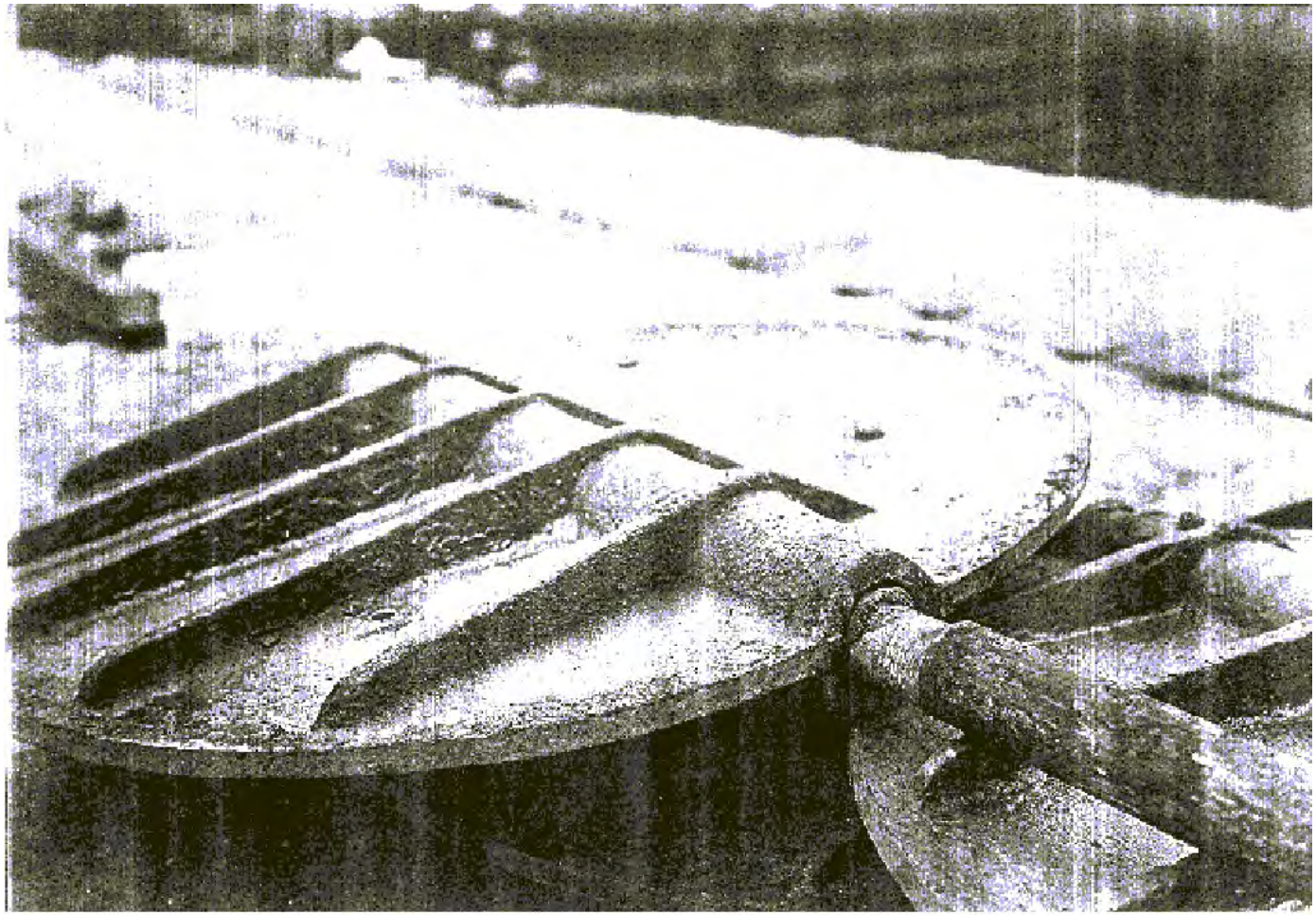


Plate 1-21. Dashields Lock. New emptying valve (U.S. Engineer Office, Pittsburgh 1933). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

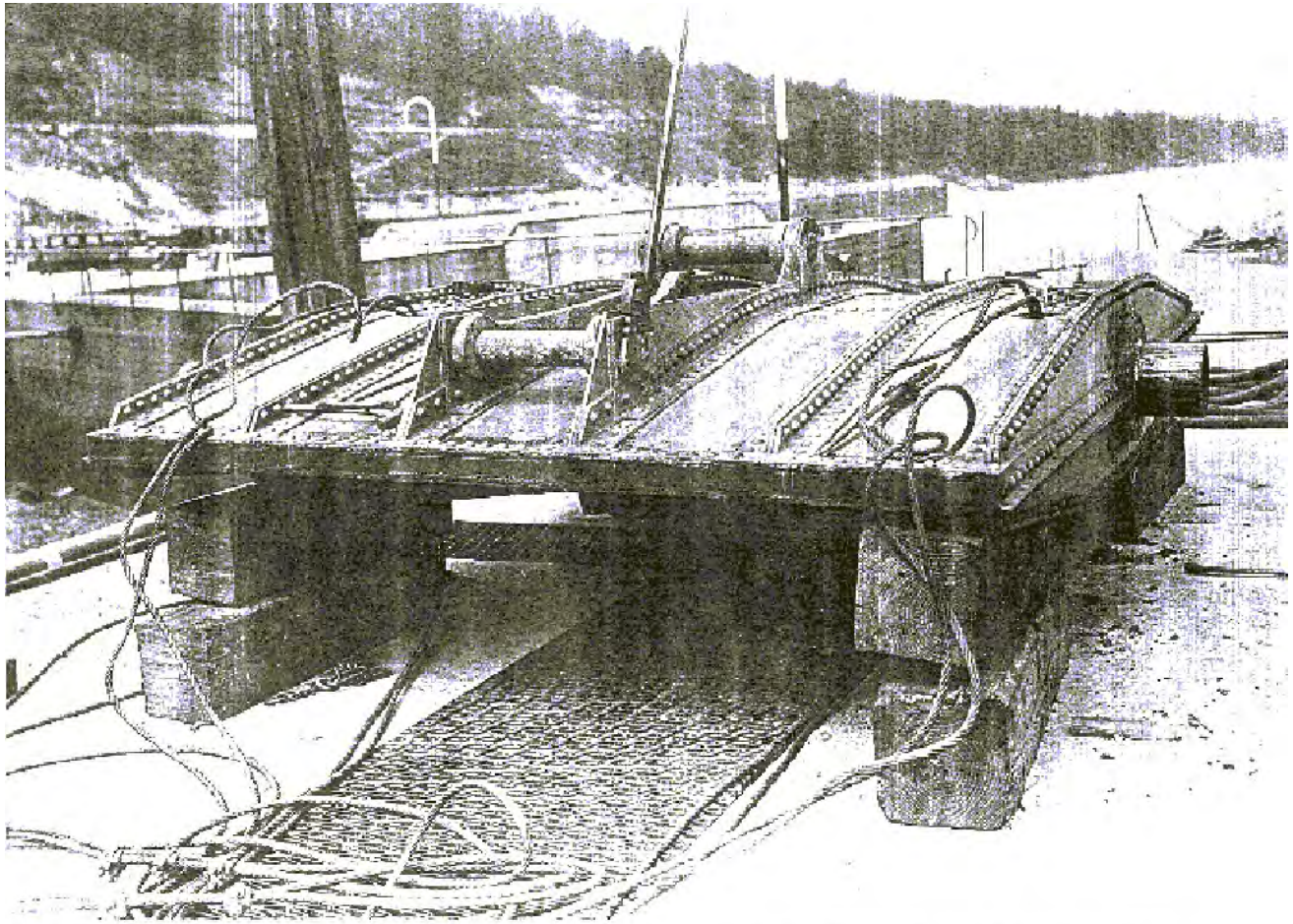


Figure 1-12. Emsworth Lock and Dam. Vertical butterfly valves and frames (U.S. Engineer Office Central Division 1919). From Cartographic Branch, National Archives.

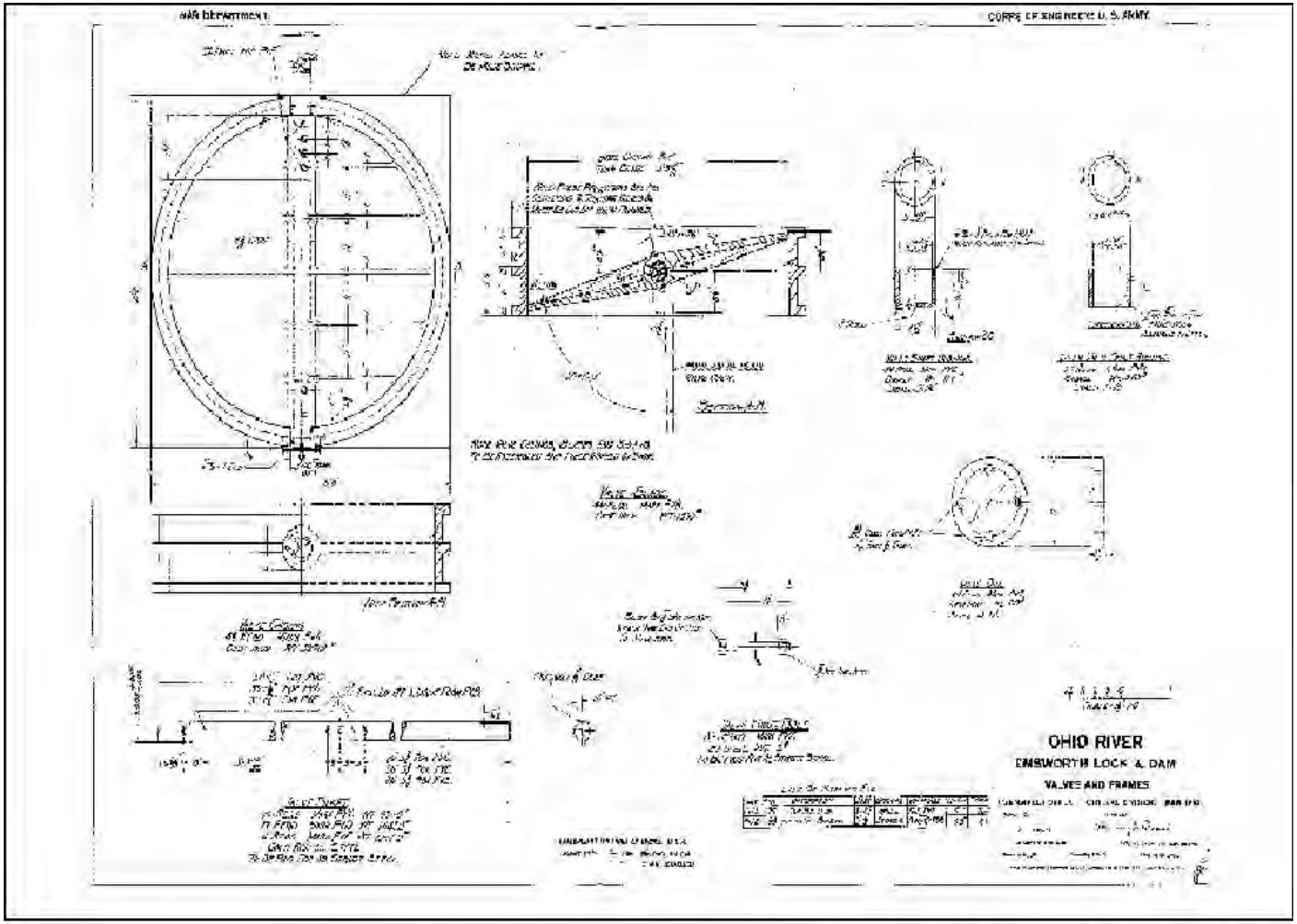


Figure 1-13. Gallipolis Locks and Dam. Tainter valves. General drawing (U.S. Engineer Office, Huntington 1933). (From USACE-Huntington 1970).

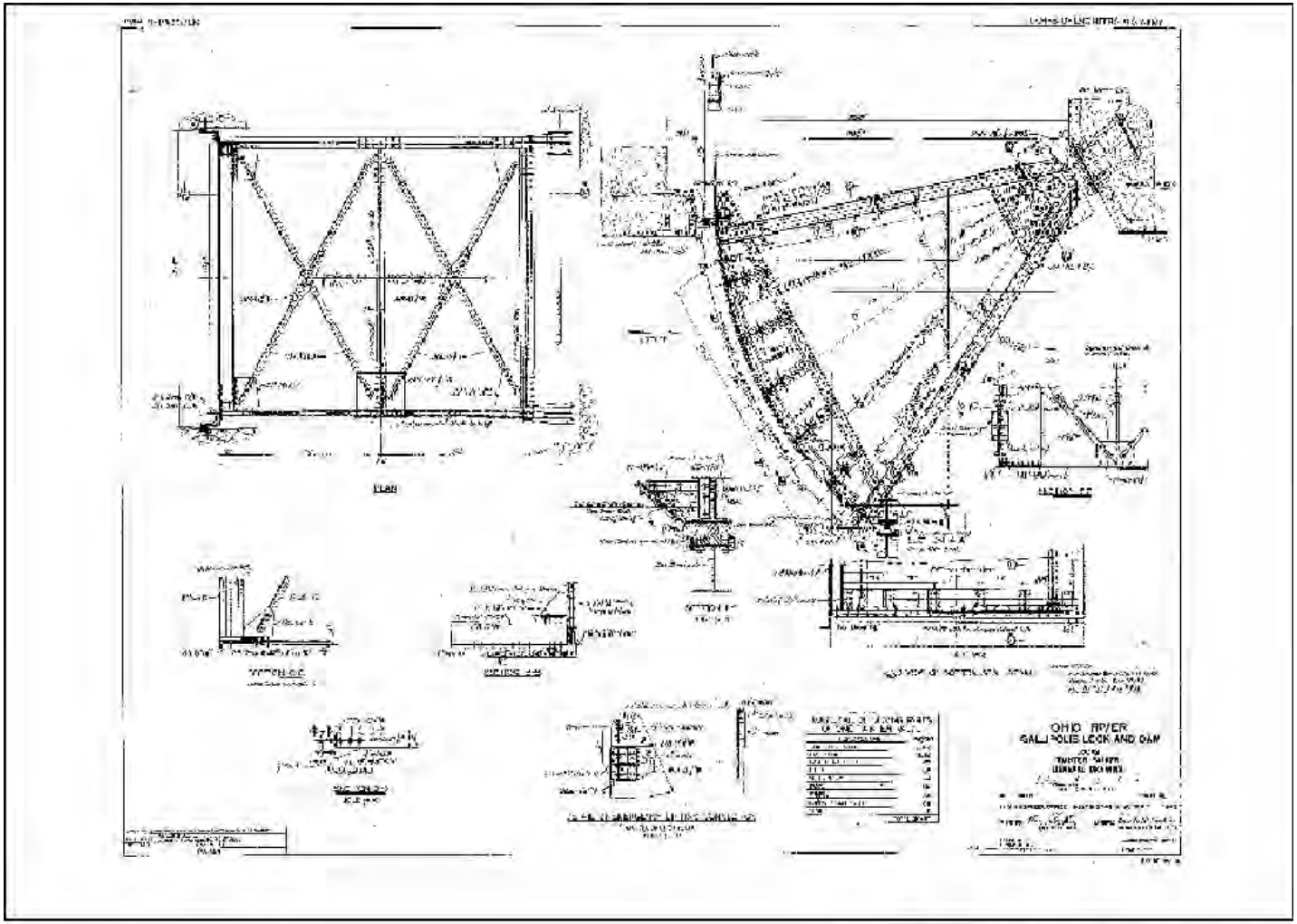


Figure 1-14. Gallipolis Locks and Dam. Tainter valve operating machinery (U.S. Engineer Office, Huntington 1938). (From USACE-Huntington 1970).

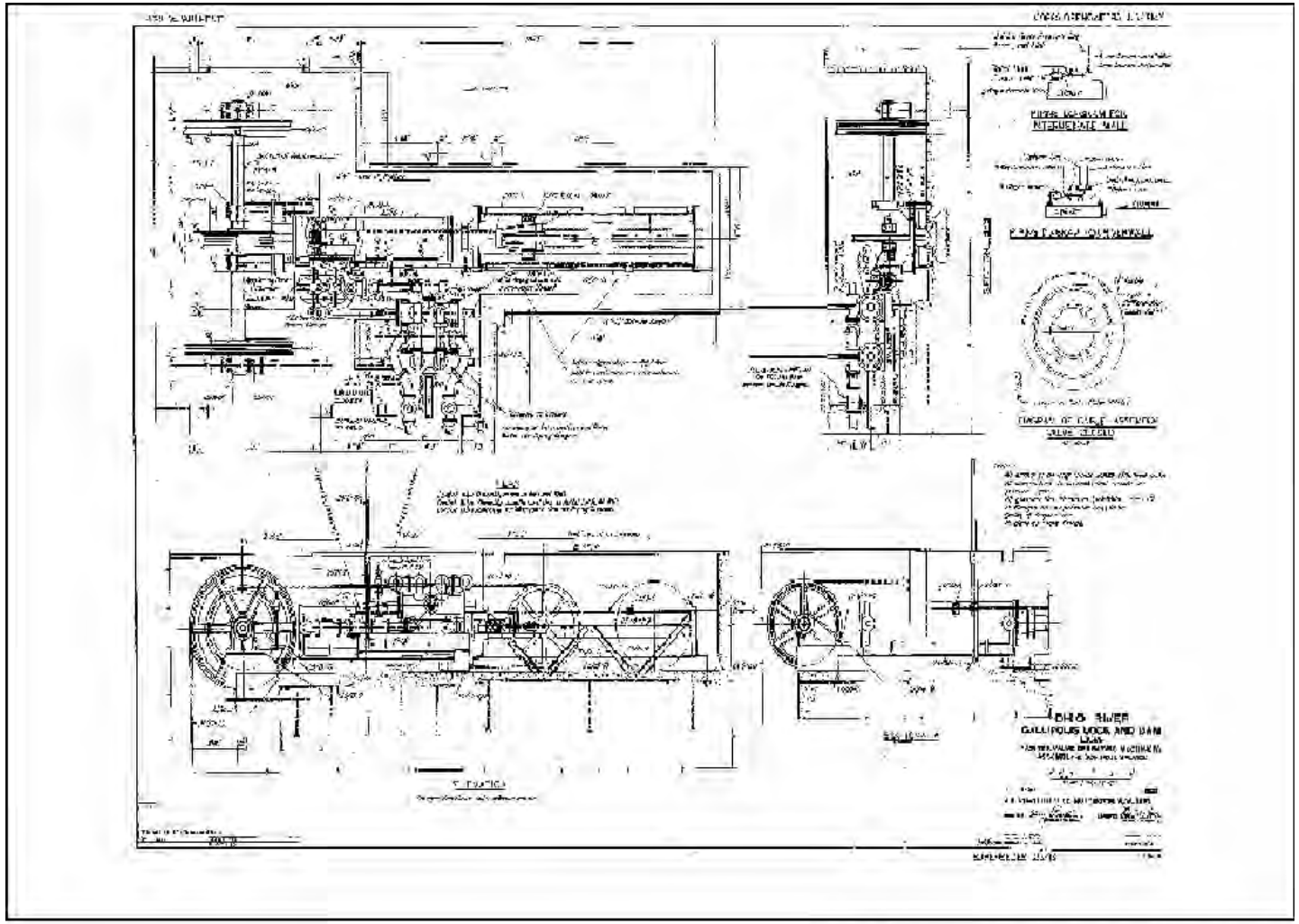


Figure 1-15. Winfield Lock and Dam. Reverse tainter valve and wire rope mechanism (USACE-Huntington n.d.).

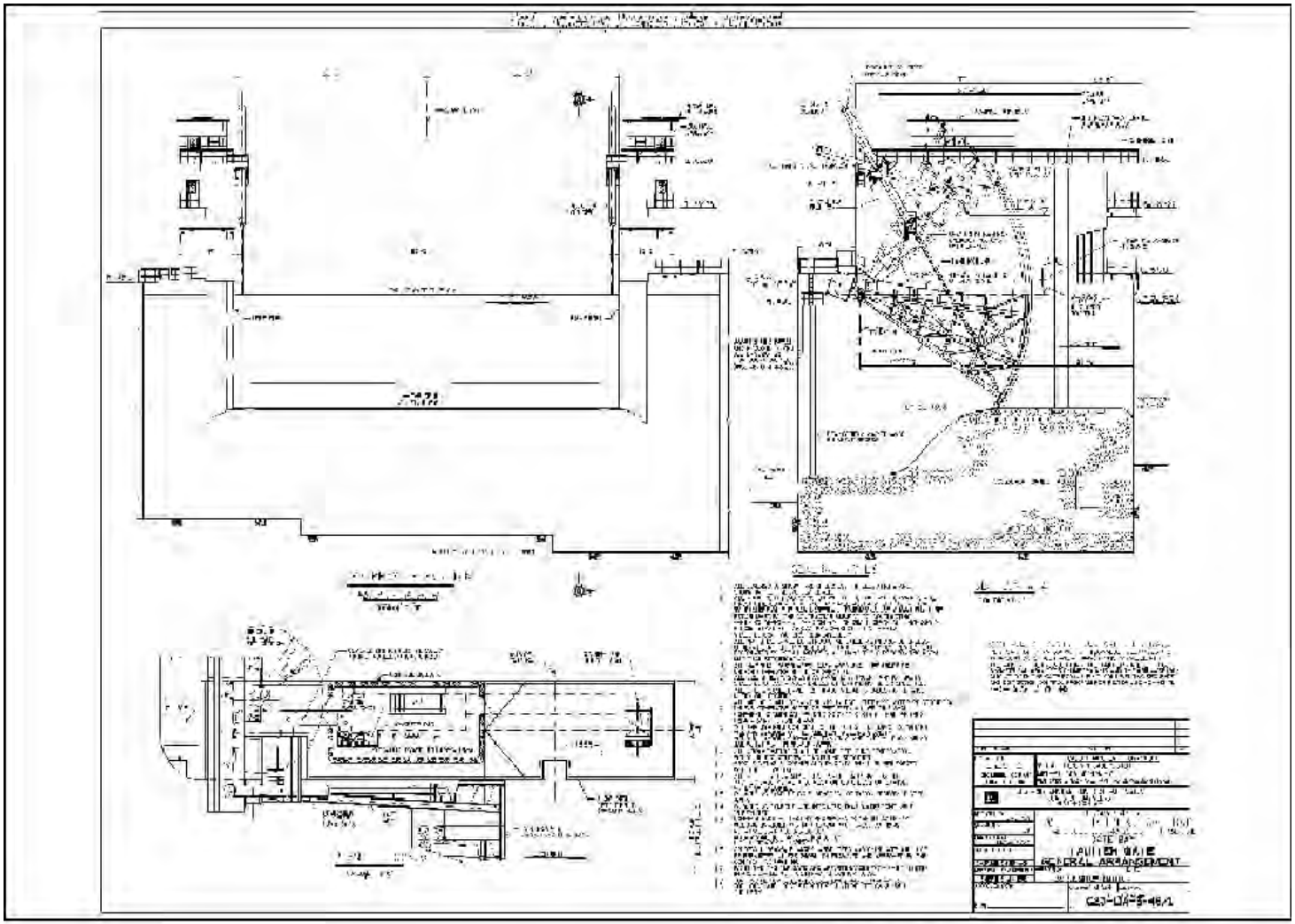


Figure 1-16. Belleville Locks and Dam. Locks. Culvert valve details showing vertical framing of valve (USACE-Huntington n.d.).

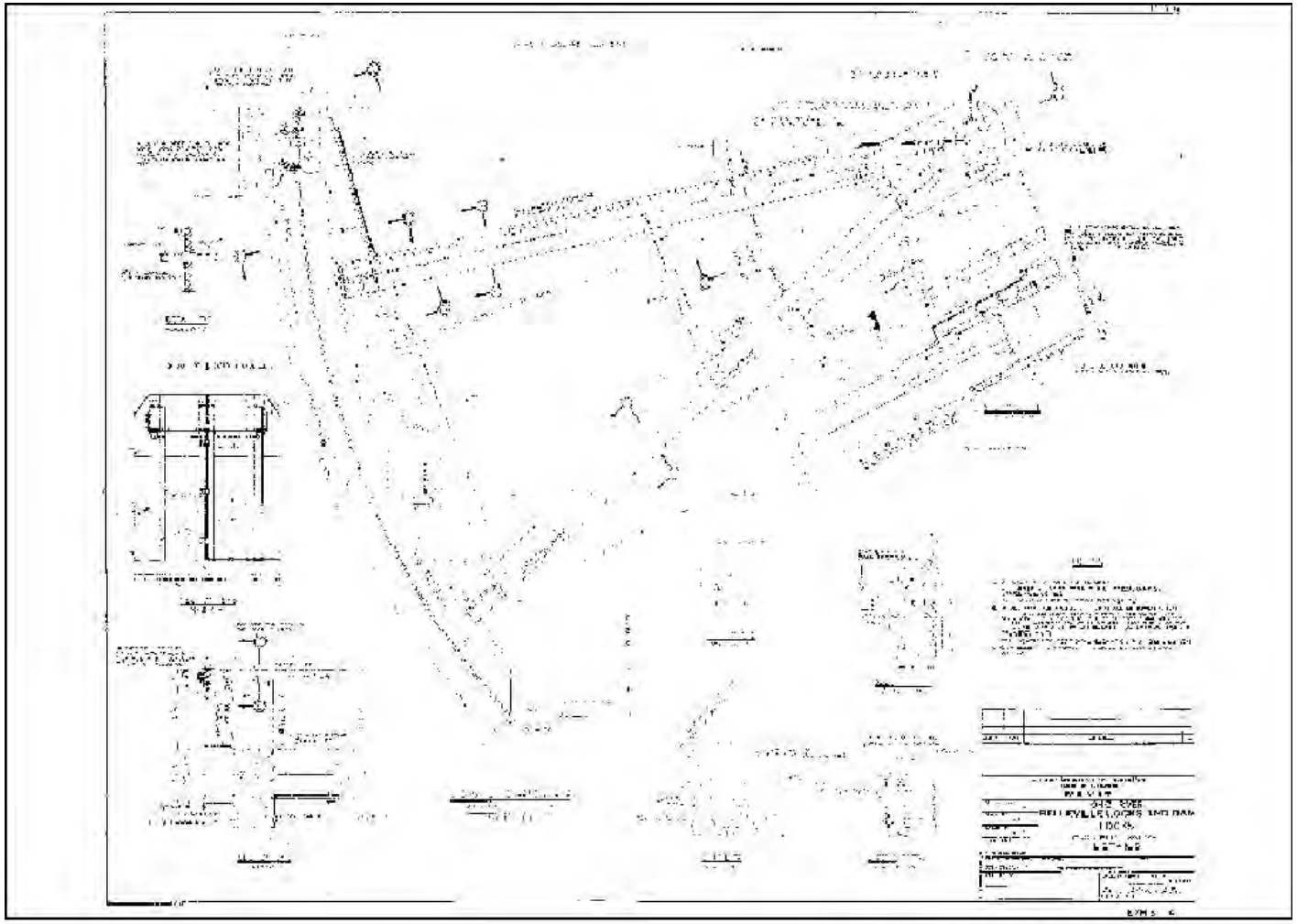
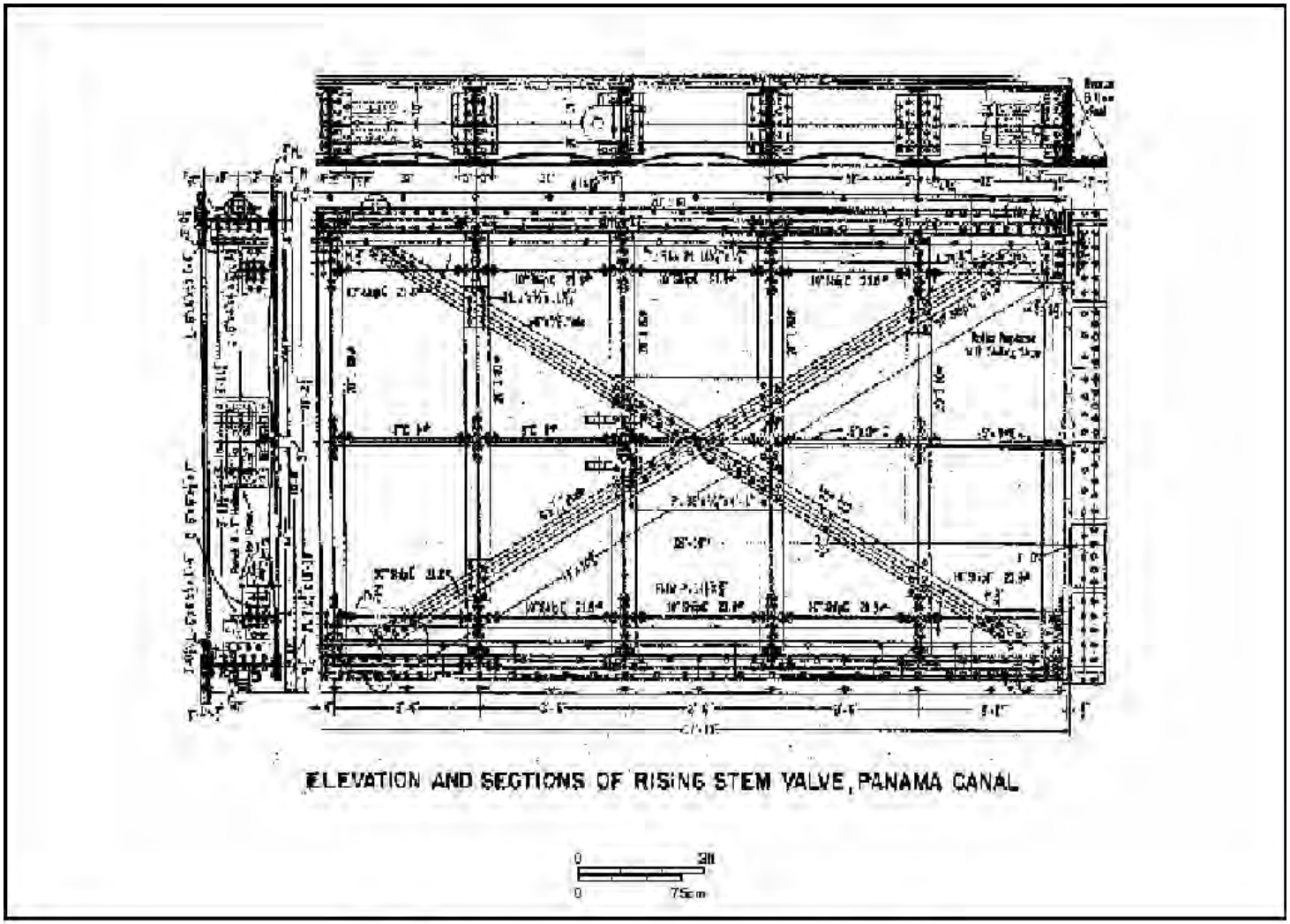


Figure 1-17. Elevation and sections of Stoney valve (Engineer School 1940).



At Davis Island, the lock was filled by seven, circular butterfly valves, 4 ½ feet in diameter, in the river wall with the same number in the downstream wall of the upper gate recess. The lock was emptied by seven valves of the same kind and size in the downstream wall of the lower gate recess. The water was discharged into a large conduit that emptied into the tail bay. Gate valves were also used (Sibert 1908:1198). A hydraulic jack connected to a rack and sector gear operated the wall valves (Figure 1-18).

The valves of the subsequent early locks were placed in the river wall of the lock, those above the dam for filling the lock chamber, and those below the dam for emptying it (Figure 1-19). All were circular butterfly valves, of cast iron, 4 ½ feet in diameter (Sibert 1908:1198). A shaft extended from the valve to the top of the wall, and a small compressed air engine or "jack" operated each shaft. The 16 jacks were operated simultaneously (Anonymous 1909b:236; Figure 1-20). Butterfly valves were also employed in the St. Mary's Falls Canal lock in Michigan, and on the Monongahela River (ASCE 1930).

Deadman Island (present Dashields), one of the first of the new generation of locks on the Ohio River, employed structural steel butterfly valves operating on a horizontal axis (Plate 21). These valves operate on cast steel axles rotating on phosphor bronze removable bearings. The smaller chamber culverts uses 10 by 12 foot valves, identical to those installed in locks 6, 7 and 8 on the Monongahela River. The larger chamber uses eight foot by ten foot butterfly valves (Casey 1929:446). These valves are hydraulically operated by a cylinder, cross head and guide, connecting rod, rocker, and strut arrangement (USACE-Pittsburgh 1972a:5).

Montgomery, the second in the new generation of locks on the Ohio River, fills and empties by culverts located in all three walls. The 110 by 600 foot lock fills and empties through culverts in the land and middle wall, and the intake or outlet of water is controlled by four butterfly valves, 13 feet by 14 feet 10 inches, located one at each end wall of the lock. The smaller lock is controlled by a culvert located in the river wall with one butterfly valve, 10 feet by 12 feet, located at each end (Keelor 1935:187). The six butterfly valves are horizontally mounted and hydraulically operated by a cylinder, cross head and guide, connecting rod, rocker, and strut arrangement (USACE-Pittsburgh 1972b:5).

The original Gallipolis Locks used tainter valves for filling and emptying (see Figures 1-13 and 1-14). The complex's first periodic inspection report described features of these valves:

> The tainter valves located in the main culverts to control the water elevations in the lock chamber are framed structures. Each valve has a water-tight skin plate on the upstream side of the valve recess. It is provided with steel-on-steel bottom and wood-on-steel side seals, and with a rubber-on-steel seal at the top. The valves are operated by cables running to hydraulic hoisting machinery; the valve rotates about the center line of the trunnion bearing pins. The trunnion bearings and anchorages are located on the downstream side of the valve recesses, 2 feet above the culvert roofs (USACE-Huntington 1970:21).

Figure 1-18. Davis Island Lock and Dam. Operating machinery of valves in lock walls (reprinted by USACE-Pittsburgh 1985).

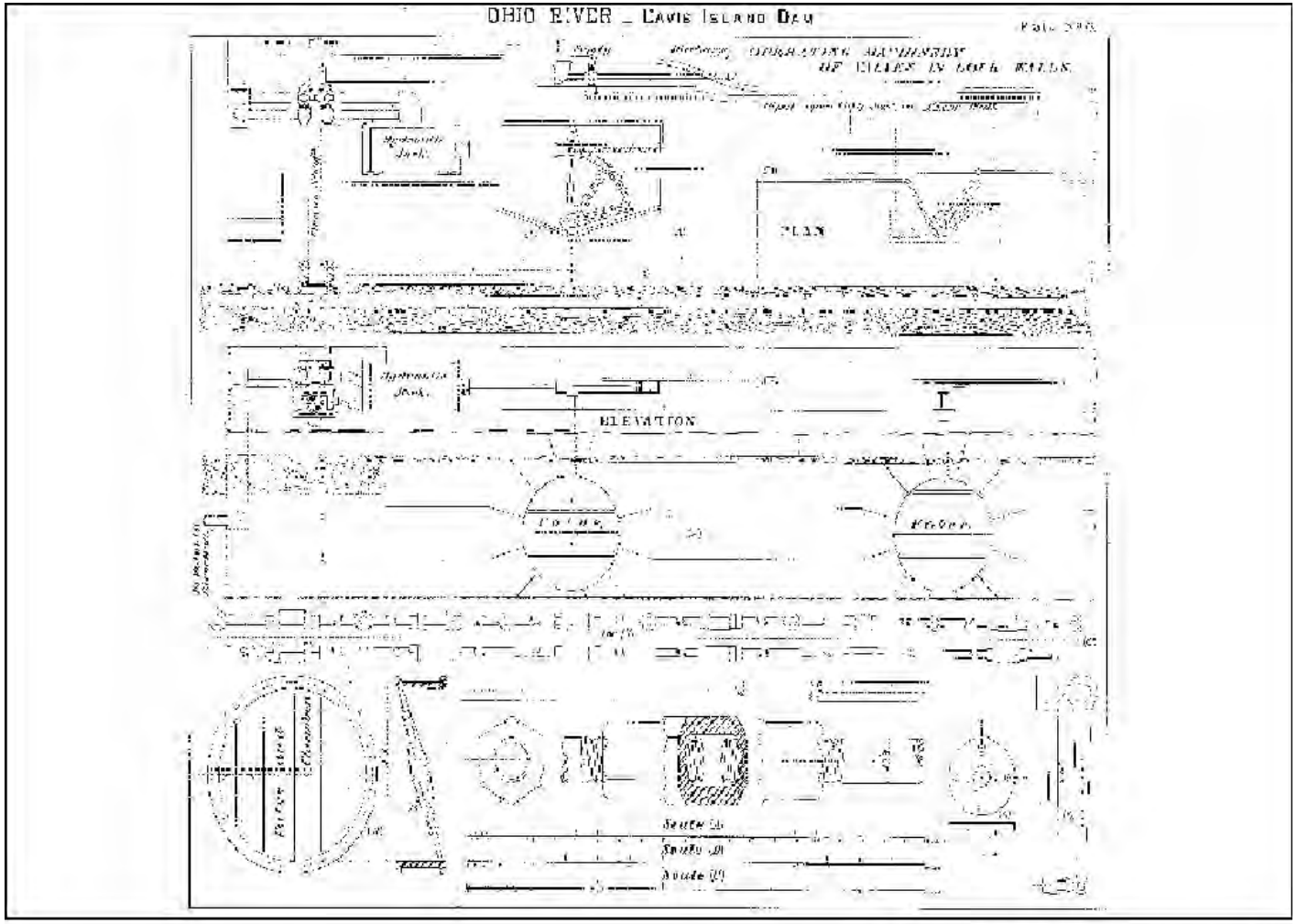


Figure 1-19. River wall valve with spring debris device used at Dam No. 6, Ohio River (U.S. Engineer Office Pittsburgh n.d.). From Cartographic Branch, National Archives.

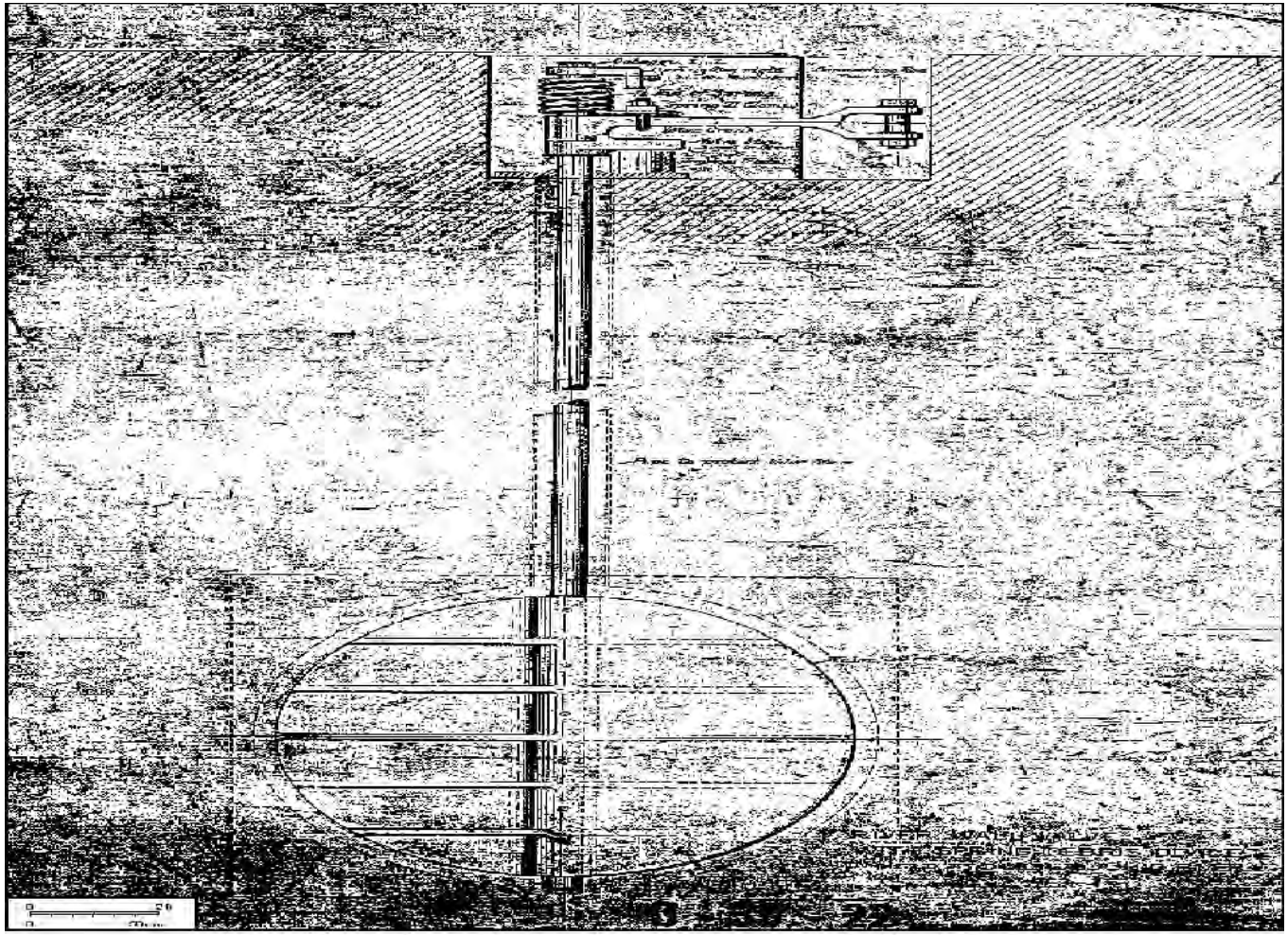
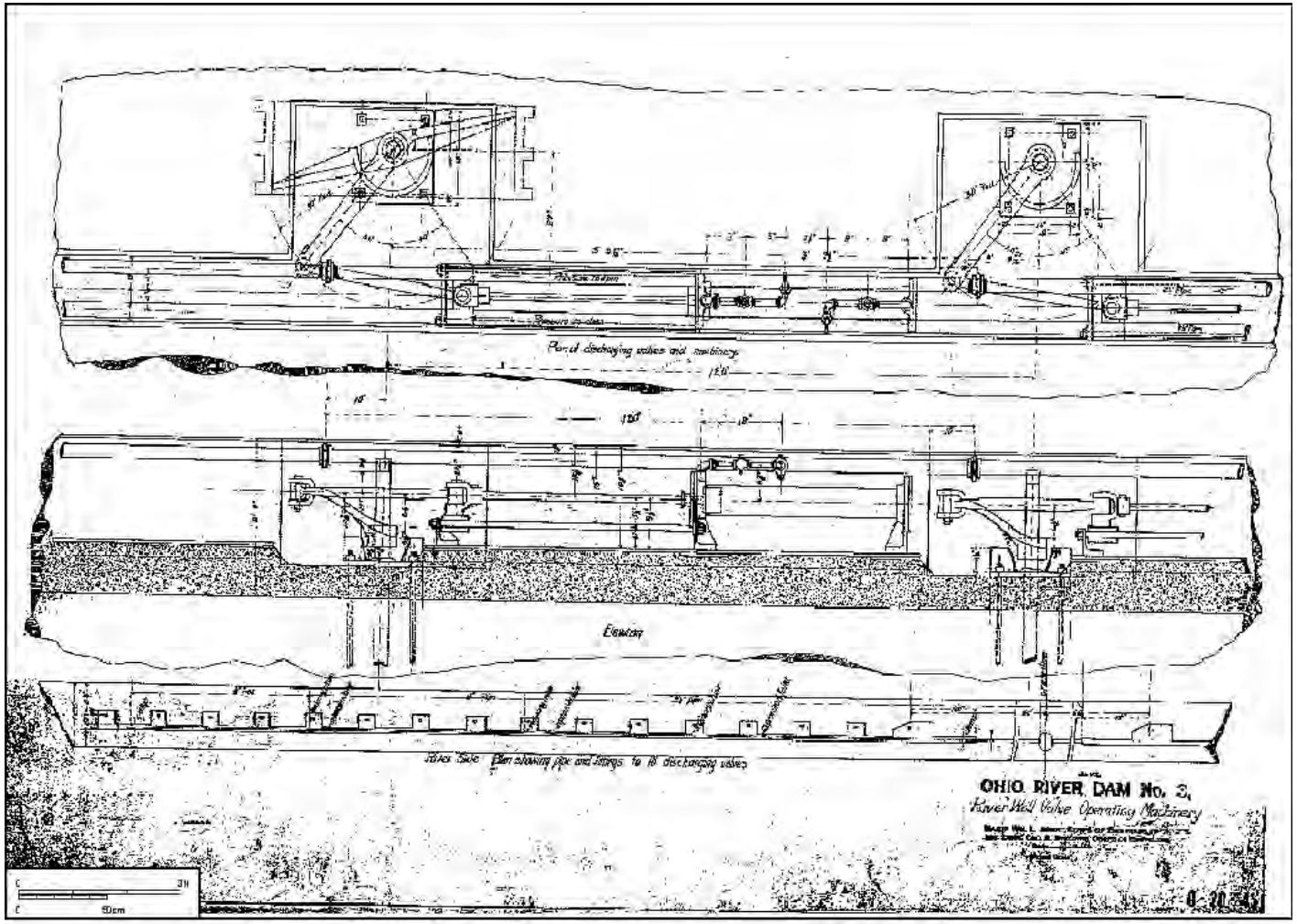


Figure 1-20. Ohio River Dam No. 3. River wall valve operating machinery (Spalding n.d.). From Cartographic Branch, National Archives.



Montgomery, the second in the new generation of locks on the Ohio River, fills and empties by culverts located in all three walls. The 110 by 600 foot lock fills and empties through culverts in the land and middle wall, and the intake or outlet of water is controlled by four butterfly valves, 13 feet by 14 feet 10 inches, located one at each end wall of the lock. The smaller lock is controlled by a culvert located in the river wall with one butterfly valve, 10 feet by 12 feet, located at each end (Keelor 1935:187). The six butterfly valves are horizontally mounted and hydraulically operated by a cylinder, cross head and guide, connecting rod, rocker, and strut arrangement (USACE-Pittsburgh 1972b:5).

The original Gallipolis Locks used tainter valves for filling and emptying (see Figures 1-13 and 1-14). The complex's first periodic inspection report described features of these valves:

> The tainter valves located in the main culverts to control the water elevations in the lock chamber are framed structures. Each valve has a water-tight skin plate on the upstream side of the valve recess. It is provided with steel-on-steel bottom and wood-on-steel side seals, and with a rubber-on-steel seal at the top. The valves are operated by cables running to hydraulic hoisting machinery; the valve rotates about the center line of the trunnion bearing pins. The trunnion bearings and anchorages are located on the downstream side of the valve recesses, 2 feet above the culvert roofs (USACE-Huntington 1970:21).

Tainter valves became the standard valve type for United States locks beginning in about 1930. Among the first locks to employ tainter valves were Lock No. 2 on the Mississippi River, completed in 1930, and the Welland Ship Canal Locks in Canada, completed in 1933. These early valves were oriented in the manner of a conventional tainter gate, with the trunnions downstream of the skin plate causing the convex surface of the skin plate to face the flow and seal along the upstream end of the valve wall (USACE-ChE 1975:1-3).

However, model tests for the Pickwick Lock on the Tennessee River pointed to a flaw in this design. During the opening period, the pressure gradient immediately downstream of the valve skin plate dropped below the top of the culvert. As a result, large volumes of air were drawn down the valve well and into the culvert. The air formed large pockets in the model culvert which restricted the flow until sufficient pressure was developed to expel the air through the ports or into the downstream bulkhead recess. Air expelled through the ports erupted at the water surface with considerable force causing disturbances that could be hazardous to small craft.

By reversing the tainter valve, placing the trunnions upstream of the skin plate with the convex surface of the skin plate facing downward and sealing against the downstream end of the valve well, air was prevented from entering the culvert at the valve recess. Reverse tainter valves became the standard on Corps of Engineer locks (USACE-ChE 1975:1-3-1-4) (See Figure 1-15).

Reverse tainter valves use one of two types of operating machinery: the strut arm and the wire rope. Strut arm machinery, such as that used at Greenup and Captain Anthony Meldahl consists of a cylinder, piston, piston rod, crosshead, crosshead guides, connecting rod, bell crank, and strut. The piston rod is connected to the crosshead which is pin connected to one end of the connecting rod. The other end of the connecting rod is pin connected to the upper arm of the bell crank and the strut is pin connected to the lower arm of the bell crank. The bell crank is connected to a trunnion which is anchored into the concrete. The bottom end of the strut is pin connected to the center of the valve.

In wire rope operating machinery, the hydraulic cylinder and piston rod is connected to a multiple wire rope single part line which passes over a multiple grooved sheave and is connected to the center of the culvert valve. The sheave is supported on anchorage supported on the concrete. The connection between the piston rod end and the wire rope is a universal joint which incorporates a sliding shoe. The sliding shoe rides on a rail which supports the piston rod and wire rope connection in a horizontal plane. The lock wall masonry is recessed to receive the embedded metal for the cylinder, the sliding shoe rail, and the multiple grooved sheave bearing plate (USACE-Huntington 1962:3-4).

A design memorandum for Belleville Locks cited some of the disadvantages of the strut arm type of machinery:

> 1) The machinery consists of many massive components carrying heavy loads.
> 2) The components are extremely difficult to install in proper alignment.
> 3) Experience at Greenup showed that misalignment of the components causes excessive wear and may entail difficult and expensive maintenance (USACE-Huntington 1962:4).

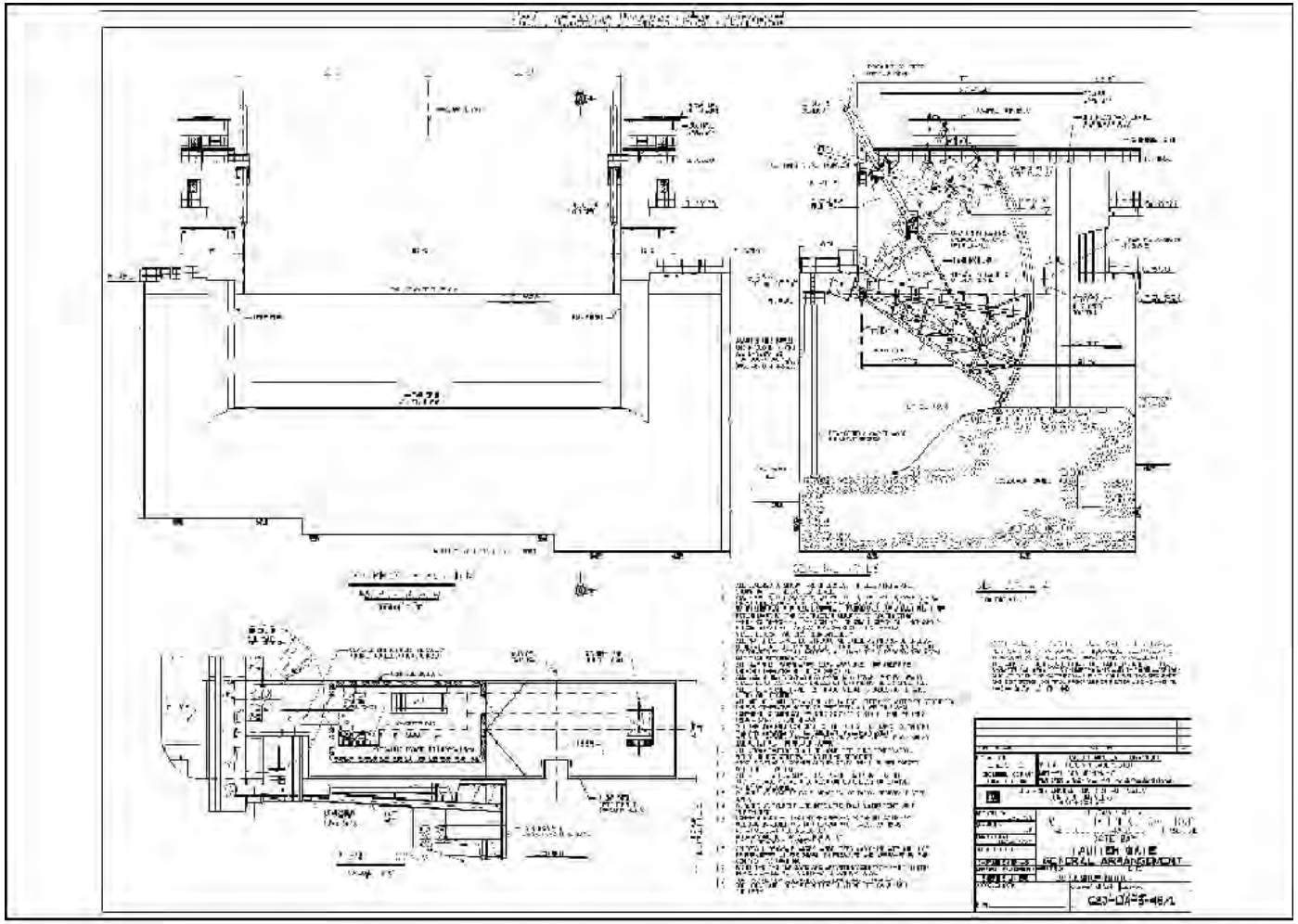
Wire rope operating machinery eliminates the disadvantages of strut arm machinery and is much simpler to fabricate and install. The estimated cost of the machinery was also substantially less. In October 1962, the Corps of Engineers estimated that the cost of wire rope machinery for one valve at $233,000, while the cost of strut arm and bell crank machinery was estimated at $314,000 (USACE-Huntington 1962:10-11). Wire rope operated tainter valves were first successfully used at Gallipolis Lock with negligible wear on the corrosion resistant ropes. This system was subsequently installed at Racine, Willow Island, and R.C. Byrd locks on the Ohio River and Winfield Lock on the Kanawha River (McCoy 2000).

The Meldahl locks employ a typical modern tainter valve installation. All of the valves at the Meldahl locks are identical and have a radius of 26 feet. The valves are larger but similar in design to those used at Lock No. 19 of the Mississippi River. The construction of a typical tainter valve is described in the first periodic maintenance report for Meldahl:

> They are made of welded construction with rolled beams of structural steel, plate material of low alloy steel and the bottom seal edge of corrosion resistant plate. The valve blade is horizontally framed with skin plating on the downstream face. The bottom shape of the valve was designed to provide a narrow bottom edge to improve underflow characteristics and eliminate any tendency of the valve to vibrate. The water load is carried to the trunnion bearings through end frames (USACE-Huntington 1969:5).

The valves have a radius of 26 feet from the center of the trunnion to the inside face of the skin plate. Horizontally framed valves and trunnion mechanism for hoist were used at Greenup and Meldahl locks in the Huntington District. These valves have required more maintenance than the wire rope and vertically framed valve arrangement (McCoy 2000; Figure 1-21).

Figure 1-21. Winfield Dam. Gate bay showing non-submergible tainter gate and hydraulic cylinder hoists (USACE-Huntington n.d.).



Dams

The original numbered dams on the Ohio River Navigation System consisted of a navigable pass section with a fixed weir and a series of movable weirs used to regulate pool level. By the mid-1930s, the Ohio River navigation system included 48 movable and two fixed dams. The navigable passes of the movable dams ranged in width from 600 to 1,248 feet (USACE-ChE 1958:924).

Movable Dams

Several requirements governed the design of each movable dam on the Ohio River. Captain P.S. Bond of the U.S. Army Corps of Engineers listed these requirements in an article on the improvement of the Ohio River:

1) Its lift should be as great as practicable, since high lifts would decrease the first cost of the system because of the small number of dams required.
2) It should be capable of being quickly and easily raised in a considerable depth of water without a chance of failure.
3) It should be capable of being very rapidly lowered without chance of failure.
4) The entire dam should be down when water is released.
5) The parts should be very strong, so that they will not readily be injured by boats, ice, etc.
6) The leakage through and under the dam when up should be less than the least low water discharge of the stream.
7) The foundations should not be liable for injury due to the sudden opening of the dam.
8) When the dam is down, there should be absolutely no obstruction to navigation.
9) The capacity of the weir should be so great that the pass can be raised in a considerable depth of water.
10) It should be possible to pass small freshets, drifts and ice without lowering the entire dam (Bond 1908:713).

Navigable Pass

All of the original movable dams on the Ohio River used Chanoine wickets (see Figure 1-18) for the navigable pass. Francis H. Oxx described the reasons for these wickets' use in an article in *Military Engineer*:

> The Chanoine wicket dam has been chosen because on a river having the characteristics of the Ohio, it is desirable to provide slackwater in times of low water, to have the pass available for open-river navigation during high-water periods, and to eliminate obstruction to the river when floods occur (Oxx 1935:51).

The total length of the movable sections of the dam was such that with all the dam down, the velocity over the pass sill would not exceed four miles per hour. The length of the regulating weir was designed to be sufficient to pass, with all gates lowered, the ordinary summer fluctuations of flow without change in upper pool level. The length also had to permit discharging enough water to maintain the lower pool immediately below the dam at a level within six feet of the upper pool. When the width of the natural channel exceeded that needed for the movable portions of the dam, a fixed section was included. Typically of masonry ogee construction with a crest at or slightly

above upper pool level, the fixed section ranged in length between 57 and 890 feet on the Ohio River (Engineer School 1940:316-317).

As J.W. Arras wrote in an article published in the *Proceedings of the Engineers Society of Western Pennsylvania*, engineers modified the Chanoine wicket pass as a result of testing at Davis Island dam:

> Formerly they were constructed of a heavy wooden framework with interior panels of 2 in. planks, while the more recent wickets are built of the same thickness throughout their width, either of three or of four timbers running longitudinally. The prop was originally designed as a round shaft for the upper half of its length, while the lower half was much heavier and flattened vertically, but retaining the thickness of shaft above, resembling in appearance the old style paddle-shaped oar. Just what was the purpose of this peculiar design is not clear, since a uniform distribution of metal, practically in the form of a round shaft recently experimented with, apparently affords a much more rigid and desirable prop in every way. Except to build them materially heavier, and very recently to slightly alter their internal bracing, no changes of consequence have been made in the construction of the horses.
>
> The most valuable improvement is probably that made in the hurter, introduced in several dams, and which has been sufficiently tested to indicate its worth over the old Pasqueau hurter in use at Davis island dam. That hurter was designed to be set on the top of the dam foundation, and provided a very narrow extension for carrying the prop after its return to the main track or runway. Consequently, there was continual trouble in retaining the prop on the hurter, and when off, not only required considerable time for replacing, but almost invariably resulted in more or less injury to the floor of the structure. The new hurter has practically overcome all of these objections. Its downstream half is trough shaped, gradually winding from the fixed step or main prop support to a width of two feet at the lower end. When set, the top edges of its guard walls are in the plane of the dam floor. This renders it almost impossible for the prop to leave the hurter altogether and, in the event of such an occurrence, makes its return much easier (Arras 1908:249-250).

In his article on Ohio River movable dams, Francis H. Oxx described the design of the Chanoine pass (Plate 1-22; Figures 1-22 and 1-23):

> Each wicket in the navigable pass is built of oak timbers and is about 10 inches thick and 3 feet 8 inches wide, with a length dependent on the lift at the dam. Between each two wickets, which are independent of each other in action, there is an open space of 4 inches. This space is closed when necessary by placing a small square timber, called a needle, cornerwise between the wickets. Needles are usually from 4 to 6 inches square in cross section. Running the full length of the pass, at most of the dams, is a 14-inch by 14-inch oak sill, protected by steel plates, which is set on and bolted to the concrete foundation of the dam. The sill acts to brace against and align the butts of the wickets when they are in an upright position....

Plate 1-22. View from abutment showing Chanoine pass wickets, Dam #41. February 1938. From the files of the Louisville District, U.S. Army Corps of Engineers.

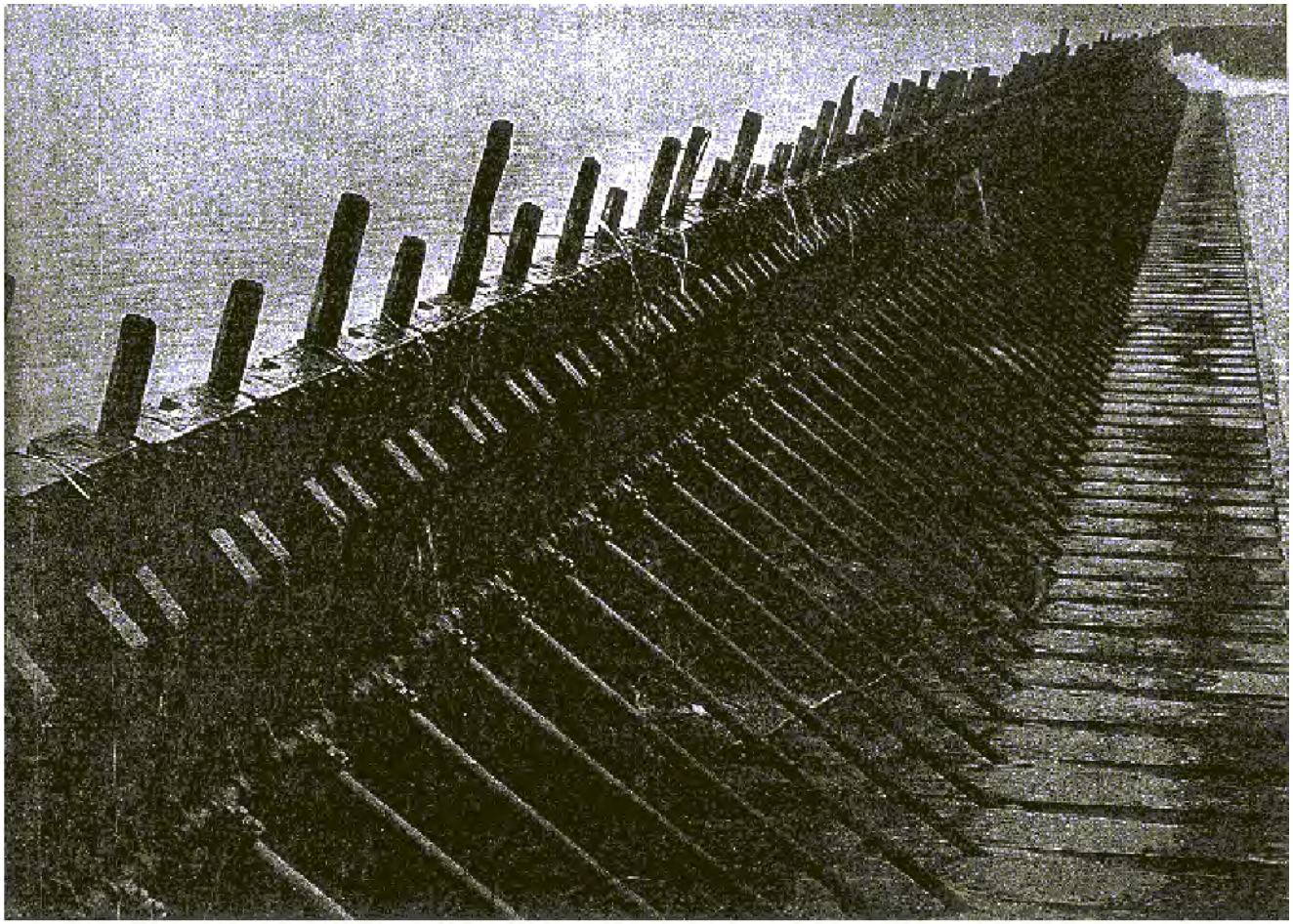


Plate 1-23. Locks and Dam No. 41. Maneuverboat lowering Chanoine pass wickets. January 30, 1940 (U.S. Engineer Office, Louisville District 1940). From Still Photographs Branch, National Archives.

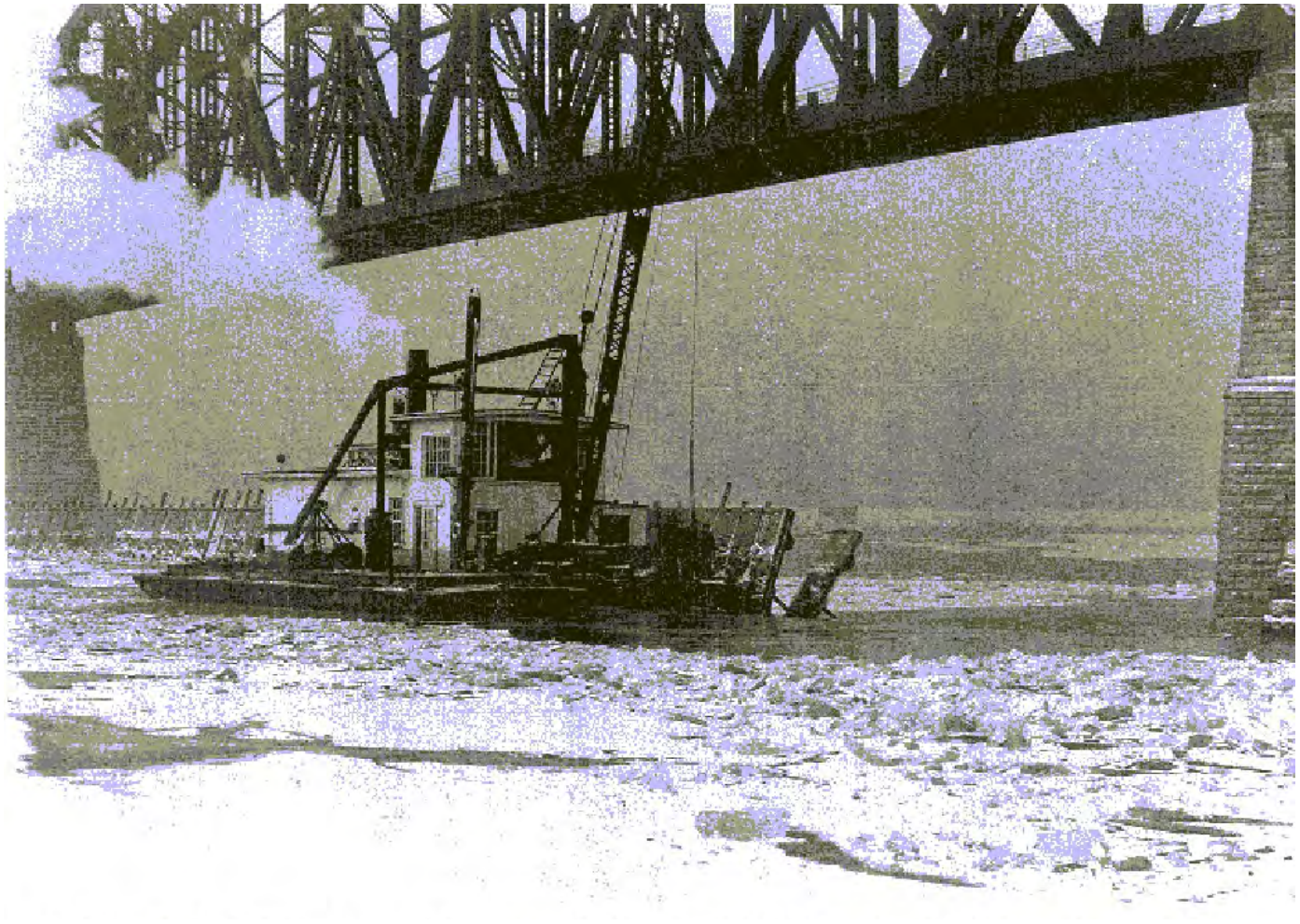


Figure 1-22. Typical section. Chanoine wicket. From files of Louisville District, U.S. Army Corps of Engineers.

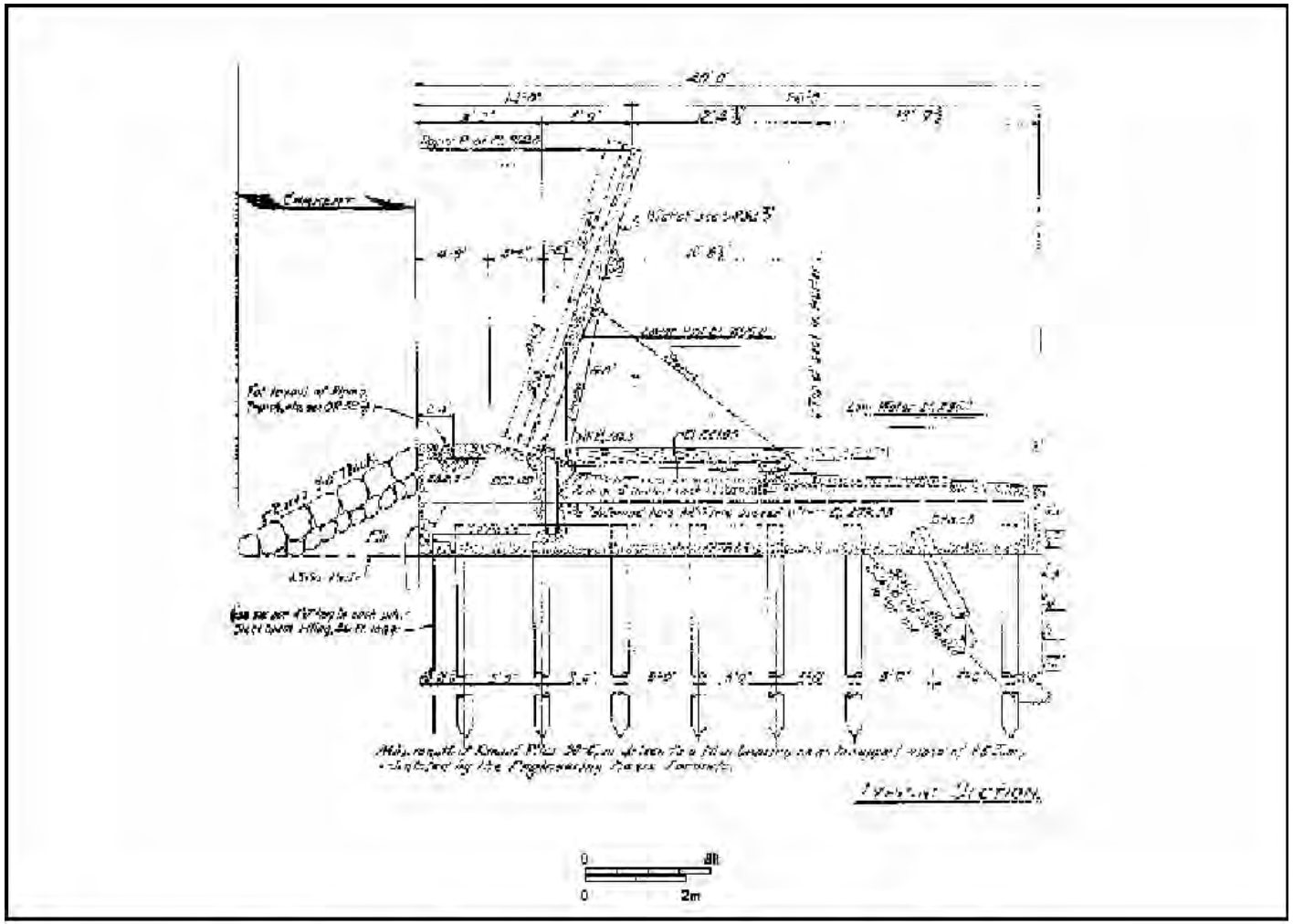
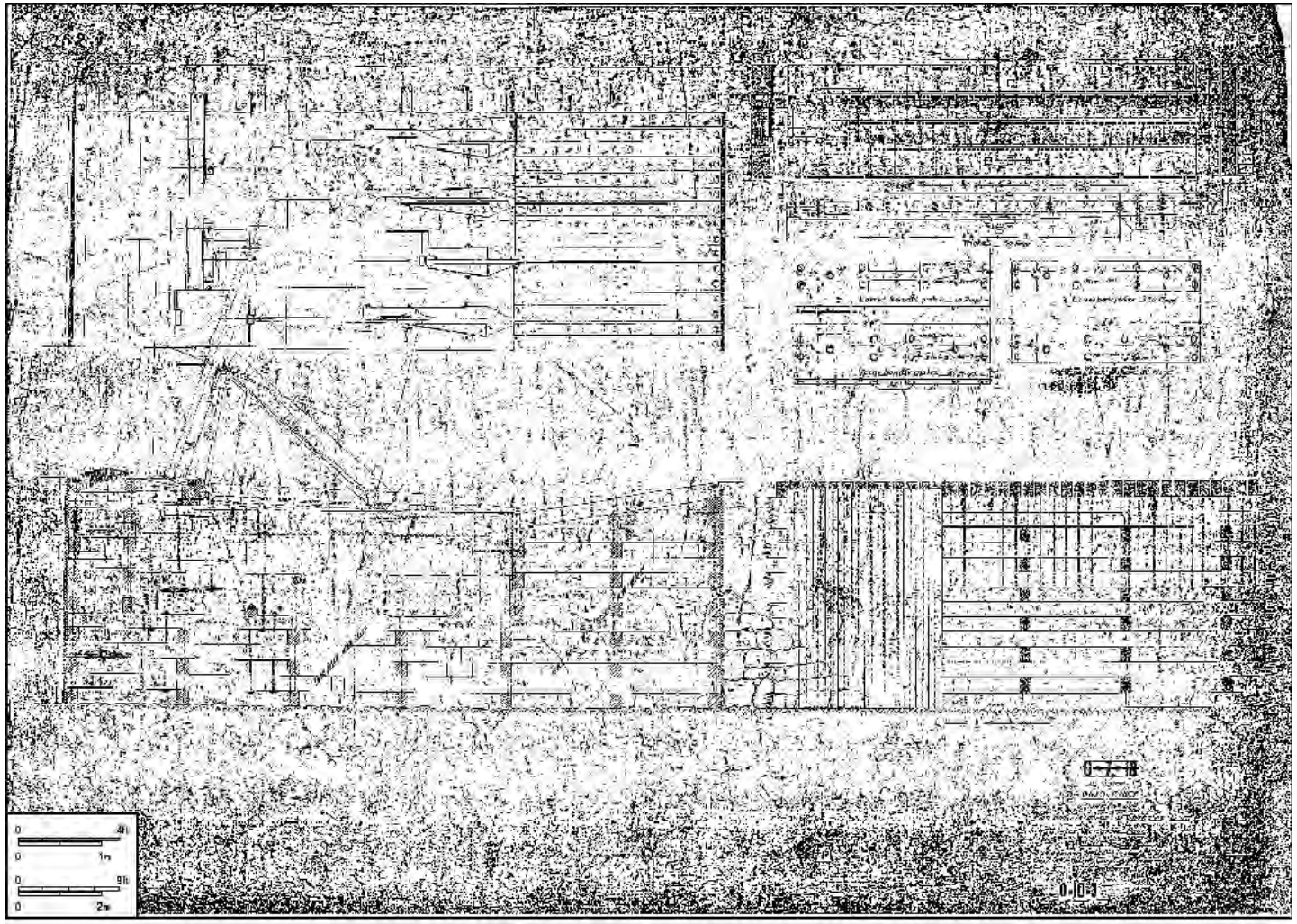


Figure 1-23. Ohio River Dam No. 2. Plan and elevation of Chanoine dam for navigable pass (Pittsburgh District n.d.). From Cartographic Branch, National Archives.



> The wicket itself is...a heavy timber shutter pivoted to a link-like steel frame called a horse, which, in turn, is pivoted to the foundation and which restrains the wicket from lateral displacement. The horse is attached to the wicket below its transverse axial line by means of a suitable horizontal shaft and the necessary bearing, or wicket, boxes. The other end of the horse is connected to the concrete base just downstream from the sill, through a second horizontal shaft and the horse boxes. Attached to the upper shaft of the horse and free to rotate on it is a long heavy forging called a prop about 5 inches in diameter and may be of any length between about 14 and about 18 feet, depending upon the height of the wicket it supports. Its lower end rides in grooves in a cast iron hurter which is imbedded in the foundation....The hurter has two grooves, one to guide the lower end of the prop when it is moved forward and another to guide it when it is moved backward. The first of these grooves contains a shoulder against which the prop rests when the wicket is in an upright position (Oxx 1935:52).

The wickets were raised and lowered by personnel aboard a maneuver boat (Plate 1-23). These boats, which measured about 60 by 22 by four feet, were equipped with fenders for holding the boat off the wickets. Close to the forward end of the boat two spuds were installed, each of which was long enough so that it would bear against a wicket below the hinged point of the wicket when the boat lies along the upstream face of the dam. The spuds were designed to prevent the wickets from tipping over.

Each maneuver boat was provided with a stern capstan engine, a three-drum hoisting engine, an electric light plant, and a compressor. Sibert described the process of raising and lowering the wickets:

> The wickets are raised by a wire line leading from the hoisting engine around a sheave held at the end of a structural-steel beam, which projects from the bow of the boat. The wire line is fastened to an iron hook at the end of a long pole, which is used to guide the hook until it engages in the handle of the wicket. After the prop is seated in the hurter, the wicket is assisted in seating itself against the sill by pike poles in the hands of the dam-tenders. In lowering the wickets, the upper ends are pulled slightly up stream, until the prop unseats itself, when the wicket is allowed to fall upon the foundation behind the sill (Sibert 1908:1209-1210).

A good crew could raise the navigable pass section of the dam in about three and one-half hours (Johnson 1975:230).

As originally planned, the lift of the Ohio River dams would not exceed eight feet, which required the use of wickets about 16 ft. long. Later, 18-ft. wickets were used, and one of the last dams to be constructed with wickets had 20-ft. wickets with a lift of 12 ft. (Kutz 1930:433).

In addition to the navigable pass wickets, each of the movable dams included one or more regulating weirs. Thirty-four of the dams had Chanoine weirs similar to the dams in the passes except for higher sills and shorter wickets. Thirteen of the dams were equipped with Bebout weirs, and one, with a weir of the Boulé type. In addition to the wicket weirs, all dams except two contained at least one beartrap for the rapid lowering of the pool in the event of a quick but

temporary rise and for the passage of floating ice and drift (Oxx 1935:51-52).[2]

The function of the beartraps and other weirs was to regulate the pool levels within certain limits without having to resort to lowering of the wickets in the navigable pass. Beartrap weirs were structures of iron, steel and wood in the form of two leaves, hinged at their outer ends. The lower leaf of the bear trap is a hollow structure like a pontoon, into which air can be forced to increase its buoyancy by displacing the water. By the effect of this buoyancy and the pressure due to hydraulic head caused by raising the wickets in the navigable pass, the lower leaf rises into position, carrying on its upper surface one edge of the upper leaf. When the beartrap is up, it forms an A-like structure supposed to bear some resemblance to the deadfall used in trapping bears. Beartraps were usually two in number and were operated independently of each other (Anonymous 1923:51).

In Dams No. 13, 21, 22, 23, 24, 25, 27, 30, 39, 43, 45, and 48, a portion of each dam was furnished with an automatic wicket. This wicket was designed by Guy B. Bebout, assistant engineer in the Army Corps of Engineers Wheeling District, and bore his name. It was used as a substitute for a Chanoine wicket or weir, or in the case of Dam 21, as a substitute for a bear trap (Anonymous 1923:52).

A-Frame weirs

The A-Frame weir was used only at Dam No. 6 (Figure 1-24). This 120-foot weir was developed by Benjamin Franklin Thomas, a civilian engineer, based on extensive experiments on the Big Sandy River. His design represented an effort to make the trestles of service bridges function as a dam, thereby eliminating the need for wickets. Each metal trestle, instead of supporting a walkway from which Chanoine wickets were raised, took the structural form of the letter “A”. The upstream leg of the A was so wide that it touched the next when in raised position, forming a solid surface which could serve as a dam. The installation at Dam No. 6 did not work well, becoming covered with sand and gravel shortly after installation. The A-Frame system was adopted on the Cumberland River and served successfully on that waterway until replaced by modern structures in the 1950s (Johnson 1985:115).

Beartrap weirs

Josiah White of Philadelphia invented the beartrap gate for use on the Lehigh Navigation. The first beartrap was completed in 1819, and a dozen more were installed the following year (WVU n.d.:I:26).

Beartraps were used at Ohio River dams as automatic weirs for the regulation of the pool levels and as a drift pass (Sibert 1908:1206; Figure 1-25). Beartrap weirs were constructed of iron, steel, wood and concrete. Each trap was built in two leaves, hinged at their lower edges. The lower leaf (Plate 1-24) is a hollow member built entirely of steel plates and beams a containing on the under surface a series of compartments averaging three by six feet in size. Compressed air could be pumped into the compartments to force out the water if it was desired to increase the buoyancy of the leaf. The upper leaf was constructed of 8 by 10 inch oak timbers, reinforced with steel beams (Plate 1-25). The lower leaf was equipped at its upstream edge with rollers to
decrease the sliding friction between the leaves. In a raised position, the leaves form an inverted V with the upper leaf resting on the top edge of the lower leaf. The bear traps were generally

[2] The movable dams that lacked beartraps were Dam #21 and Dam #48.

installed in pairs at each dam. The traps were installed between 12 to 14 foot wide and 100 foot long concrete piers. Old bear traps varied in size between 50 and 120 feet, while newer bear traps were 91 feet in length. The maximum clear opening of the newer bear trap was about 15 feet (Kutz 1930:435).

Operation of the beartrap was made possible by apparatus which permitted the hydrostatic pressure on the under surface of the leaves to be changed. To lower the trap, a filling valve was closed and an emptying valve opened, discharging water from beneath the leaves into the lower pool. The leaves fell gradually as the upward water pressure was diminished. When the crest had been lowered, the filling valve was reopened. The operation of raising the trap was the reverse of lowering (Oxx 1935:53-54).

Except for limited trouble caused by sediment deposits under the beartrap leaves and in the filling and emptying culverts, the operation of the modern beartraps proved satisfactory and dependable. Sediment deposits could be minimized by proper arrangement of the culverts and valves to permit flushing of deposits.

The first Ohio River beartraps, installed at Davis Island in 1889 were made of wood and were 52 feet long.[3] In about 1905, the original beartrap was replaced by a new beartrap with leaves heavily bound with steel. William L. Sibert described the next bear traps to be installed on the Ohio, those of Dam No. 6:

> ….two beartraps were installed, each being 120 ft. long. The principal members were steel filled in with wood. The leaves were proportioned on the basis of 100 lifting force to 80 downward. In order to assist the raising of the gates, arrangements were made for increasing the buoyancy by air forced to the under side of the lower leaves. The air was intended to be pocketed between the ribs of the girders. This proved to be of little value, because the air could not be retained where it was needed (Sibert 1908:1206).

During the twentieth century, beartrap technology evolved. Steel was substituted for wood, and the lower leaf was modified in design. In later beartraps, the leaf was built as a flat steel tank which was filled with air to give it buoyancy (Bell 1923:405).

Wicket regulating weirs functioned as supplements to the beartraps. The wicket weir was less suitable for certain purposes because of its slow operation, and more suitable for others because of its greater capacity (Engineer School 1940:29).

[3] The installation of the beartrap weirs at Davis Island followed the 1886 installation of dual, sixty foot wide beartraps on the Kentucky River at Beattyville, Kentucky (see Johnson and Parrish 1999:101).

Plate 1-24. Dam No. 36 Bear Traps. Lower leaf showing hinge. November 1, 1922. From the files of the Louisville District, U.S. Army Corps of Engineers.

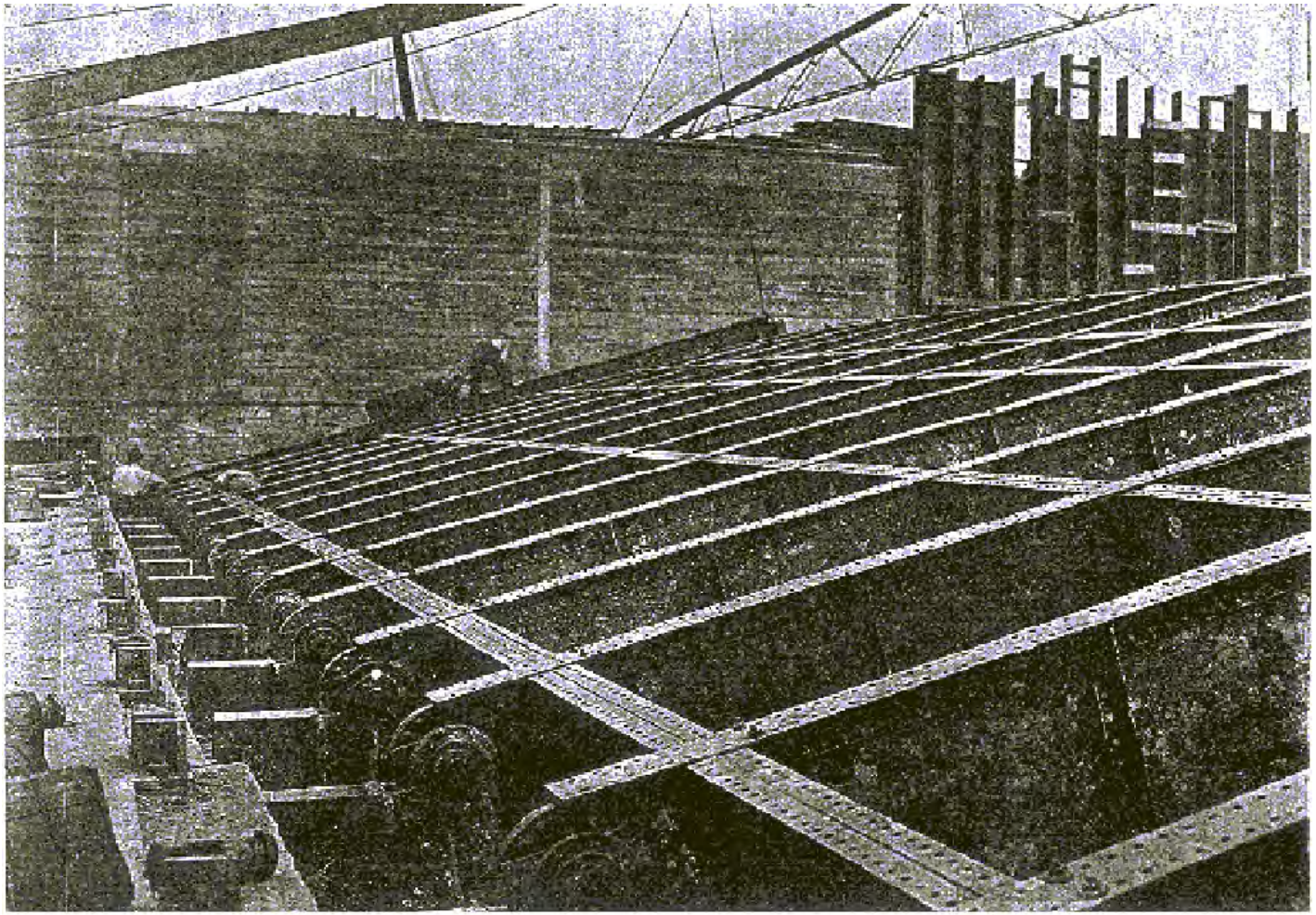


Plate 1-25. Bear Trap No. 1, Ohio River Dam #47. October 24, 1927. From the files of the Louisville District, U.S. Army Corps of Engineers.

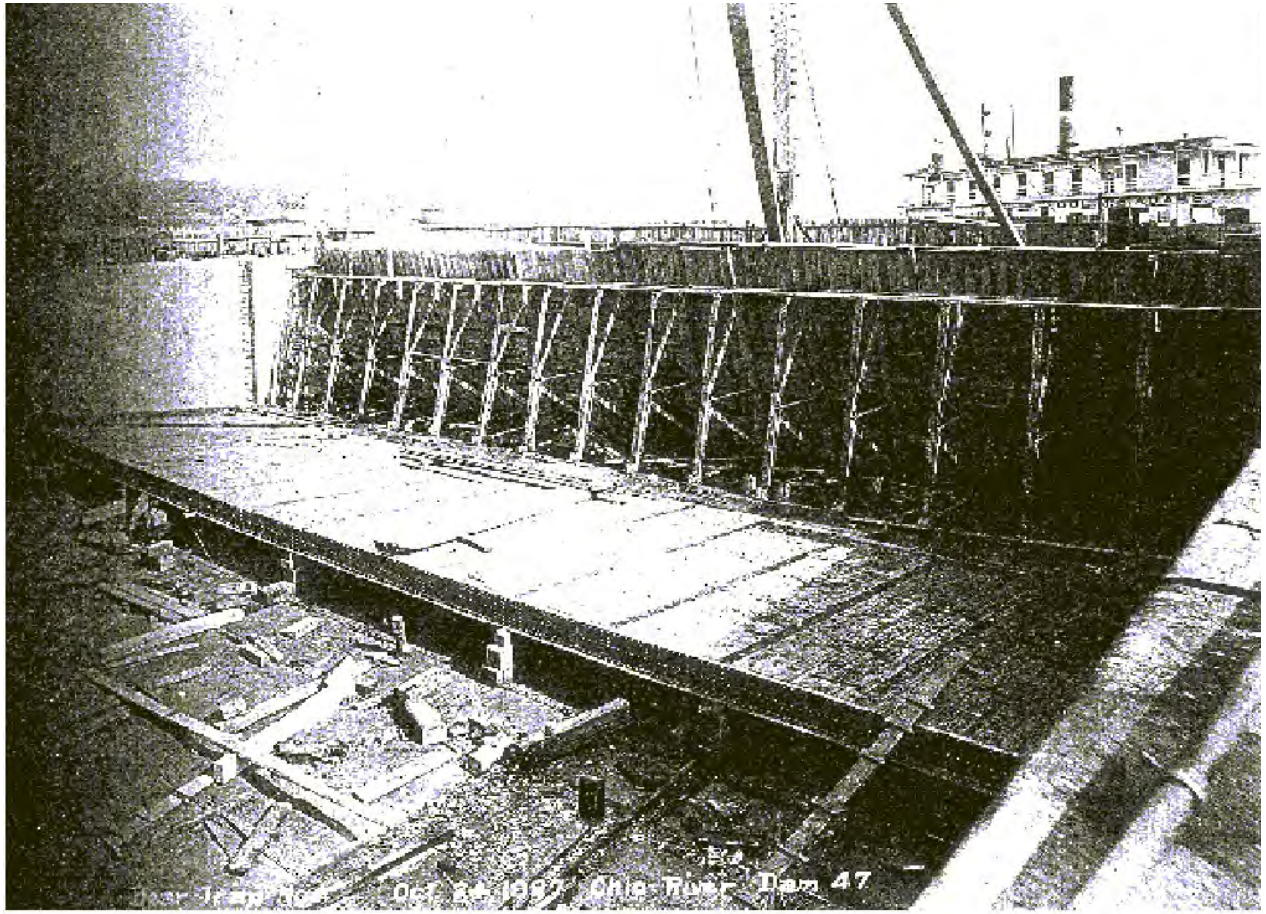


Figure 1-24. Ohio River. Movable Dam No. 6. Details of A-Frame dam and escape bar (Bowman 1899). From Cartographic Branch, National Archives.

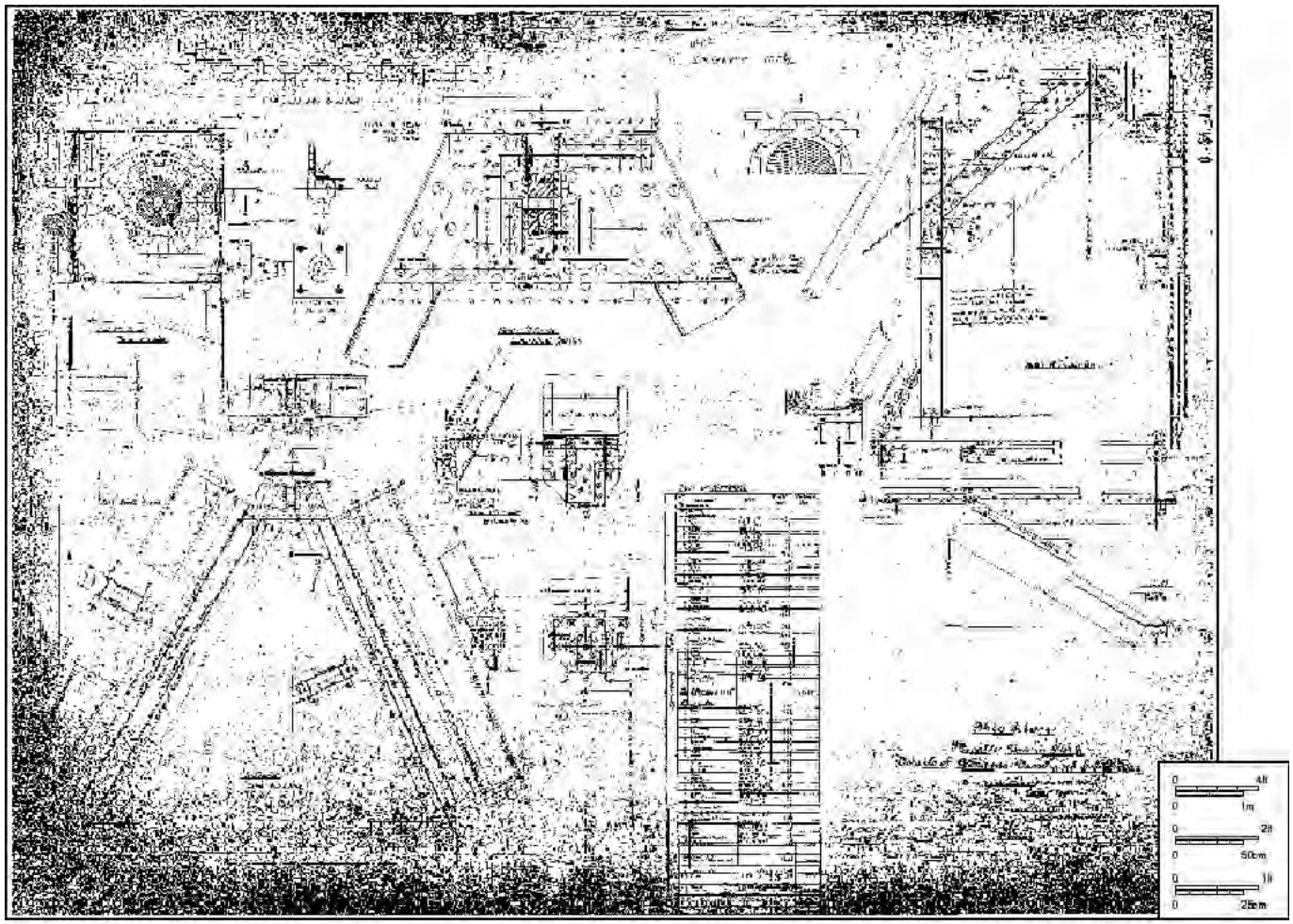
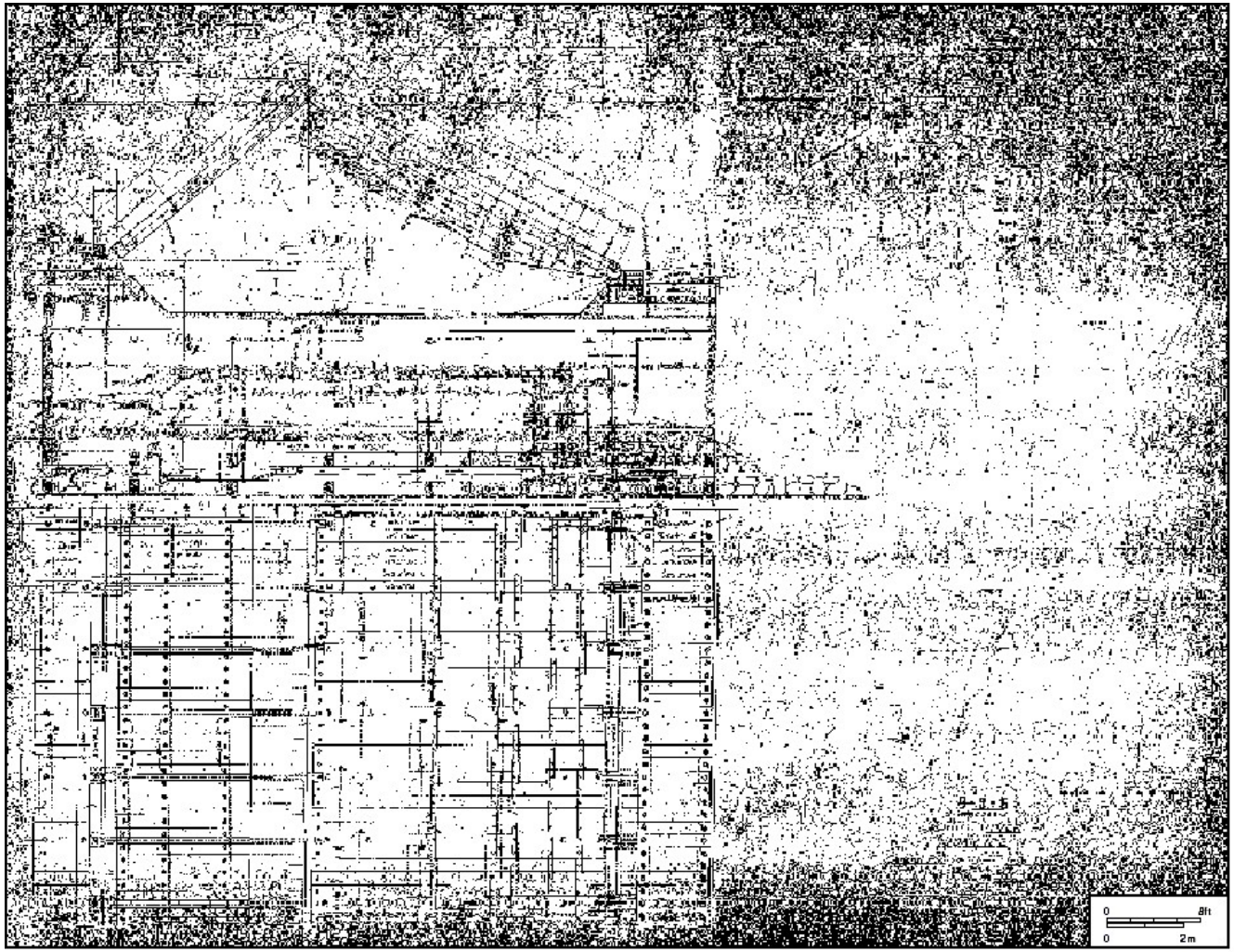


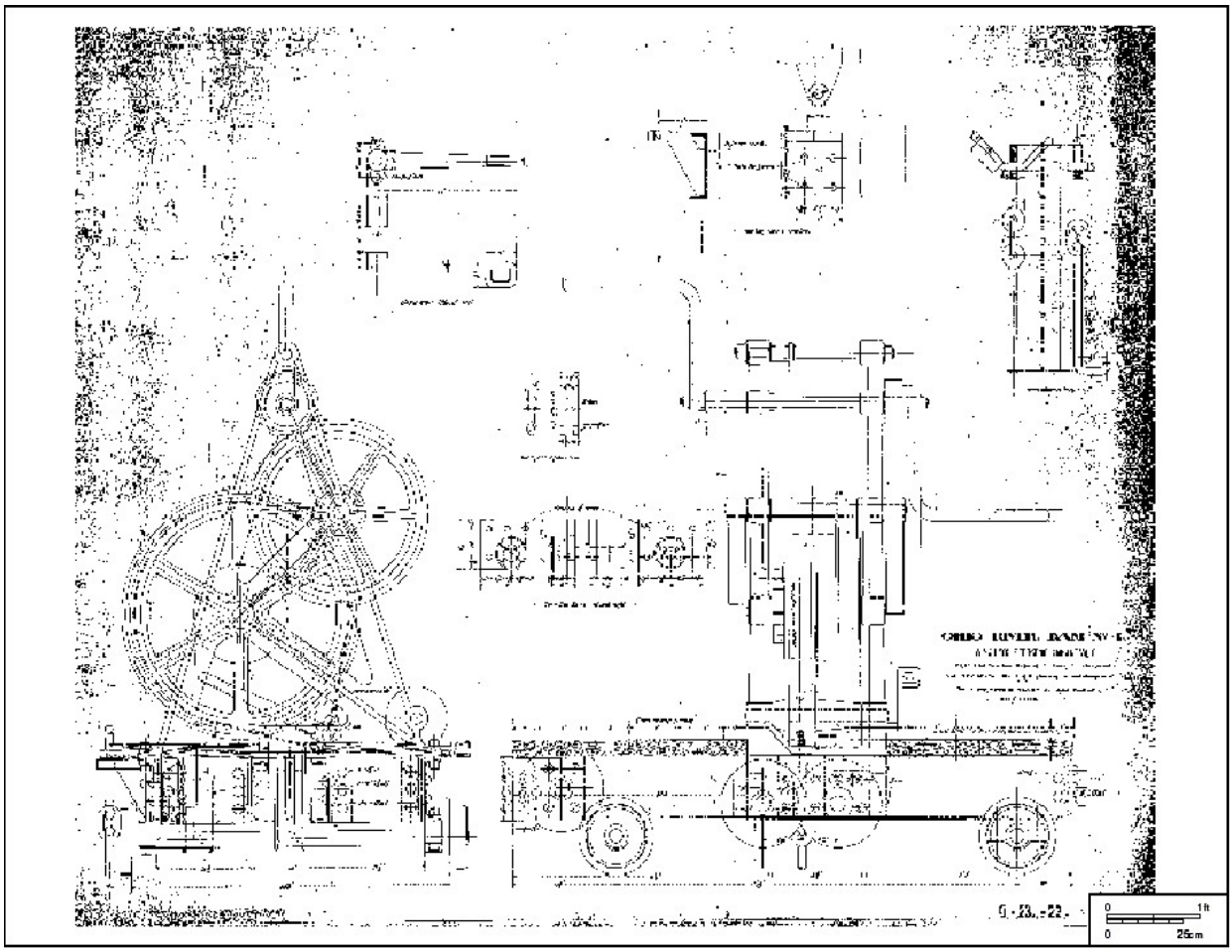
Figure 1-25. Ohio River Dam No. 2. General plan of bear trap dam (U.S. Engineer Office Pittsburgh 1903). From Cartographic Branch, National Archives.



Chanoine weirs

The Chanoine weirs had sills placed somewhat higher than the Chanoine pass to allow easier operation. These weirs were used in conjunction with the beartraps to pass moderate rises exceeding the capacity of the beartraps. The length and number of regulating weirs varied with location (Bond 1908:715).

Figure 1-26. Ohio River Dam No. 4. Winch for operating Chanoine weir (Cutting n.d.). From Cartographic Branch, National Archives.



In the upper river, regulating weirs were small-scale replicas of the Chanoine dam. The earliest Chanoine weirs on the Ohio River were located between the beartraps and the abutments of all upper river dams except No. 6. Rather than being raised by maneuver boats, as were the passes, the wickets were raised by a winch that ran on a structural steel service bridge on the weir foundation (Sibert 1908:1208; Figure 1-26).

Sibert described the operation of these weirs:

> The latest weir service-bridges for these dams have trestles 8 ft. apart, center to center, the trestles being arranged to rotate about their bottom axles, which turn in junction boxes anchored to the foundation….When raised, the trestles are kept

> in place by steel floor-panels, each hinged at one end to the top of a trestle, and held at the other end by pins attached to the adjoining trestle, the pins passing through holes in castings attached to the end of the floor apron. The floors form a track for the winch used to operate the wickets, and serve also as a footbridge for the dam-tenders (Sibert 1908:1209).

The Davis Island Dam was operated using a hand-operated winch, while the winches for Dams 2 and 5 were operated by compressed air (Sibert 1908:1209).

At other dams that used Chanoine wicket weirs, the weirs were equipped with tripping bars. The tripping bar was a flat piece of metal with teeth installed to move along, parallel to the sill, just under the feet of he props. It was operated by machinery located on the abutment or the nearest beartrap pier. The teeth were arranged so as to strike each prop in turn and pull it sideways, disengaging the prop from the hurter shoulder and causing the wicket to fall. The wickets were raised using the same method as the navigable pass wickets (Oxx 1935:54).

Bebout weirs

The wickets used in Bebout weirs were similar to those used in Chanoine dams (Figure 1-27). The major difference was that the supporting frames were constructed to permit the wickets to fall automatically when the rise in the river reached a specified amount. The horse consisted of two arms coupled together in the form of a hinge by a horizontal shaft. The prop was also a trussed structural steel member. The upper ends of the props and upper horse arm were coupled to each other and to the timber wicket by a second horizontal shaft free to rotate in the wicket boxes. The lower horse arm and the lower end of the prop were pivoted to the concrete foundation. As long as the head of water in the upper pool was insufficient to cause the wicket to turn on its bracing shaft, the arms of the horse remain in tension. When the head increased to an extent that the wicket is no longer held against the sill, the tension dropped to zero and the frame collapsed.

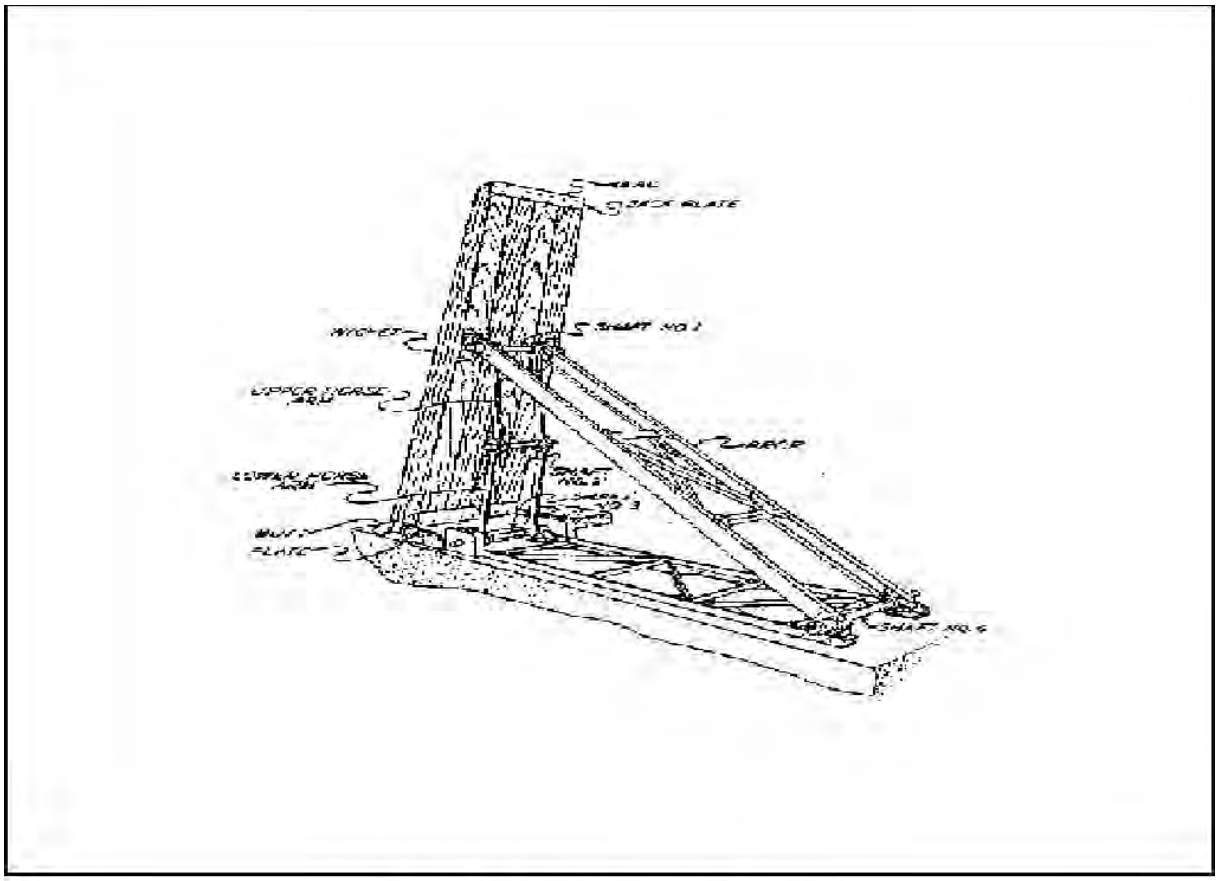
A disadvantage of the automatic tripping feature was that wickets could be tripped by the bow waves or wash of passing vessels, or by direct impact of either vessels or heavy drift (Engineer School 1940:17).

Bebout wickets were raised by the dam-tender working from a maneuver boat. The raising was accomplished by hooking the wicket line to the top of the wicket. If hand lowering of the wickets was necessary, the tops of the wickets were simply pushed downstream with a spar or pike pole (Oxx 1935:54).

A Bebout wicket weir was placed in service at Dam No. 13 in 1915. Cited advantages of this weir included:

1) It can be raised at any open river stage to the top of wickets without any serious loss of time.
2) It can be raised against any difference in pool levels, sufficient power being applied at the chains.
3) It can be lowered under all conditions of river stages and pool levels.
4) When raising the wicket, drift cannot obstruct or become entangled in the parts to such an extent as to prevent raising.
5) A boat, barge, or heavy drift striking the top of the wicket will cause the wicket to collapse without damage to the boat or dam (Black 1929:206).

Figure 1-27. The Bebout Wicket (Oxx 1935).



Boulé dam

At Dam #41, the regulating weir took the form of gate dam of the Boulé type. The sill of this dam sat 10 feet below normal pool level. The supporting members of the dam were steel trestles placed five feet apart at right angles to the crest line and hinged to the foundation (Plate 1-26). The trestles could be lowered behind the sill when not in use (Plate 1-27). The trestles were raised successively with the assistance of the maneuver boat.

The trestles were connected at their tops with chains long enough so that when one trestle was in raised vertical position, the next two or three stood at an angle with the horizontal. The men on the dam, standing on a plank at the foremost vertical trestle, hooked a line from the derrick of the maneuver boat to the first inclined trestle. The trestle was raised by the derrick to the vertical position and was then latched to the previously raised trestle by means of a forged steel frame.

The curtain of the dam was formed by placing a row of steel plates against the upstream side of the trestles. The plates, which were 10 feet high, slid vertically on the upstream faces of the trestles. They were swung into position by the maneuver boat and dropped under their own weight until the lower edges rested on the water sill. Water pressure forced the plates tightly against the trestles, allowing practically no leakage (Oxx 1935:54-55).

Operations of the Movable Dams

To minimize currents in the lock approach and to insure the maintenance of channel depth, the wickets, weirs, and beartraps ordinarily operated in a certain step by step sequence (Engineer School 1940:72).

In the Pittsburgh District, when a rise was imminent, maneuver boats were put under steam. At the beginning of a rise or when only slight regulation was necessary, the needles were removed from the navigable pass. Maneuvering of the pass wickets and operation of the regulating weirs were usually required when there was a depth of from about 9 to about 11 feet of water in the pools (Oxx 1935:58).

When a completely lowered dam was to be raised the other sections were left open and the pass wickets were raised first to minimize the head opposing their operation. Then the weir wickets, with their higher sills, were raised. With the whole wicket length raised, sufficient head was usually available for operation of the beartraps. These were then raised to make the final closure (Engineer School 1940:29).

If the rise continued, the next step was to place one or more of the beartraps in operation. The amount by which the dams were lowered depended upon both the height and rapidity of the rise. If both beartraps were completely down and the rise was continuing, preparations were made to operate the Chanoine dam. Francis Oxx described this procedure:

> In raising the dam, the wickets are first brought up and the valves are set for raising one of the beartraps. As the upper pool is built up the head normally increases sufficiently to cause the beartrap to rise. The needles are installed in the pass and the second beartrap is raised when desired….it is sometimes necessary to needle the dam as soon as the wickets are raised, in order to secure enough head to operate the beartraps (Oxx 1935:55).

When the dam was up, the weir wickets were lowered to assist in passing rises for which the capacity of the beartraps was insufficient but which were not great enough to provide the stages necessary for open navigation (Engineer School 1940:29).

One of the Chanoine wicket dams, that at Dam No. 26, located about 30 miles north of Huntington, West Virginia, failed after completion. The dam, completed in 1911, failed on August 8, 1912. A special board of inquiry appointed by the Chief of Engineers analyzed the reasons for the failure of the dam foundation.

According to eyewitnesses, the failure began when several wickets in the middle portion of the pass fell as the dam was lowered to the foundation. Immediately after the wickets on either side of these began to move downstream. The break gradually extended to the pier dividing the navigable pass from the first beartrap and almost to the lock wall at the other end. One hundred

Plate 1-26. Dam No. 41. Sections 2 and 3 of new Boulé dam. Trestles raised and first row of wickets in place (Office of the Chief of Engineers 1908). From Still Photographs Branch, National Archives.

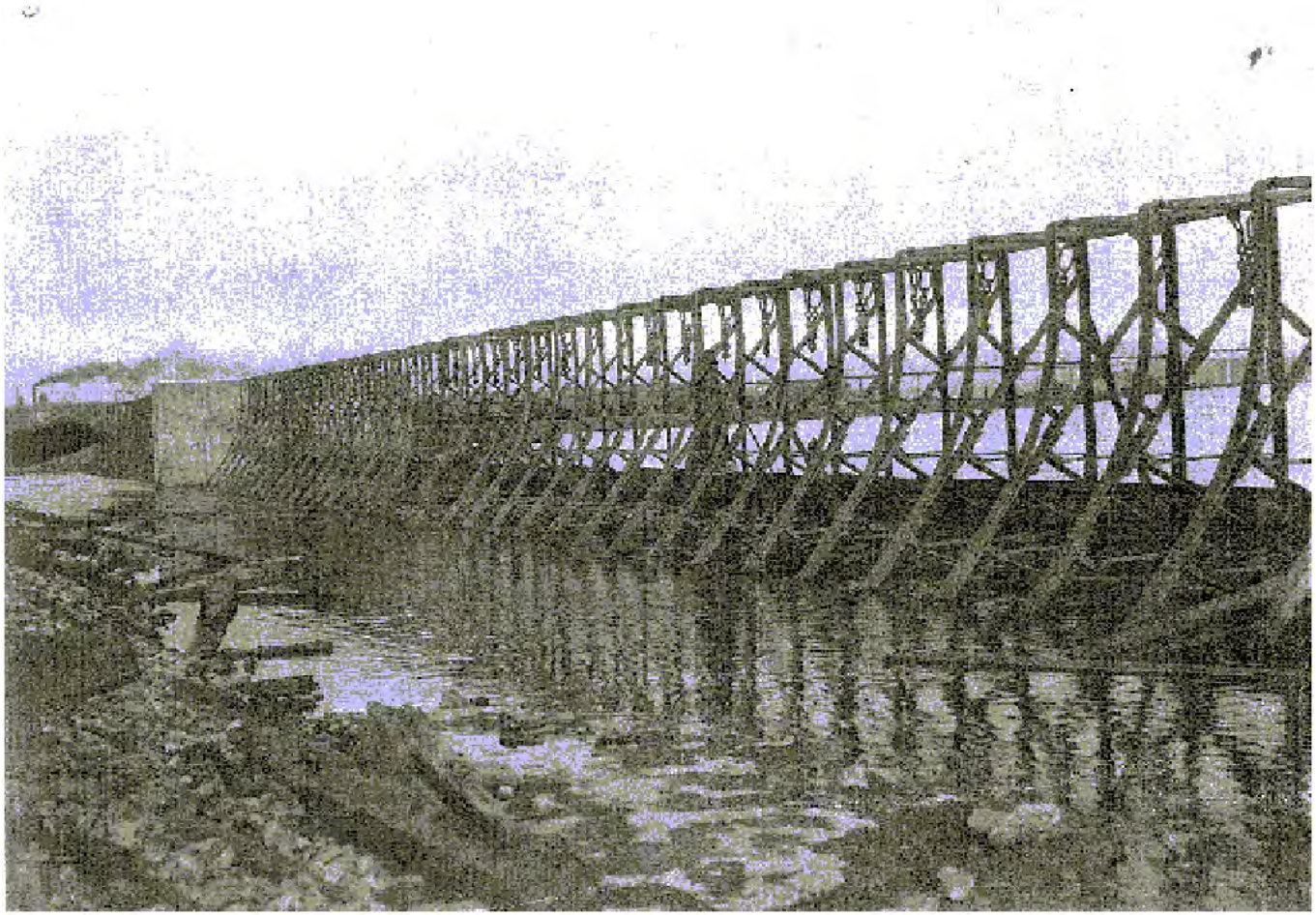
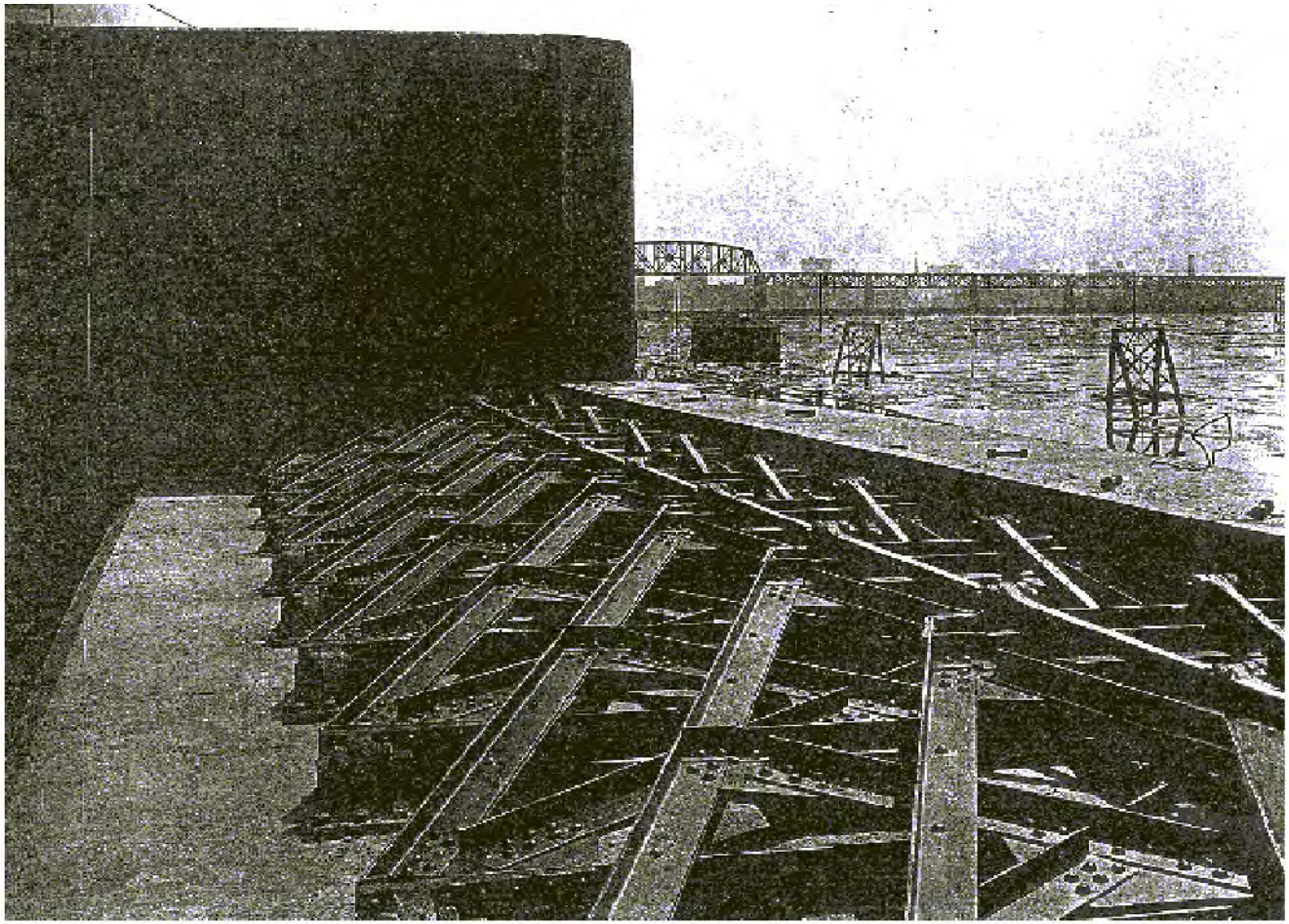


Plate 1-27. Boulé trestles in lowered position, Dam #41. September 14, 1927. From the files of the Louisville District, U.S. Army Corps of Engineers.



and twenty-nine wickets remained standing in their vertical position, while the remaining 21 disappeared beneath the surface of the water. A portion of the foundation moved downstream with the lock end of the portion as a pivot. Total displacement was between three and four feet.

Examination of the foundation revealed that the key near the lock wall had disappeared at some points and had been reduced to a minimal size at other points. The foundation concrete did not abut against the rock immediately above and below the key but was separated from it on each side by an open trench about 1.5 feet wide.

The board members noted that the rock upon which the foundation concrete rested had a very small frictional coefficient and was composed of layers through which water could penetrate and produce an upward pressure on the base of the dam. To prevent a similar accident in the future, the board recommended that a greater thickness be given to the concrete foundation in order to insure sufficient weight to counteract any water pressure under it, that greater care be taken to bond the concrete to the rock by a key having a depth of at least five feet, and, as an additional precaution that the concrete be securely fastened to the rock by anchor rods (Roessler et al. 1915:315-322).

Fixed Dams

During the 1920s, replacement of the original numbered locks and dams on the Ohio began. The first two replacements occurred when Emsworth and Deadman Island complexes, located near Pittsburgh, were built. Emsworth Dam replaced dams 1 and 2, while Deadman Island replaced dams 3 and 4. Both of these replacements were designed as fixed, concrete, gravity section dams.

The Corps selected a fixed concrete dam at Emsworth for several reasons. Major Franklin Bell of the Corps outlined these reasons in an article on the dam:

1) The upper Ohio River from Pittsburgh to the Beaver River has a steep slope. As a consequence, when the dams were down the current was swift and navigation was difficult. Upstream progress for a tow was very slow. Consequently, navigators preferred pool navigation to open channel navigation in this stretch.

2) Due to the steep slope, the back water curve for a low fixed dam for extreme flood height ran only a few miles upstream. The increase of height for any extreme flood at Pittsburgh would be negligible for a fixed dam.

3) The movable dams could not be kept up during high stages of water nor when there was a heavy flow of ice.

4) All the dams then in use on the Monongahela were fixed. None had shown a buildup of silt cited as a detriment of fixed dams (Bell 1923:406).

Protection against failure by sliding was provided by use of a wide base, and by securing adhesion to the foundation by round piles. The piles were also the principal support for the concrete top. Sheet steel piling, driven to rock and with tops embedded in the concrete near the upstream toe of the dam, served as a cutoff wall to prevent water from finding its way under the dam. Bell indicated that the most unusual feature of the Emsworth Dam was the shape of the

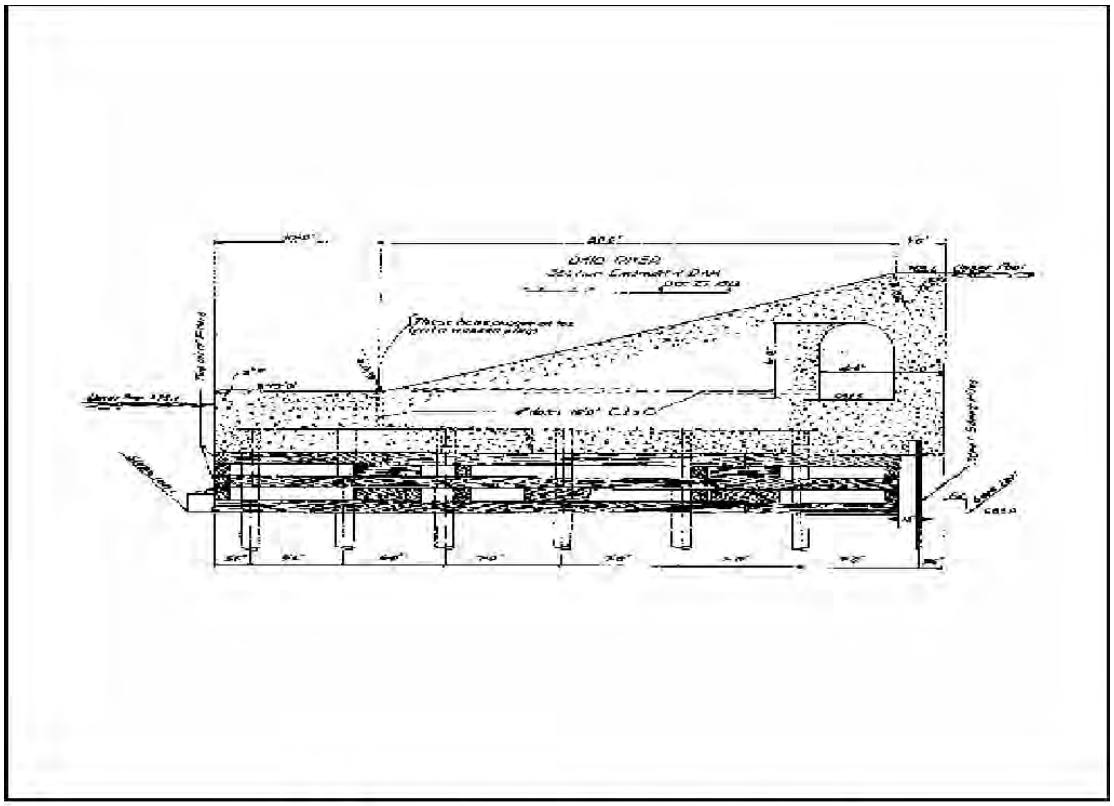
downstream slope and apron, and the absence of riprap, or crib protection, below the dam (Figure 1-28). Bell cited the rationale for the apron design:

> It was expected that at stages when the material below the dam would be eroded by the overflow, the take-off from the apron would be almost horizontal, and that the resulting slope below the dam would be gradual with no deep holes next to the dam. Soundings at various time, below the back channel section of the dam…indicate that the effect has been produced (Bell 1923:406-407).

In his article on construction of Deadman Island Lock and Dam, Hugh J. Casey of the Corps of Engineers cited the reasons why a fixed dam design was chosen for Deadman Island:

In the upper reaches of the Ohio River, the old movable type of dam has proved less desirable than the fixed type. The steep slope of the stream, the rapid fluctuations of stage, the dangers of running ice, and the shorter periods in which open river navigation conditions obtain, all tend to make the operation and maintenance of movable dams difficult. The advantages of open river navigation are at a minimum and the disadvantages inherent in the movable type of dam are always present. The fixed type of dam, in providing a fixed pool, at decreased cost with greater ease of operation and maintenance, will supersede movable Dams Number 3 and 4 (Casey 1929:444).

Figure 1-28. Section of Emsworth Dam, Ohio River (Bell 1923).



Beginning in the 1930s, Corps engineers designed high-lift dams for the Ohio River. These dams permitted regulation of pool height. They did not contain navigable passes, and thus, all traffic had to pass through the lock. The first of these new dams were of two types. Montgomery, completed in 1936, uses vertical lift dam gates. Gallipolis, completed in 1937, uses roller gates. Subsequent dams constructed on the Ohio River employ either vertical lift or tainter gates. One bay of the back channel dam at Emsworth uses a Sidney gate, a hybrid of the vertical lift and tainter gate.

Ohio River dam design criteria for gated dams provided for clearing maximum river stages with the gates in the fully raised position to avoid the hazard of trapping debris and large floating objects. The criterion chosen specified at least five feet of clearance between the maximum flood stage of record and the bottom of the gates in the fully raised position. Since the range of stage was so great, as much as 80 feet between extreme low and high water near Cincinnati, the piers needed to be quite high (Bruce et al. 1957:1239-7).

Vertical lift gates

A vertical lift gate is, in principal, the basic form of the ordinary Stoney gate. Its distinguishing features as installed on canalization dams being its large size and the type of rollers used. Vertical lift gates are generally framed with trusses or built up girders which support the watertight skin plate or sheathing. The water loads are transmitted to steel girders set in recesses at the pier faces. The rectangular section lifts vertically between guides recessed in the piers. The hoisting machinery is placed atop the piers. The actual contact at points of horizontal support is made through fixed rollers. Sliding side seals are made of wood, metal or rubber strips and bottom seals are made of similar materials (Engineer School 1940:44).

The first vertical lift gates were installed at the replacement dam at Emsworth (Plate 28; Figure 29) and Montgomery on the Ohio River; at Bonneville Dam on the Columbia, at Dam No. 17 on the Warrior River; and at Savannah Bluff (Engineer School 1940:45). The **eight** vertical lift gates of the Emsworth main channel dam and the five vertical lift gates on the back channel dam are described in the first periodic maintenance report for the complex:

> Each gate weighs approximately 128 tons, is 102 feet long center-to-center of tracks, 12 feet 10 inches deep and 11 feet wide, and has an effective damming surface of 100 feet by 12 feet. In cross-section it is approximately rectangular consisting of two longitudinal trusses, each composed of 12 panels, 8.5 feet long, reinforced by vertical and lateral braces. Each gate has a 3/8-inch watertight skin plate on the upstream face and a wrought iron apron on the top…. Each gate can be raised to a point where the bottom is 39.4 feet above the sill level, or 5.6 feet above the highest recorded flood at Emsworth, and lowered to a point where its top is 3 feet below normal pool level. In the latter position, 3 feet of water is allowed to run over it to maintain the pool elevation (USACE-Pittsburgh 1971:6).

Plate 1-28. Emsworth Dam. Main channel. Downstream face of dam looking toward right bank (Pittsburgh Office, U.S. Army Corps of Engineers 1948).

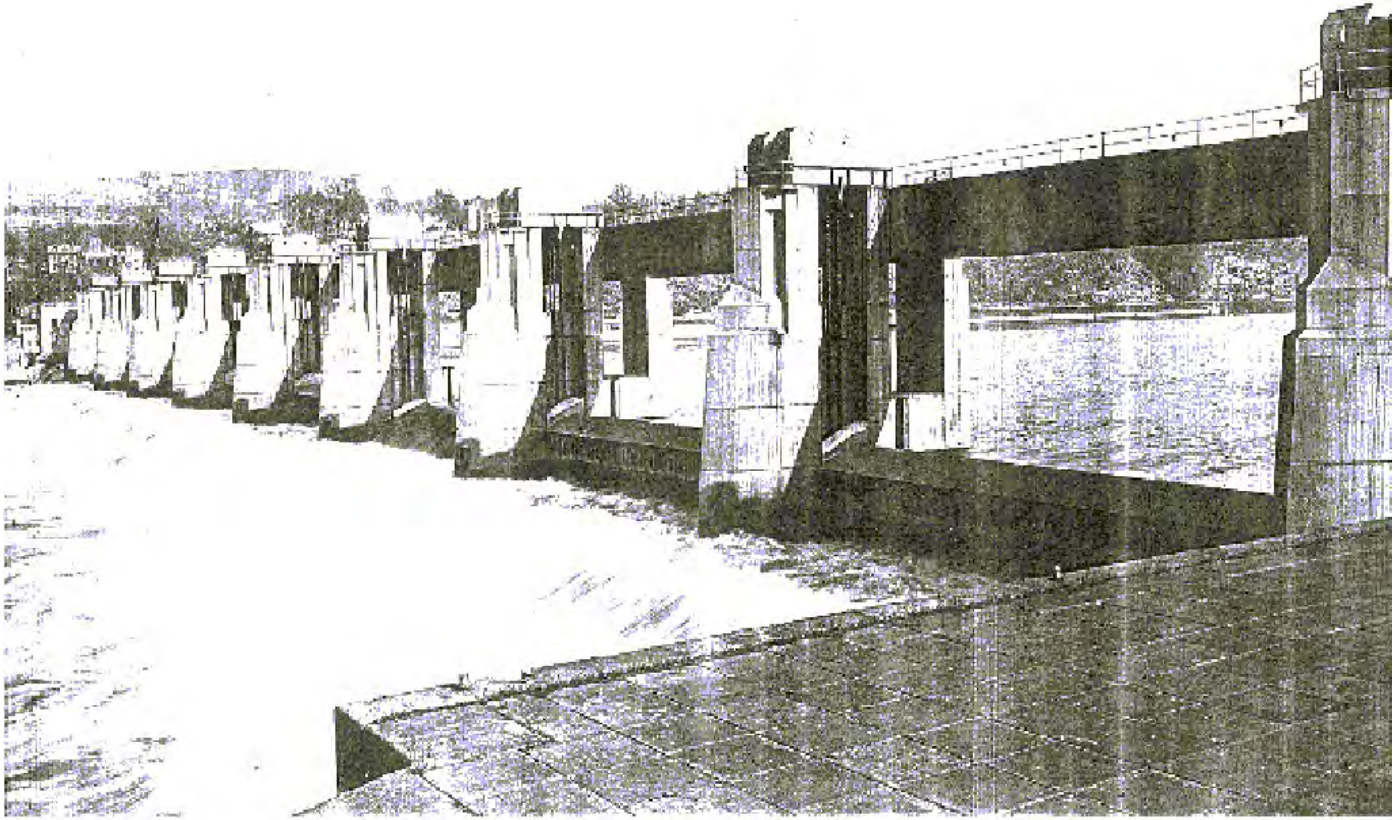
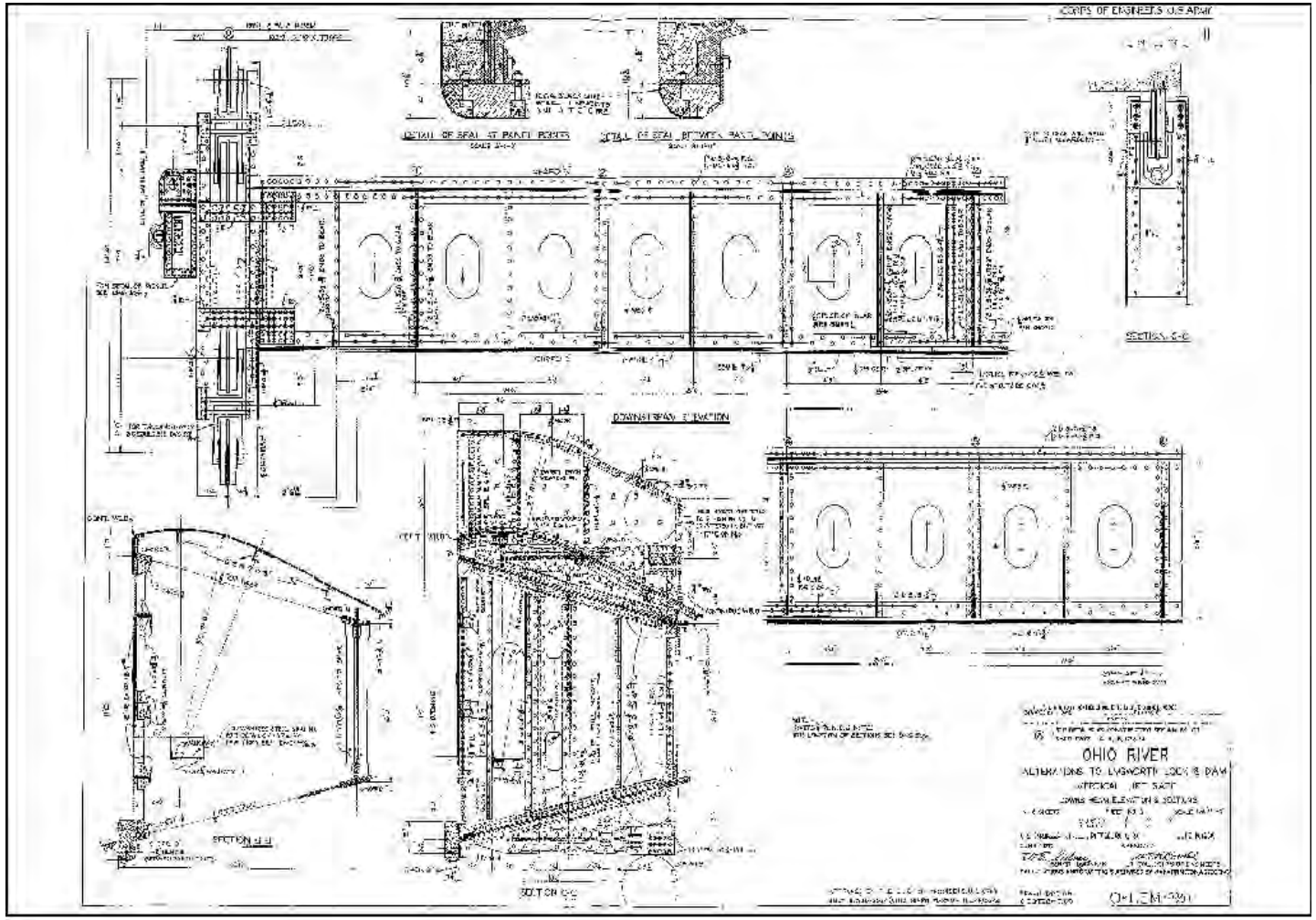


Figure 1-29. Alterations to Emsworth Lock and Dam. Vertical lift gate. Downstream elevation & section (U.S. Engineer Office Pittsburgh 1936). (From USACE-Pittsburgh 1971).



The Montgomery gate is constructed with three chords but operates as a vertical lift gate (Bruce 1957:1239-7). The design of this gate is described in the first periodic inspection report for the complex:

> The dam has been equipped with 10-100 foot direct lift type gates. The gates are of riveted steel truss type construction. Bottom and side seals are made up from timbers. A device is provided for dogging the gates in the fully raised position. Two hoisting machines are provided for each gate. The hoist mechanism includes shafting, gate guide wheels, lift chains and sprockets external spur gearing, inclosed worm gearing, and two motors for each hoist coupled together with a brake on the end of the shaft of the forward motor (USACE-Pittsburgh 1972b:7).

Montgomery gates are unique in that they are tapered on their ends; the concrete pier's sealing surface is also tapered.

Roller gates

The roller gate was invented by Dr. Max Karstanjen of Mainz, Germany, the director of the bridge department of the Maschinenfabrik Augsburg-Nurnberg (MAN), Germany. The first roller gate dam was built in 1902 on a branch of the river Main near Schweinfurt, Germany. The installation consisted of a single roller about 13 feet in diameter with a width of opening of 59 feet. The roller was raised and lowered by rolling it up and down masonry inclines by means of wire ropes. The gate was hand operated by two winches and required 12 men to operate (Dravo 1947:34).

The dam crest height is adjusted by raising the large steel tube or roller off the dam crest. Professor K.E. Hilgard introduced the roller dam to the United States by discussing it in a paper at the 1904 International Engineering Conference in St. Louis. By the end of 1913, two power dams and two irrigation dams using roller gates were either completed or under construction in Washington, Idaho, and Colorado. The first completed project, the Washington Water Power Company's Long Lake Dam, used three roller gates for spillway crest control (O'Brien et al. 1992:68). By 1928, 250 roller gates dams had been constructed including 24 in the United States (Kemp 2000:106).

The first roller gate dam designed by the U.S. Army Corps of Engineers was Mississippi River Dam No. 15 at Rock Island, Illinois completed in March 1934 (O'Brien et al. 1992:67). Following the completion of this dam, additional roller dams were completed at London, Winfield and Marmet on the Kanawha River. On the Kanawha River, Corps engineers specified that one of the dam gates be fully submergible. Later Mississippi River installations, at dams 4, 3, and 9, 11, 15, and 18 also used submergible roller gates (O'Brien et al. 1992:71-72).

The earlier roller gates consisted of a plain cylinder, the cylinder resting directly upon the crest of the sill when in a closed position. Later gates were developed with aprons or shields projecting downward and upward from the cylinder, thus reducing the diameter of the cylinder for a given height of gate (McAlpine 1934:420). In his article on roller gates, W.H. McAlpine described the construction of these later gates:

> The shell plating of the drum is kept in a cylindrical shape by internal bracing consisting of structural steel cross frames and longitudinal channels. The shell plating varies in thickness along its length according to the strength required. The

> apron is a segment of a cylinder and is made uniform in thickness. It is attached to the upstream side of the drum slightly below its center axis and is held rigidly by struts connected to the drum (McAlpine 1934:421).

Gates were hoisted by means of a multiple side bar chain at one end of the drum. A typical chain was made of special high-strength steel with a minimum working strength of 85,000 pounds per square inch. It was wound part way around the drum and unwound as the roller rose. Power to raise the gate was provided by a large, electrically driven hoisting engine (McAlpine 1934:421).

By the time that the roller gate dam was completed at Gallipolis, more than 160 roller gate dams had been completed in Europe. As of 1939, there were 146 roller gate dams installed in the United States including 22 locations on the Upper Mississippi Navigation (Kemp 2000:115).

Engineers for the Corps believed that roller gates were superior to vertical lift or tainter gates because of the inherent stiffness of the roller tube. This allowed openings of much greater length than previous movable dams. The roller gate also had the advantage of low maintenance and trouble-free operation (WVU n.d.:II:25-26). A 1913 *Engineering Record* article compared gate types:

> The alternative for rollers are Tainter or sliding gates. It is difficult to say exactly where the economic limit lies for the Tainter type, but it may be said with certainty that gates 30 ft. wide and 12 ft. deep are not far from the economic limit. For sliding gates of the Stoney type, those used in the Panama spillways, which are 46 ft. wide and 19 ft. high, are about as large as gates of that type can be built with economy. Furthermore, the Stoney gates, on account of their submerged rollers, with their bushed journals and roller guides, offer too many chances for trouble (as cited in Kemp 2000:109).

In the subsequent construction of the Mississippi River 9-foot channel, it was discovered that roller gates had to be raised above the level to maintain the minimum pool elevation behind the dam in order to pass ice flows. With the gates wide open, the pool was lowered and the great volume of water passed tended to erode the toe of the dam. To pass ice and drift on the Kanawha River, flaps were installed on one roller at each of the Kanawha River projects. Early design studies for the Kanawha River considered the use of submergible roller gates. This technology was rejected in favor of the installation of flaps (McCoy 2000).

Dravo engineers described the operation of the roller gate:

> The standard roller gate consists of a cylindrical steel shell heavily reinforced with internal bracing and having an apron attached to the bottom of the cylinder to give increased damming height.
>
> Flexible steel diaphragms extending out from the upstream side of the cylinder and the apron at each end of the gate are held against the faces of the pier by the water pressure and make water-tight seals at these points. The main body of the gate with its attached apron rests directly on the sill of the opening. The apron and the end seal diaphragm are faced with timber seals.
>
> Recesses are provided in the piers at each end of the gate with the gate ends extending into these recesses. Each end of the gate is provided with a circular

> combined track and rim gear which run on and mesh with a similar track and rack section which is anchored to the concrete on the downstream side of the recess. For the raising and lowering of the gate a hoisting unit is provided at one end only of the gate structure with a lifting chain attached to a fixed point near the upper part of the cylinder and carried completely around the cylinder and thence up to and over the sprocket of the hoisting unit.
>
> The hoisting unit, located on top of a pier, consists of a series of reduction gears, and is motor driven. By rotation of the chain sprocket the chain is pulled up causing a rotation of the gate body upward along an inclined track. The speed of movement on various installations is usually from 6" to 9" vertical lift per minute (Dravo 1947:34-35).

When the gate is in the saddle or zero position, the apron or the main cylinder rests against the sill, the line of contact sealed by a rubber strip. At this position the gate crest is at pool level, and there is no flow either over or under it. When the gate is partially raised, water flows under the gate, between it and the sill. When raised clear of the water, free flow between the piers is permitted (Engineer School 1940:32).

At the time of their installation, the Gallipolis roller gates were the largest roller gates in the world (Dravo 1947:43; Figure 1-30). Each gate measures 29.5 feet in diameter and 120.5 feet in length (Kemp 1991:1). The machinery for raising and lowering the gates is located at the top of the piers in a concrete housing. The gates are operated on a sloping rack and move by an electrically powered gear train which drives a huge sprocket chain connected to the roller gates. Access to the housing is by means of a steel walkway that takes the form of a structural steel Pratt truss (Kemp 1991:2).

Tainter gates

The basic design for what became the tainter gate was developed by American inventors as early as the 1820s and refined throughout the nineteenth century. Thomas Parker, a Wisconsin lumberman, developed the modern tainter gate in about 1880 for use in the lumber industry. He designed the gate to control water levels in mill reservoirs. Not only did the gates control these levels but also passed ice and other debris when necessary. He sold the rights to his invention to Jeremiah Burnham Tainter who patented the gate system in 1886. The Corps of Engineers purchased the rights to use the tainter gate patent. In 1889, Major William Marshall became the first Corps officer to use tainter gates, developing a manual-operated version of them for use on a movable dam across the Rock River in Illinois. Tainter gates were installed in the 1890s on the Fox River in Wisconsin and the Illinois and Mississippi Canal (WVU n.d.:II:9; Johnson 1985:135; O'Brien et al. 1992:79).

In their earliest form, tainter gates were restricted to openings of only 35 feet or less. The first use of tainter gates for the entirety of gate bays on an American river occurred in 1938-1939 when they were installed at Dam 24 on the Mississippi River (WVU n.d.:II:9-10). At this

Figure 1-30. Gallipolis Locks and Dam. Dam. Roller gates general arrangement (U.S. Engineer Office, Huntington 1938). (From USACE-Huntington 1970).

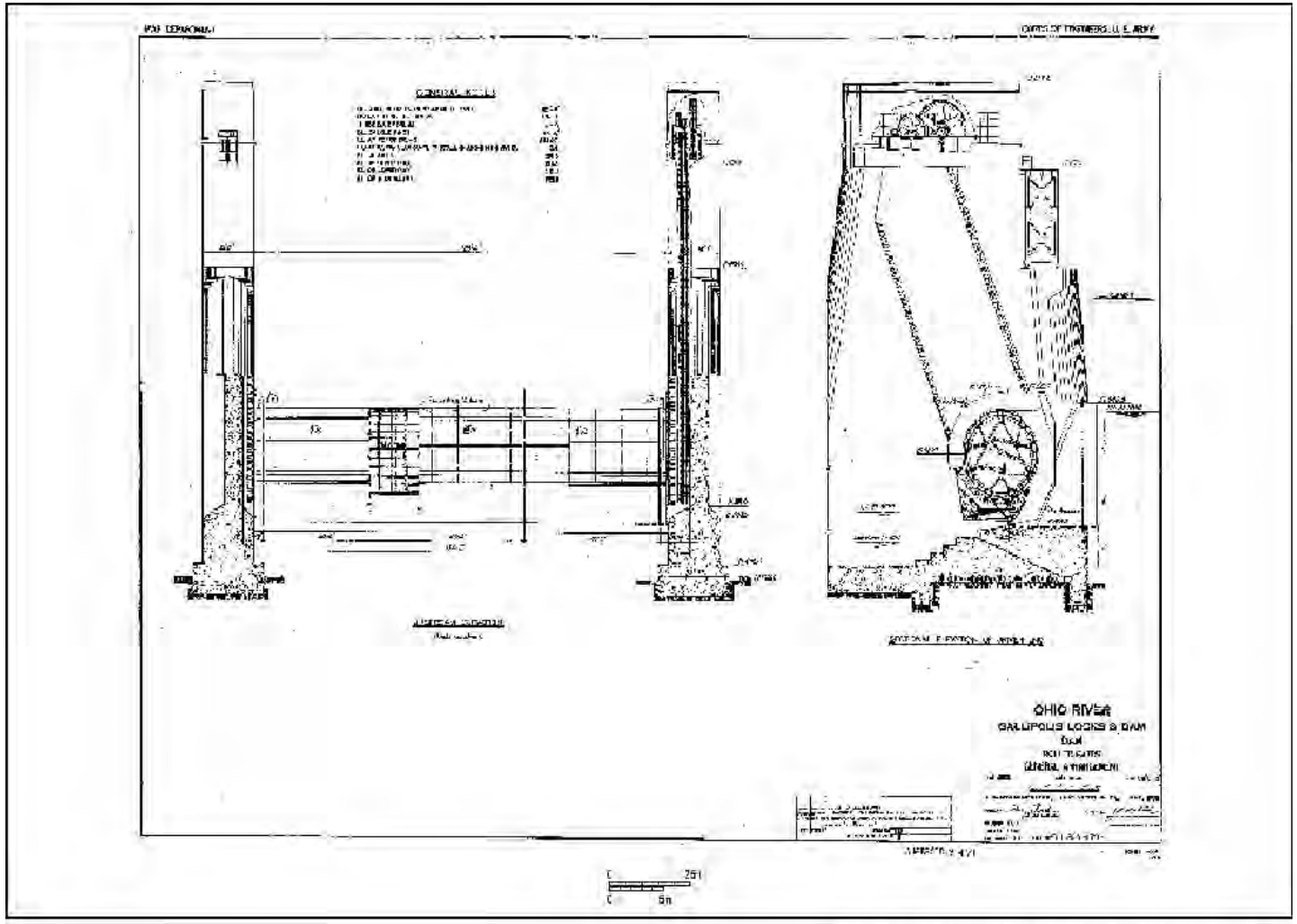
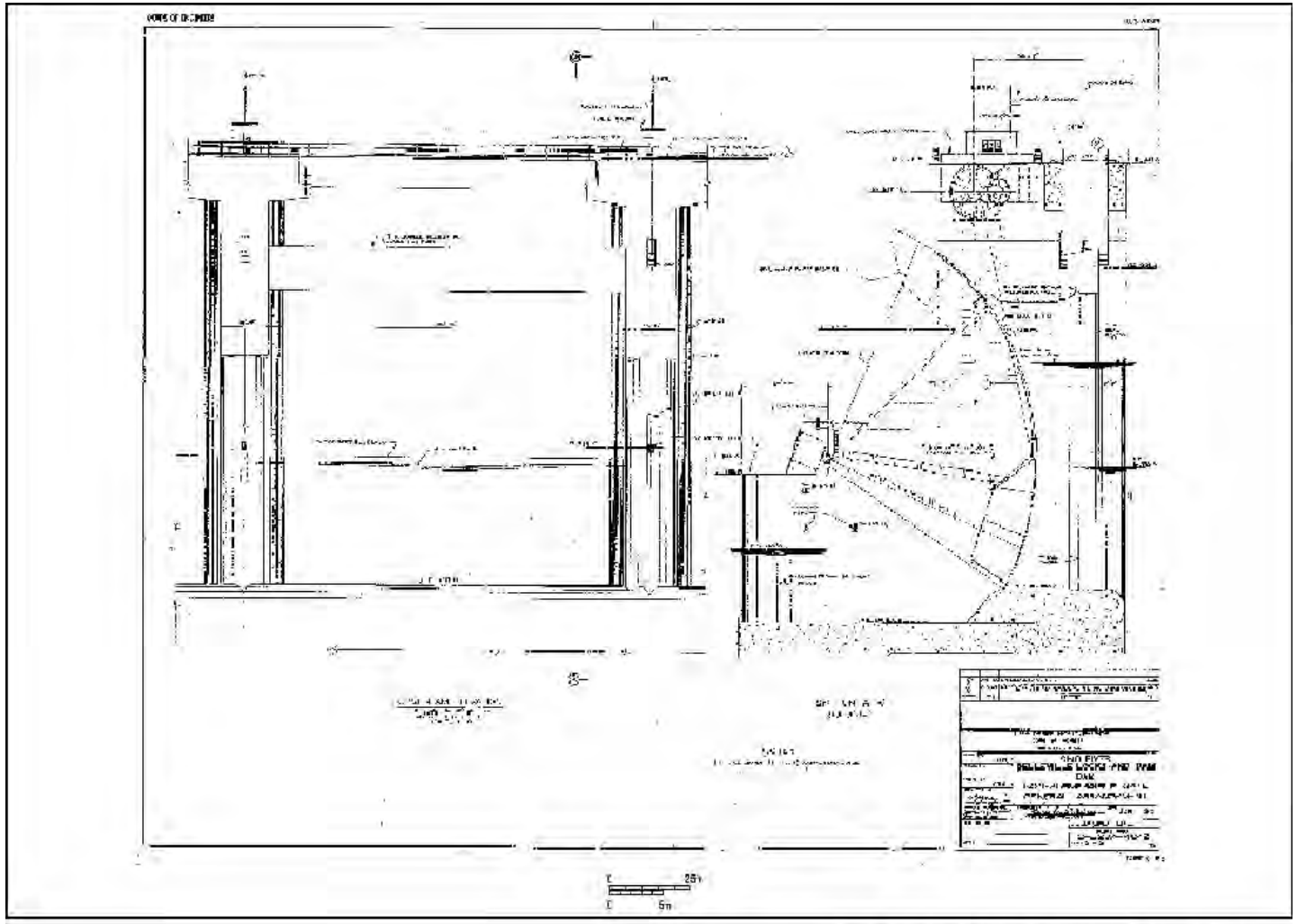


Figure 1-31. Belleville Locks and Dam. Dam. Non-submergible Tainter gate (U.S. Army Engineer District, Huntington 1964). (From USACE-Huntington).



installation, fifteen 80-foot long gates were used and were believed to be the largest Tainter gates constructed to that time (O'Brien et al. 1992:79).

Tainter gates may be divided into two types: non-submergible and submergible. The most common form of tainter gate is the non-submergible (Figure 1-31). A tainter gate is an internally framed sector of a cylinder with a system of radical bracing and a trunnion arm at each end which carries the gate load to a trunnion pin.

The trunnion pin is anchored to the pier, and the arm and gate rotate about the pin. The gates are mounted upstream from the trunnion pins, and the gate skin plate is convex upstream. When the gate is closed, the lower edge of its cylindrical surface is in contact with the sill, making a tight joint. Rubber seals along the end of the gate rest and slide against plates set in the sides of the piers. When the gate is closed against the sill, water stands against the upstream surface of the gate but does not normally overflow. When the gate is partially raised water flows through between the lower edge and the sill (Engineer School 1940:35). The tainter gates on the Ohio River are raised and lowered by wire rope and hoists with spiral drums.

The tainter gates at Racine Dam are typical in design:

> Rubber "J" seals of standard manufacture are used for side seals and bear against seal plates of corrosion-resisting steel. The gates are of welded construction with the skin plates, web plates, diaphragms, tee sections and side frames of structural steel. The hoist cable bearing surface of the side frames and side arms are of low alloy steel. The bottom horizontal lip on the bottom of the gates is of extra high strength steel. The gate body is composed of two longitudinal cells with a stiffened cantilever portion of the upstream skin plate extended approximately nine feet above the top cell (USACE-Huntington 1971:6).

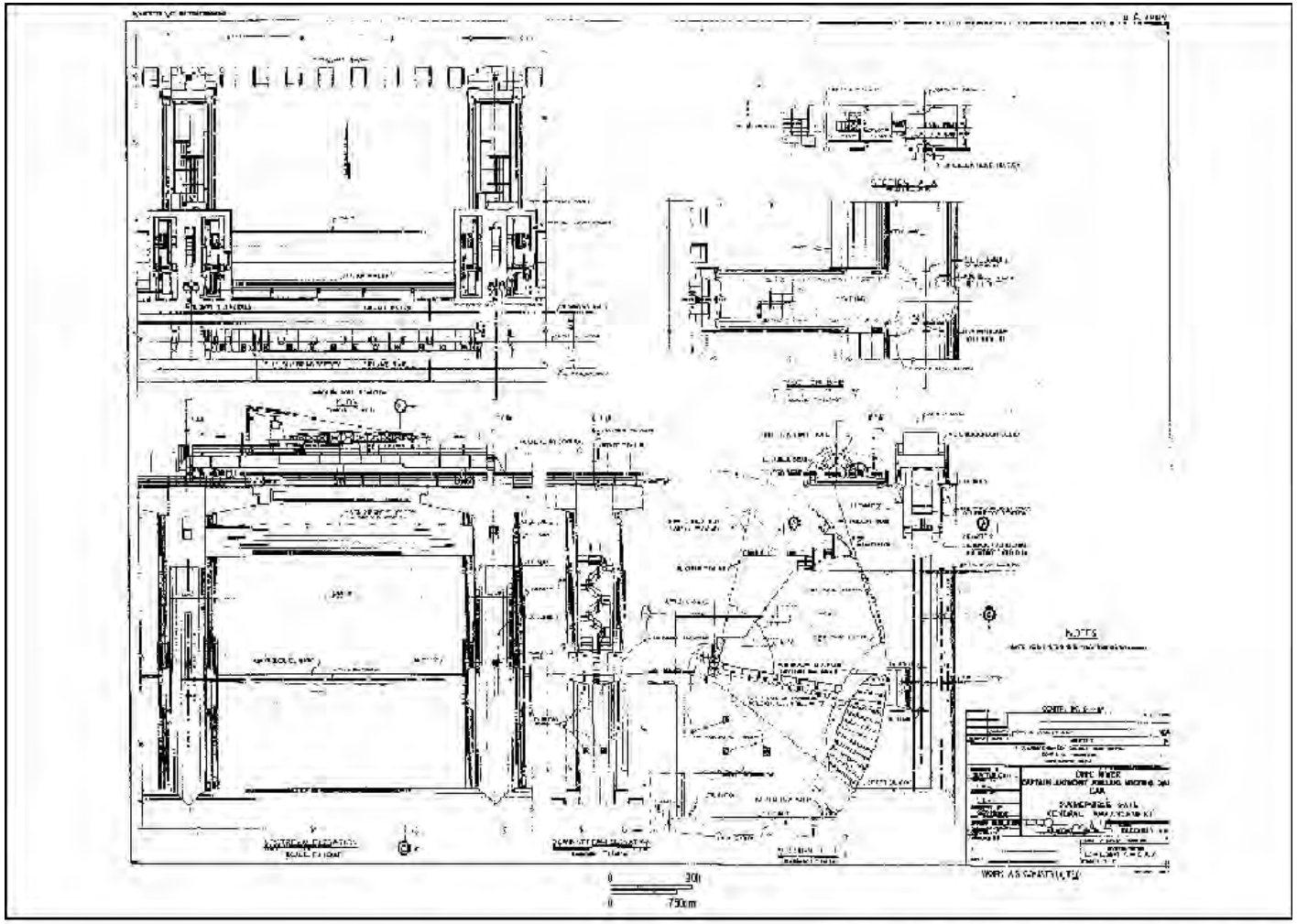
The Tainter gates at Racine dam have tubular cross sections. At Willow Island Dam, the gates have an open framing and sector shape similar to that of the tainter valve (McCoy 2000).

Each of the tainter gates at the Racine Dam is raised and lowered by multiple-cable hoists mounted on the top of the piers at each end of the gate. The two hoists for each gate are synchronized by a torque shaft spanning the gate bay and powered by a single electric motor. A pushbutton control station is mounted at each motor location (USACE-Huntington 1971:7).

The submergible tainter gate (Figure 1-32) was intended to pass large quantities of drift and ice. To do this, the non-submergible gate must be raised until the floating material is drawn into the gate opening. Often the size of the opening necessary to suck the debris from the surface was so great that the amount of pool water lost was substantial. The submergible gate was designed to allow discharge over rather than under it, making it possible to skim off surface debris with a relatively small discharge. The gates were designed so that with the top at pool level, the gate made a tight joint with the sill, and water can pass only by overflow. As the gate was lowered from that position, the bottom seal was usually released, but the principal discharge was by overflow (Engineer School 1940:40).

Typical submergible gates were those installed at Meldahl Dam. The gates are of cellular stressed-skin construction with a radius of 64 feet from the trunnion pin to the upstream face of the skin plate. The gates were designed so that they could be lowered 9 feet from the normal

Figure 1-32. Captain Anthony Meldahl Lock & Dam. Dam. Submergible Tainter gate (U.S. Army Corps of Engineers Huntington 1960). (From USACE-Huntington 1969).



closed position to the fully submerged position in order to pass debris or ice that has accumulated upstream of the gate.

The Meldahl submergible gates suffered from excessive vibration when submerged (USACE-Huntington 1969:9). As a result the gate was modified to eliminate submersion. In 1977, submergible gates at Markland and McAlpine dams were converted to non-submergible. No submergible gates are presently in operation on the Ohio River.

In several instances, the two-part gates were welded together to form a single non-submergible tainter gate. In instances where the original design called for submergible gates, such as at Racine Dam, this type of gate was not included in the final design (USACE-Huntington 1971:6).

The most recently constructed tainter gates are designed as non-submergible. As a result, lighter framing was used. In addition, recent gates, such as those installed at Winfield Dam use hydraulic cylinders as hoists for the tainter gate. These cylinders permitted the reduction in pier height and the setting of upstream bulkheads from floating plant on the downstream side (See Figure 1-21) (McCoy 2000).

Sidney gates

As noted, only one dam on the Ohio River uses a Sidney gate, the back channel dam of Emsworth located between Neville Island and the south bank of the river. The gate closest to Neville Island is a 100 ft. clear span Sidney gate (Engineer School 1940:296; Plate 1-29; Figure 1-33).

The Sidney gate, developed by William E. Sidney, chief mechanical engineer of the Pittsburgh District, Army Corps of Engineers, constitutes a special type of tainter gate equipped with movable or sliding trunnion pins (Plate 1-30). Sidney's invention grew out of experimentation with movable crest gates for dams during the Depression. In preliminary studies for Emsworth, the roller gate and a modified tainter gate were considered in addition to the vertical lift gate. The Sidney gate was a hybrid of the tainter and vertical-lift types (Johnson 1979:247; Bauknight 1937:665).

Sidney developed the gate to overcome the disadvantages of limited maximum clearance of other tainter gate types caused by the fixed trunnion. This disadvantage precluded the use of tainter gates on rivers where stage ranges were great. The pins of the Sidney gate are seated in slots in the pier face which cause the gate to open in the ordinary way, by rotation about the trunnions, until the center of gravity is vertically below the point of lift. From this point the entire gate is lifted to full clearance, the pins rising vertically along the pier tracks. This type of gate was later used at Dam No. 4 and Point Marion Dam on the Monongahela River.

Bauknight described the configuration of the Sidney gate in an article in *Engineering News-Record*:

> It combines certain features of the tainter and the vertical lift types in that it revolves part way and then lifts vertically to the height required to clear the opening. In cross-section, the gate is triangular; the upstream face consists of a girder and the upper and lower legs are trusses with a common downstream chord. The skin plate forms a segment of a circle in cross-section, the center of

Plate 1-29. Emsworth Dam. Back channel. Sidney gate. Gate shown closed. (U.S. Engineer Office, Pittsburgh 1940). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

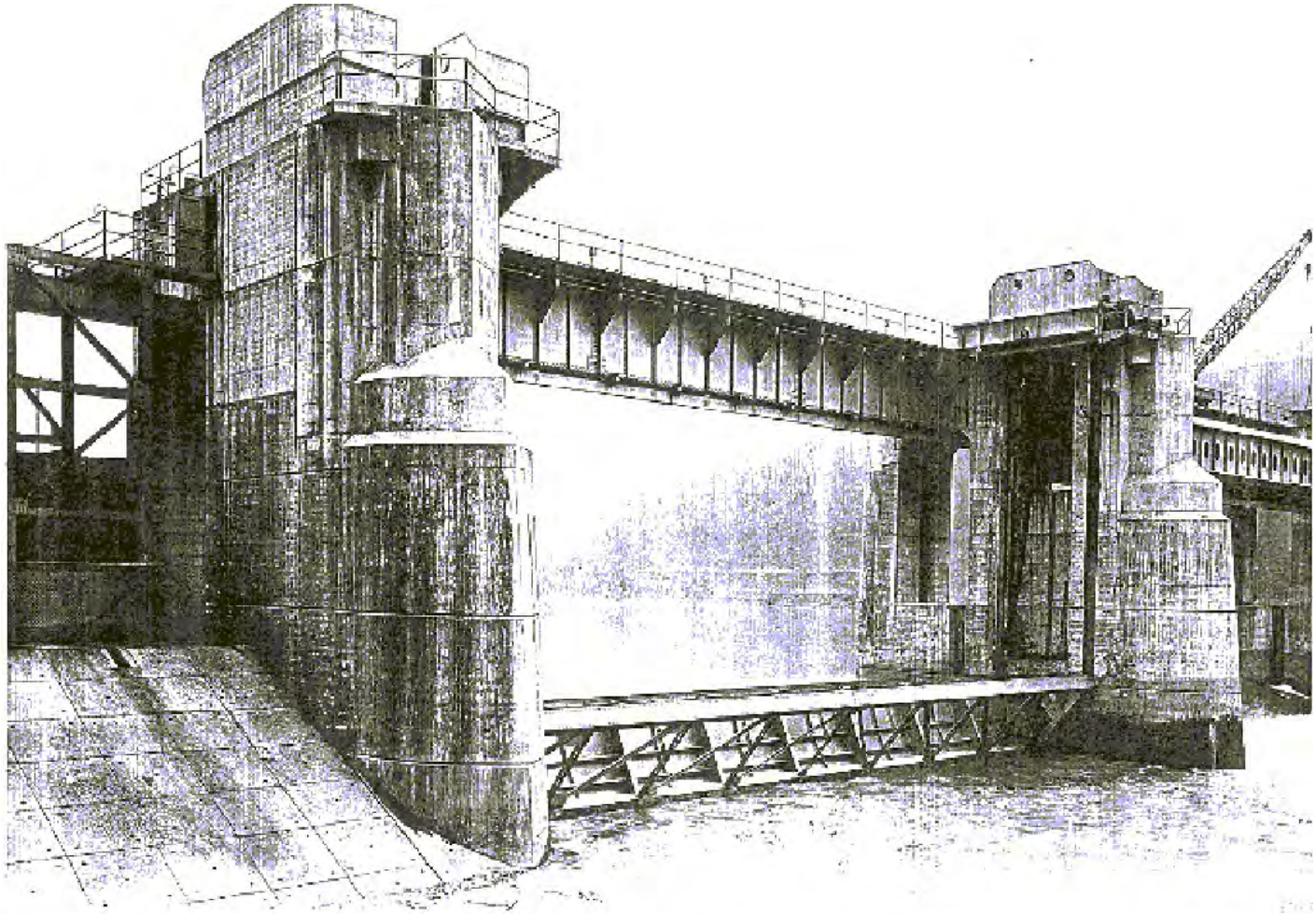


Plate 1-30. Sidney's sectional model. Modified type tainter gate (U.S. Engineer Office, Pittsburgh 1933). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

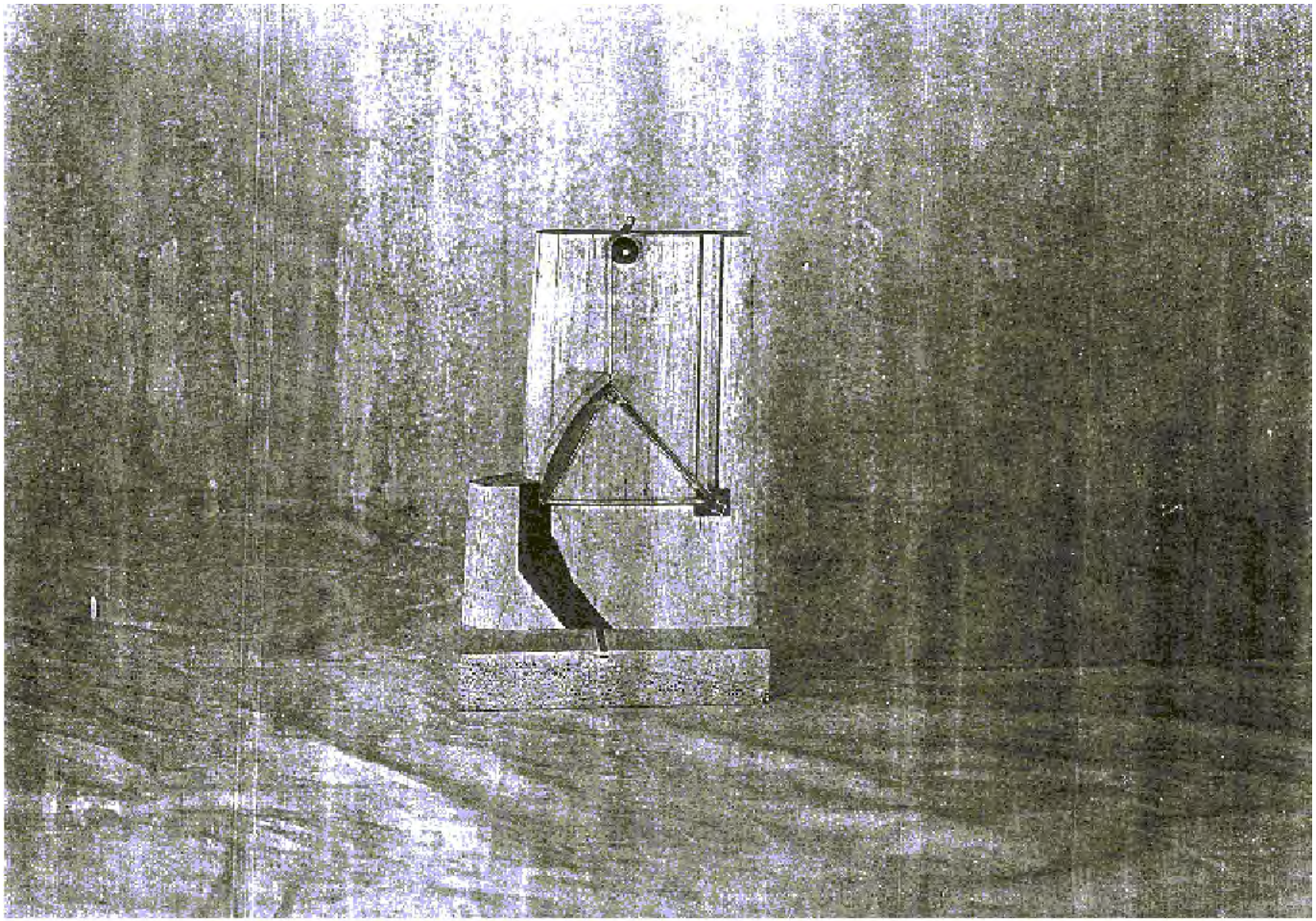
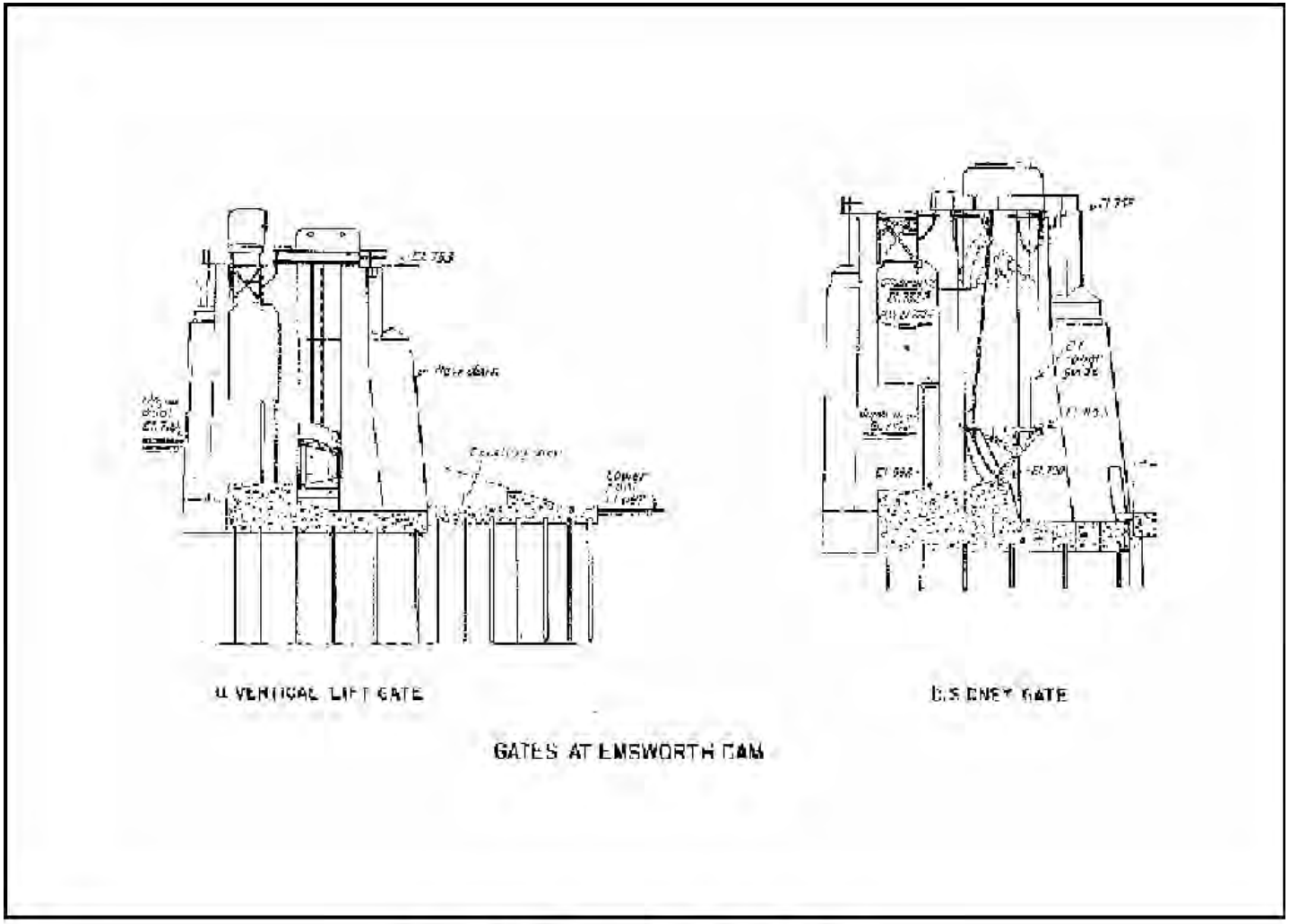


Figure 1-33. Gates at Emsworth Dam (Engineer School 1940).



> which is coincident with the neutral axis of the downstream chord (Bauknight 1937:665).

The gate is operated by means of lifting chains and synchronized hoisting units, one at each end of the gate. When it becomes necessary to provide a larger discharge area during flood stages,hoisting is continued after the gate has reached the limits of its rotation, at which point he entire weight of the gate is supported by the chains. The maximum travel limit for the Emsworth installation is 38 feet above the sill (USACE-Pittsburgh 1971:8).

Bauknight cited some of the advantages of the Sidney gate:

- As the entire weight of either the Sidney or lift-type gate must be suspended from the lifting chains, it follows that the lighter the gate the smaller the cost of chains and hoisting machinery [The Sidney gate, as designed, was considerably lighter than the vertical lift gate.]

- The depth and width of the recess in the pier is much less for the Sidney gate than for either the lift or roller gate, and where suitable foundation conditions exist, a smaller pier may be used for the Sidney gate than the other two types (Bauknight 1937:666).

To test the performance of a Sidney gate, a one-fifth scale model of the gate to be erected at Emsworth was erected at Dam No. 3, Allegheny River during the summer of 1935. It performed satisfactorily (Bauknight 1937:666).

Emergency and Maintenance Lock and Dam Closures

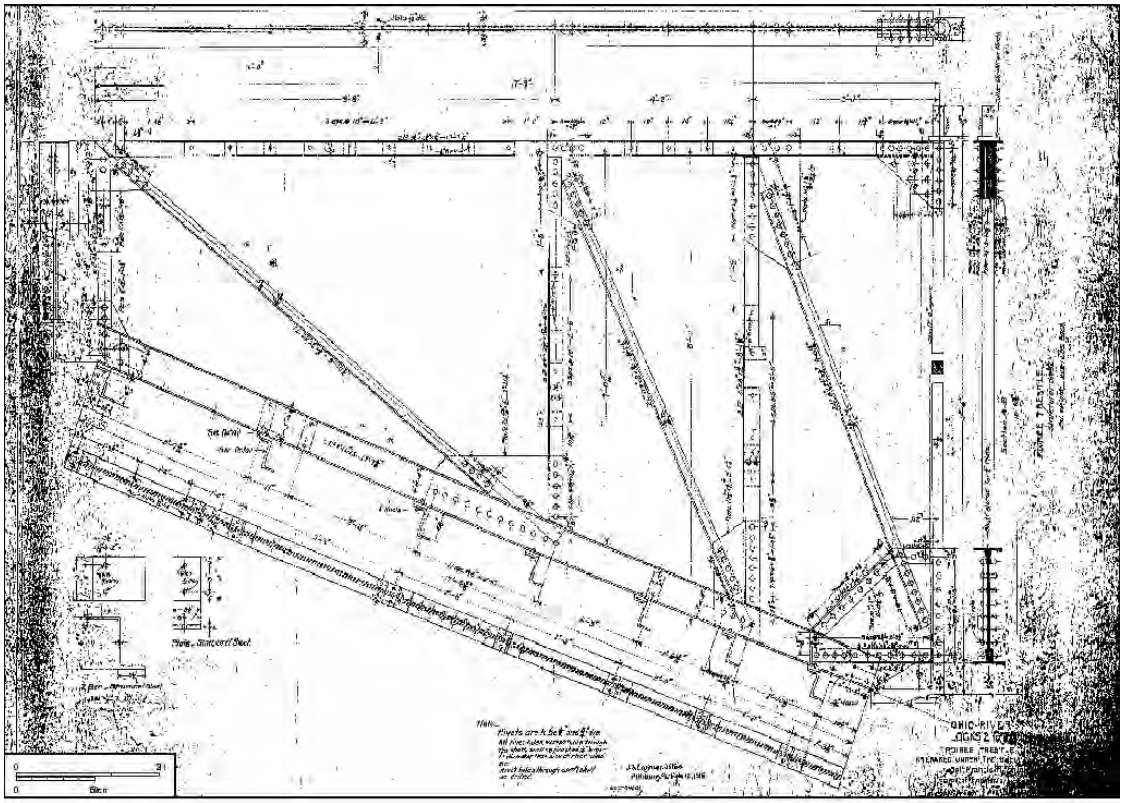
In an article published in the *Transactions* of the American Society of Civil Engineers, C.E. Blee divided supplementary lock closures into three categories:

> 1) Provisions for unwatering the lock and its operating equipment for ordinary routine inspection and maintenance, in which closure can be made under conditions of balanced head;
> 2) Provisions for safeguarding, or preventing damage to, lock operating gates and other equipment; or
> 3) Provisions for making an emergency closure of the lock under an unrestricted flow of water resulting from damage of disastrous proportions to the lock gate (Blee 1951:853).

A fourth category of lock closure, not mentioned by Blee, is to pass ice and drift in the approach to the locks. Lock closures on the Ohio River Navigation System are used for the first, third and last mentioned purposes (McCoy 2000).

The early numbered locks used a Poirée needle dam to close the chamber in case of an accident to the gates. A row of steel bents was place across the chamber, the bents being pivoted at their feet to swing laterally. The bents normally lay in the recess across the concrete floor. To close the opening, the bents were raised by chains and were connected by rigid members at the top. Timber needles were then set in place by hand from a bridge laid upon the bents, the lower end

Figure 1-34. Ohio River Locks 2 to 6. Poirée trestle (Arras 1916). From Cartographic Branch, National Archives.



of each needle rested against a sill and the upper end against the bridge (Anonymous 1909b:236-237; 34).

The Poirée dam was developed by M. Poirée in 1834 for a 72-foot navigable pass in the dam as Basseville, France on the River Yonne. This improvement over earlier pass technology involved a series of iron bars fastened to the top of iron frames to support wooden spars called needles used to close the path. A major feature of his invention was the manner in which the frames were removed when the pass was to be opened. This was accomplished by removing the needles by hand, unhooking the bars connecting the frames, and turning the frames down into recesses in the apron (Wegmann 1899:151-152).

Another means of emergency closure employs a series of wickets housed in slots in the lock sill. In its raised position, a wicket forms a modified A-frame. A handling derrick maneuvers the wickets. A disadvantage cited by C.E. Blee was that the wickets were continually immersed in water when stored and were therefore subject to severe corrosive action. In addition, the slots were subject to silting. Emergency closure wickets were installed at the Montgomery Locks on the Ohio River, as well as at Pickwick Landing Dam on the Tennessee River (Blee 1951:851-852).

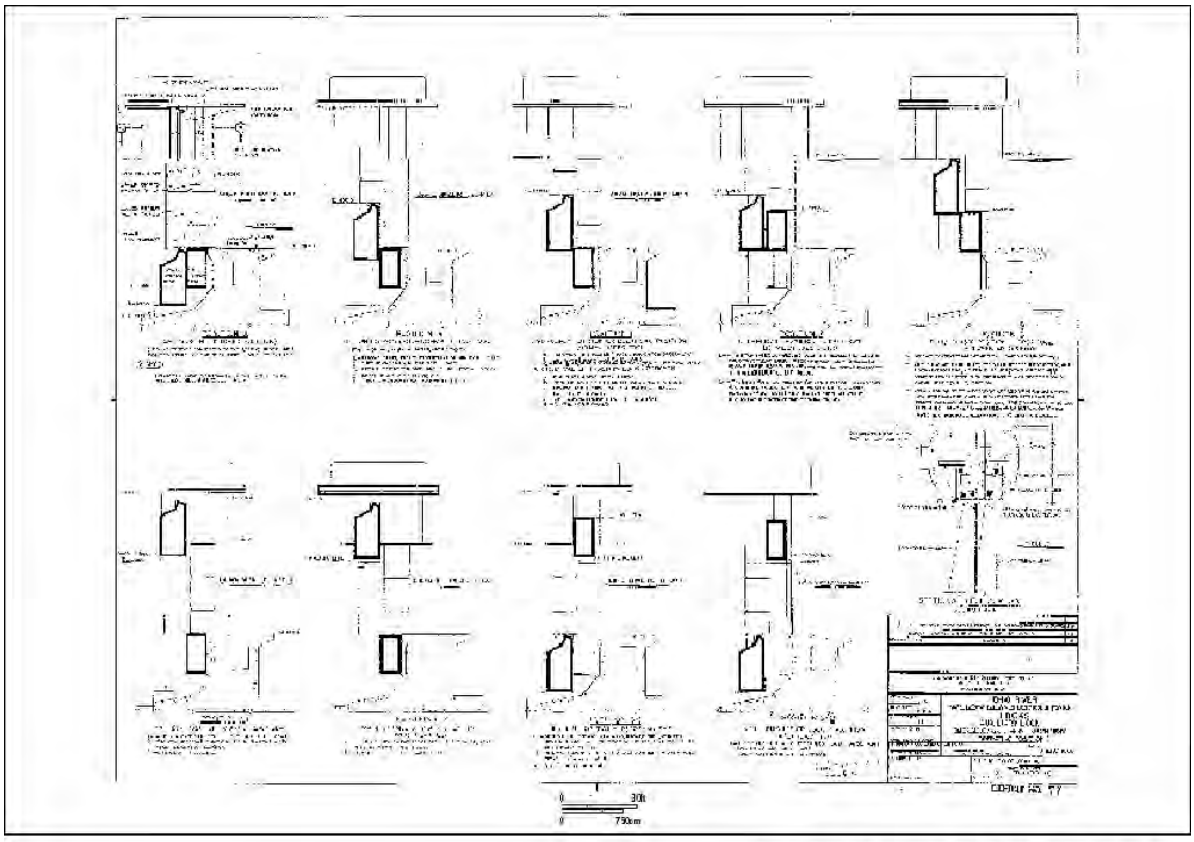
The Emsworth, Montgomery and Dashields 110-foot chambers have emergency closures consisting of Boulé dams located at the upper ends of the lock. This dam consists of trestles and bulkheads set up by a derrick crane. The trestles, with 11 feet 8 inch centers, are raised parallel to the lock walls from their trenches in the bottom of the lock chamber by a derrick crane. The trestle prop is hinged at the bottom, and the derrick is rigged with an operation chain to which the trestle chains are attached by clamps. The trestle is then raised into place bringing the next trestle's chain with it. Aprons, which serve as walkways, are pin-connected to the tops of the trestles. Maintenance closure gates, located at the lower end of the main chamber, consist of Poirée dams at both Emsworth and Montgomery. Prior to 1982, the Dashields lock also employed a Poirée dam. In 1982, this maintenance closure was replaced with a bulkhead system, identical to that used at Hannibal locks (USACE-Pittsburgh 1971:4; USACE-Pittsburgh 1972a:2-3).

The auxiliary lock chambers at Emsworth, Dashields and Montgomery each use needle dams for upstream closure. The original needle dams consisted of a coffer beam with trestle and timber needles. The present closure system uses steel needles. A derrick crane places a coffer beam into two slots cut in the walls. The coffer beam is then used as a brace for trestles that are lowered into place upstream of the beam and rest on a sill at the bottom of the chamber. The tiber needles were used to connect the box trestles to the coffer beam and each other, and the boxed trestles were edges with wood timbers for better sealing. Three sets of beams and needles were stored at the Pittsburgh district's warehouse and were used for all the 56-foot chambers in the district. Maintenance closure of all three auxiliary locks is accomplished by Poirée dams located at the lower ends of the locks (USACE-Pittsburgh 1971:3-4; USACE-Pittsburgh 1972a:2-3).

Many of the locks constructed as part of the post-World War II modernization program used a newly developed system of emergency gates. Submergible double-leaf lift gates are employed. These gates were designed to be operated under maximum head and unrestrained flow through the lock chamber (Figure 1-35). The upstream leaf, consisting of horizontal girders and a skin plate, is designed for use as a movable sill. The downstream leaf, also constructed of horizontal girders and skin plate, is designed for operation through flowing water (USACE-Huntington 1976:7). When not in use, both leaves were lowered to prepared beds behind a concrete sill across the upper lock entrance above the upper miter gates. Hoisting equipment is provided (Bruce et al. 1957:1239-10). At Meldahl locks, the two leaves are each 21 feet high and are designed so that only the downstream leaf needs to be operated when the river is at or near normal upper pool. When the river is above normal upper pool and the emergency gates are to be closed through flowing water, the downstream leaf is always raised first (USACE-Huntington 1969:3).

At Meldahl locks, the hoisting equipment is located in structures raised above the lock walls. The hoist consists of a double-grooved rope drum driven by two stages of open spur gearing, a herringbone or helical gear reducer, and an electric drive motor with brake. The rope drum has three layers of rope. The hoist components are mounted on a structural steel frame that is anchored to a concrete structure on the lock walls (USACE-Huntington 1969:4).

Figure 1-35. Willow Island Locks and Dam. Locks. Auxiliary Lock. Emergency gate hoist machinery operating positions (U.S. Army Engineer District, Huntington 1968). (From USACE-Huntington 1976).



Should one miter gate be standing open and the other be opened by a navigation accident, the emergency gate can stop flow through the lock chamber, thus saving the navigation pool and allowing navigation to continue through the other lock. The emergency gate can also function as an upstream bulkhead which, together with the downstream bulkheads, will permit dewatering of the lock and repair of damaged miter gates (USACE-Huntington 1969:2).

By 1964, vertical lift emergency gates were in use at Greenup, Meldahl, Markland, McAlpine as well as Barkley Lock on the Cumberland River and Eisenhower Lock on the St. Lawrence River. New Cumberland Locks used steel bulkheads for emergency closure as did Pike Island (Richardson 1964:81, 99). Subsequent projects installed vertical lift emergency gates at Racine, Willow Island, and Robert C. Byrd locks, as well as Winfield locks on the Kanawha River (McCoy 2000).

Maintenance closure of the locks for most of the locks is accomplished in two basic ways: Poirée dams and lock bulkheads. For example, at Racine locks a set of bulkhead sections are used for closure. These bulkheads are assembled in the lock wall bulkhead recesses, on the sill provided downstream from each of the lock service gates, and are placed by floating plant (USACE-Huntington 1971:4). The Meldahl lock bulkhead consists of 5 six-foot high sections creating a damming height of up to 30 feet. A similar lock bulkhead is used for Greenup Locks. The bulkhead can also be used as the downstream closure in gate bays of the dam (USACE-Huntington 1969:4). At Belleville locks, the bulkheads are placed by a crane operating on the crane bridge extending continuously over both locks and the dam. The Belleville bulkheads are multi-purpose, used for emergency closure of the lock chamber, as a means of skimming drift and ice accumulation from the upper lock approaches, and for dewatering the lock chamber for

maintenance and repair. The same bulkheads are intended for use at Racine, Belleville or Willow Island (USACE-Huntington:Belleville: 3).

The dam system employs metal trestles that collapse sidewise onto the dam foundation at high water. At low water the trestles are raised and boards laid across for workers to walk on. The workers lower wooden boards, known as needles, to rest on the upstream face of the trestles, forming a dam (Kemp 1991:2).

In his study of lock closures, C.E. Blee noted that in those locks equipped with rolling lock gates, maintenance of these gates was made possible by use of a floating coffer or caisson and a temporary navigation gate. He noted:

> having a broad base and a vertical access superstructure. When sunk in place over a gate track, it extends halfway across the lock. The temporary gate is used across the other half of the opening. By pumping out the central part of the caisson, access is provided to that part of the gate track covered by the caisson. The other part can be inspected and repaired by reversing the position of the caisson and temporary gate. When the caisson is on the land side of the lock chamber, it bulkheads the gate recess, thus permitting work on the gate. The caisson and temporary navigation gate are handled by suitable derrick boats. Navigation through one side of the lock is maintained by handling the temporary gate (Blee 1951:857-858).

Bulkheads are generally used for emergency closure of a dam gate bay. At Racine Dam, four similar sections are latched together to form the bulkhead. Each section is 110 feet long and 8 feet 6 inches high giving a total damming height of 34 feet above the sill. At Meldahl Dam, the bulkhead sections measure 100 feet long by 9 feet high. Because the bulkheads work as a unit, the result is basically a vertical-lift type gate.

The bulkhead sections are of welded construction and are fabricated principally of low allow steel. Each bulkhead consists of an assembly of three open horizontal trusses with lateral bracing and an upstream skin plate. Vertical tee stiffeners support the skin plate. All bulkhead sections are designed for the bottom position in the assembly for complete interchangeability. Latching devices are provided at each end of the bulkheads for latching the sections together.

Bulkhead sections are placed in the dam gate bays by a traveling bulkhead crane electrically powered from a trolley contacting conductors on the bridge beam. A lifting beam supported by the crane hoists handles placement of the bulkhead sections (USACE-Huntington 1971:8). The bulkheads, each weighing 90 tons, can be picked up and transported from their stored position in any of the gate bays and placed in a gate bay selected for closure (USACE-Huntington 1969:12). This design was used at Belleville, Greenup, and Captain Anthony Meldahl complexes (USACE-Huntington 1971:7).

The Gallipolis Dam uses a different means of placing bulkheads. The upstream emergency dam consists of seven emergency bulkhead units which are lowered into place by a floating crane unit and which rest on the upstream edge of the roller gate sill and the upstream emergency bulkhead supports. Each of the seven units consists of two trusses approximately 128 feet in length and four feet high, connected by lateral and transverse bracing, and plated on one side. Timber seals are provided where the bulkheads contact each other (USACE-Huntington 1970:5).

Power Systems

When the Davis Island Lock and Dam on the Ohio River was being planned in the 1870s, the Board of Engineers had suggested that steam engines be used to pull the lock gates and to open and close emptying and filling valves. Major W.E. Merrill preferred, instead, to use a turbine to provide power for lock operation. In his history of the Davis Island Lock and Dam, Leland Johnson described the operation of Merrill's system:

> When the turbine was spinning, it would power a pump to move water from the river into two wooden tanks on trestle towers of the sort used to replenish locomotive boilers. The system included a 25-inch-diameter turbine placed in the lock river wall, a pipe across the bottom of the lock to the pump, a pipes from the pump to the top of the water tanks. The tanks provided a reserve of water to spin turbines at each lock gate, the water dropping through pipes some sixty-two feet from the tanks to the turbines. As a redundant back up system, he also purchased a portable steam engine, albeit reluctantly. "One of my chief objections to steam," he told William Martin, "is the fear that at night, when there is little travel, the fireman will fall asleep & explode his boiler or let his steam run down so low as to be insufficient to do the required work." His fear proved well founded; several years later the steam engine boiler exploded, killing the dam tender (Johnson 1985:90-91).

At Davis Island, the steam for operating the lock gate engines was generated in a boiler at the lower end of the locks, while the steam for the upper gate engine was piped about 600 feet to the engine. Because of trouble with condensation in the long steam line, a boiler was installed at the upper gate recess.

At the subsequently constructed locks, potential waterpower available when the dam was up was not used. Power for operating the gates and valves was instead obtained from coal burning steam plants or from gas engines at locations where natural gas was available. Machinery and boilers for lock and dam operation were located in a powerhouse (Figure 1-36). In the earlier locks, compressed air was used for operating the filling and emptying valves, working through jacks, racks and sectors connected to the valve stems. Eventually, difficulties experienced with the use of air led to the substitution of an oil-hydraulic system for operating valve jacks.

At Lock No. 6, the boilers were originally located in the powerhouse, opposite the middle of the lock. Steam was piped about 300 feet to each gate engine, and condensation problems resulted. Compressed air was first used to assist in the moving of the beartrap gates. With the installation of a larger compressor, compressed air was used to power the gate engines (Sibert 1908:1199).

The original configuration of the Lock No. 6 power system is shown in Figure 1-37. The powerhouse was equipped with boilers, electric generator and steam pump for operating hydraulic jacks. A three-foot diameter pipe conduit extended from the powerhouse and subsequently branch off in several places. A three-inch steam line contained in a 12 inch by 22 inch conduit extended the length of the land wall of the lock to steam engines that provided power for operating the rolling lock gates. Four way valves were attached to each steam engine to control the jacks that operated the filling and discharge valves in the river wall. Pipes extended beneath the floor of the center of the lock to connect to pipes extending the length of the river wall. Two jacks mounted in the pipeline synchronized the operation of these valves.

An anonymous writer in the Corps of Engineers' *Professional Memoirs* suggested an auxiliary power system in which two 50 inch turbines would run an air compressor to operate the lock and dam during breakdowns in the main power plant (Anonymous 1909a:422-424). It is uncertain whether this proposed scheme was used at any of the numbered locks.

Figure 1-36. Power House for Ohio River Dams. Longitudinal section of power house (Pittsburgh District, U.S. Army Corps of Engineers 1905). From Cartographic Branch, National Archives.

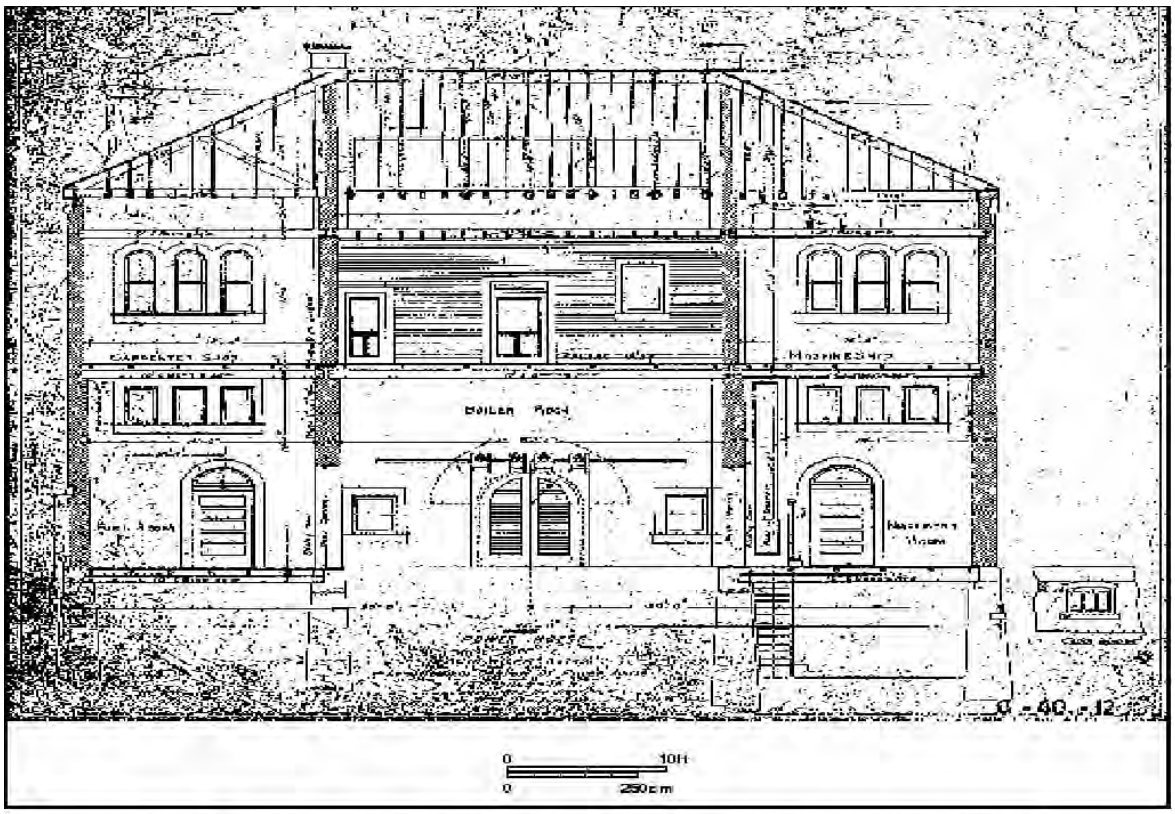
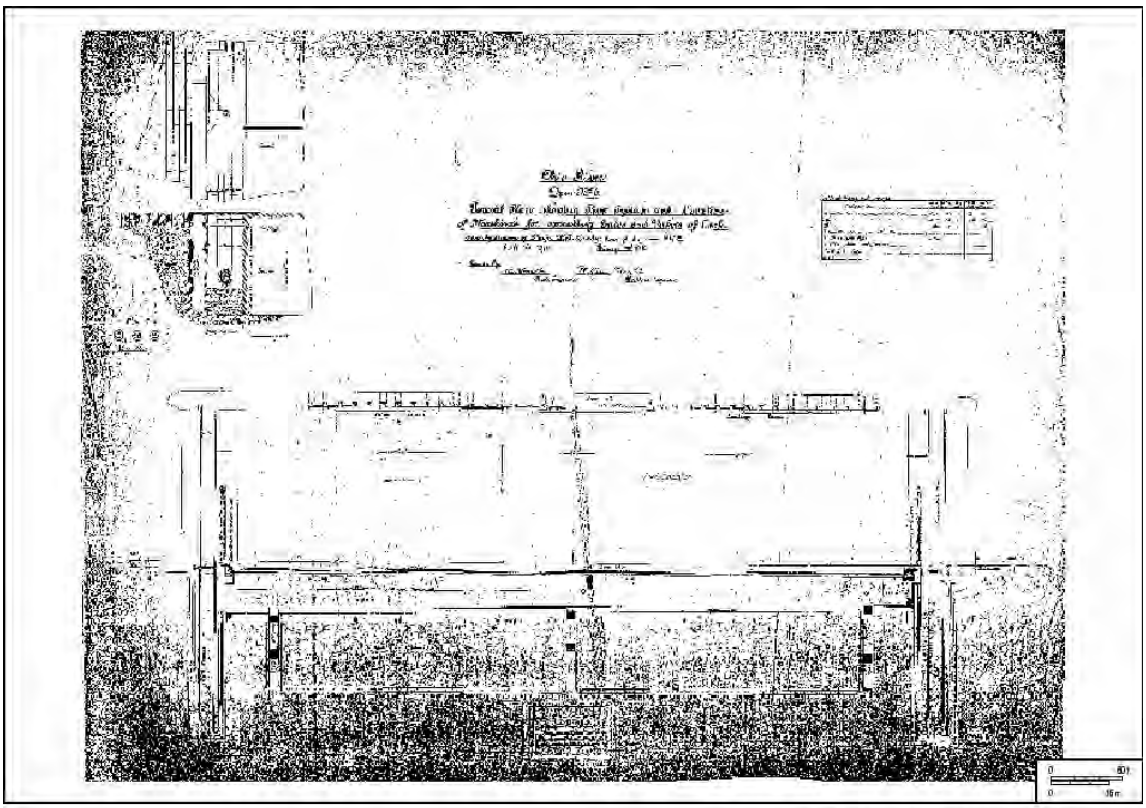


Figure 1-37. Ohio River Dam No. 6. General plan showing pipe system and location of machines for operating gates and valves of lock (Venable 1900). From Cartographic Branch, National Archives.



Subsequent locks used a power system consisting of two Westinghouse, three-cylinder, vertical, gas engines that operated on natural gas, and two-chain-driven, Blaisdell, two-stage air compressors. The operation of the beartraps was facilitated by air forced into the lower leaves, directly from the air tanks. The gate engines were also operated by compressed air. The filling and emptying valves were operated by liquid pressure; the pump was operated by compressed air (Sibert 1908:1199).

The locks built between 1914 and 1930 had a water turbine installed on the river wall that served as a primary source of power. A land power plant was also provided as an auxiliary and was equipped with a semi-diesel engine (Kutz 1930:434). For example, the original operating machinery of Emsworth locks, installed in the 1920s functioned by compressed air supplied by a turbine-driven compressor on the land wall. In 1968, this power source was replaced by a hydraulic system (USACE-Pittsburgh 1971:2).

Many of the locks and dams on the Ohio were constructed with low-head Francis turbines of 30 to 150 hp (20-125 kw) intended for use as standby power sources and where the head permitted, as primary power sources. Some of these turbines directly operated oil pumps. By 1940, commercial electric power became generally available, and turbines were rarely used. Steam plants were replaced by diesel engines or diesel-electric generators (Engineer School 1940:380).

The Deadman Island Locks and Dam were built for waterpower operation. The complex was equipped with three turbines, the independent intakes of which opened directly through the river wall at the upper pool. In addition to the turbines, the equipment included oil pumps and accumulators. The latter devices, operated in conjunction with each pump, provided the additional power needed for gate operation. Casey described the operation of the turbine system:

> The power turbines are of the vertical, open flume, wicket gate type. Two of these turbines operate vertical triplex pumps giving 250 pounds pressure in the oil lines for lock operation. The third, through a vertical shaft and bevel gearing, operates a 25 k.w. d-c horizontal electric generator for power for lighting and operating electrical facilities such as capstans. For heads of from 10 to 14 feet between upper and lower pools, either turbine will drive either pump. For heads less than this, both turbines may be connected to drive either pump….
>
> When power is used, the turbine is brought into operation by the opening of the turbine gates…. The turbine remains in operation all the time power is being used and until the accumulator is then filled, when it stops automatically. This power is transmitted to the gate and valve-operating cylinders on both locks by high pressure oil lines (Casey 1929:447).

A vertical fire tube boiler was installed to provide reserve power in the event that the turbines were out of operation.

By 1940, lock operating machinery was generally of the electrical or hydraulic type. Electrical equipment had the advantage of low initial cost, high efficiency, lower maintenance cost, and dependability, Hydraulic operation of valves and gates has the advantage of elasticity, avoiding overloads on the power units and shocks and jars on the structures themselves. There are few moving parts, and individual jacks in a large system may be controlled by one control valve. This last feature was especially necessary on the Ohio, where 34 separate butterfly valves in as many lateral culverts had to be operated at one time. In addition, hydraulic machinery is not damaged by submersion, a major point in its favor on the Ohio River (Engineer School 1940:388-389).

Presently, the lock machinery at all Ohio River locks is operated by an electrically powered hydraulic system similar to that used at most locks on both the Monongahela and the Allegheny rivers.

Construction Techniques

In his history of the Louisville District, Corps of Engineers, Leland Johnson noted the difficulties contractors faced in lock and dam construction on the Ohio River:

> Floods frequently arrived unexpectedly, topping cofferdams, injuring equipment, destroying completed work, and burying the work under tons of silt. Work was ordinarily suspended during bad weather and high water season; on this account, contractors were often allowed a certain number of “fair working days” to complete a project. Delays and accidents beyond the control of the contractor were usually considered ample reason for extending contract time, but contractors assumed all risk to the equipment and unfinished construction (Johnson 1975:182).

The original Louisville and Portland Canal, the earliest major engineering project on the Ohio River, was excavated using hand tools, oxen-drawn plows, and scrapers dragged by horses. Excavated materials were removed in wheelbarrows and horse-drawn carts. Gunpowder was used to facilitate rock excavation (USACE-ORD 1979:17).

Lock Materials

The earliest locks in the Ohio River Valley were constructed of cut stone. By the twentieth century, all of the locks with the exception of the steel gates were constructed of concrete. Given the huge masses of concrete involved, design and control of the concrete was an item of major importance. The design of the mix for the modern locks represented a combination of laboratory and field practice. Lieutenant W.E. Potter described the procedure used at Montgomery Island Locks:

> Extensive analyses were run on the aggregates for both physical characteristics and grading. After ascertaining that the aggregates were physically satisfactory, a series of sieve analyses were run. The aggregate proportioning was determined by trial…
>
> The aggregate proportion which gave the least voids was then used in the selection of sand percentage. Sand was added in quantity equal to the voids in large aggregates, plus 5 per cent. Cement to the amount of five sacks per yard was added…and several hand mixes were made and changes were made in the sand content until the best quality concrete was obtained. This is the true laboratory mix, but due to the large size of the aggregate, it does not give a true picture of the mix as used in the field. Further work is then transferred to the field where full size batches (usually 2-yard) were made….Since the mix was

Figure 1-38. Typical section through Ohio River type box cofferdam (Dravo 1947).

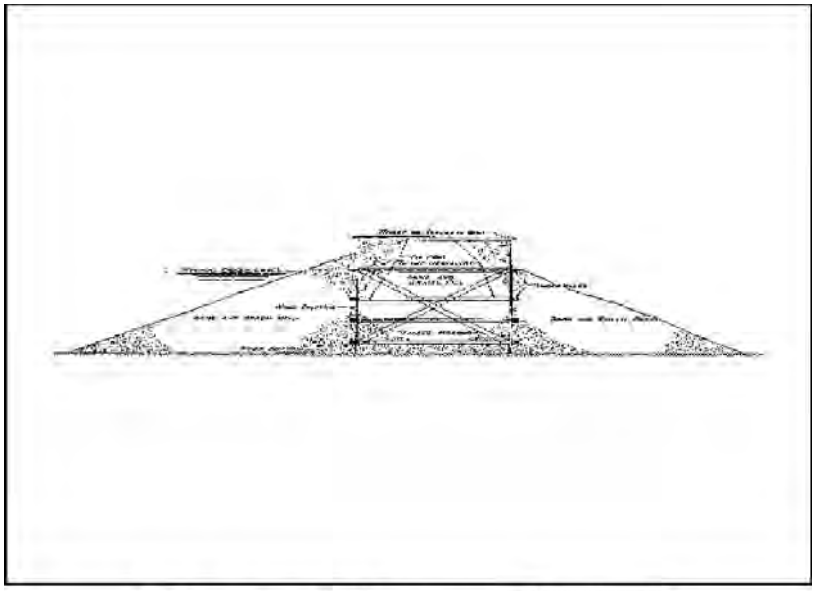
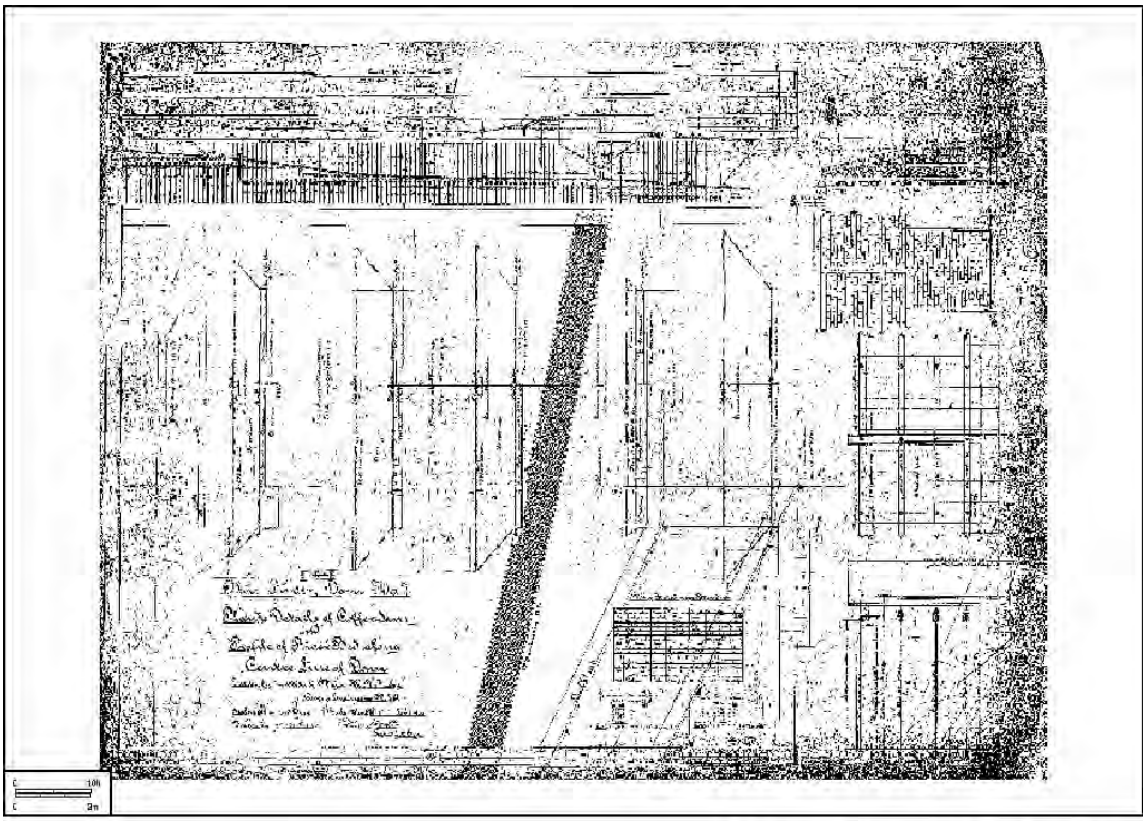


Figure 1-39. Ohio River Dam No. 2. Plan and details of cofferdam (Bowman 1900). From Cartographic Branch, National Archives.



approximately correct when it left the laboratory, only minor changes were necessary in the field (Potter 1935:105-106).

Cofferdams

The first cofferdams used in American lock and dam construction consisted of a dike of compacted earth. These cofferdams were sometimes improved by installation of a central cutoff wall of wood piling, and occasionally by the use of riprap on the exterior to reduce scour. Such primitive cofferdams were subject to major damage during high water periods.

Another early method of cofferdam construction involved the use of a crib of interlaced timbers filled with rock to provide stability and sheeted on the outer face with tightly engaged wood sheeting. These cofferdams tended to be reasonably durable during periods of high water (Jansen 1948:26).

A third type of cofferdam was developed for early Ohio River construction and was therefore called the Ohio River type box cofferdam (Figures 1-38 and 1-39). This structure consisted of two rows of wood sheeting spaced 16 to 20 feet apart with timber wales on the outside held together by steel rods passing through wales and sheeting (Jansen 1948:27). A typical box cofferdam employed for Lock and Dam No. 53 was described in a 1928 article in *The Military Engineer*:

> An ordinary box-type cofferdam, 30 feet deep, was used to enclose the lock chamber. The cofferdam was held together by ½-inch steel rods and was braced laterally by 6- by 8-inch wales. Two-inch sheeting was placed on the sides of the wales (Suppiger 1928:513).

This cofferdam was placed on the river bottom with suitable protection against erosion. If rock was fairly close, a trench could be dredged out so as to set it on rock. As usually designed, the cofferdam was not a self-sustaining structure but required extensive banking both inside and out to give it stability. This banking also helped to prevent seepage (White and Prentis 1940:151-152).

Carl Jansen described construction of the Ohio River box cofferdam:

> …the first operation was to assemble on a barge a framework consisting of the wales, rods, spreaders and bracing, with one vertical sheet of planking at each tier of rods. As the barge moved forward the structure was allowed to settle into its place on the river bottom. The remaining spaces between the rods was then sheeted on each side with 2- or 3-in. planks resting on the river bottom, the size of the planks depending on the depth of the cofferdam, which was filled immediately as near as possible to the top. A berm was then placed on both the inner and outer sides. Sand and gravel as dug from the river provided the best kind of fill and were ordinarily used. In most cases a decking was placed over the top, composed of either 2-in. plank, or a layer of concrete 4 to 6 in. thick, to prevent washing out of the cofferdam fill during periods of high water. It was often necessary to place riprap around the corners to prevent scour inasmuch as stages up to 50 ft. could be expected to overtop any cofferdam in the Ohio River (Jansen 1948:28).

The specific techniques used to construct the Lock 53 cofferdam were described by E.W. Suppiger:

> Dredge and derrick boats excavated along the line of the lock walls, and the excavated material, sand and gravel, was used to fill the cofferdam. After the cofferdam had been sunk, the water was pumped out. The pump boats settled to place on pile foundations as the pumping advanced. Two 15-inch centrifugal pumps were used on each of the boats, with steam supplied by three 150-horsepower marine boilers. An air compressor and a complete electric-lighting plant for night illumination were also part of the equipment. Work on the dam was carried on twenty-four hours per day for seven days per week.
>
> As the water inside the cofferdam fell, the railroad tracks, which had been built previously, settled to place…Four pile-driving boats were required to drive the wood and steel piles (Suppiger 1928:513).

The Ohio River box cofferdam had several disadvantages. Because of its design, the cofferdam was necessarily located a substantial distance from the enclosed work. The berm was constructed with a slope of 1 to 2 or 1 to 3 in the river near Pittsburgh and with a slope of 1 to 5 or 1 to 6 further downstream where the river bed contains more sand and gravel (Dravo 1947:7). The cofferdam also necessitated the provision of two types of plants on each job, a floating plant for use on the outside and for building the cofferdam itself, and a land plant for work inside the

cofferdam. This type of cofferdam also occasionally suffered substantial damage from high water (Jansen 1948:28).

To address these disadvantages, several new types of cofferdams were developed. One type was the internally braced interlocking steel sheetpile cofferdam (Figure 1-40). After several unsuccessful attempts, this type of cofferdam was successfully used for the first time at Dam No. 23 on the Ohio River. This type of cofferdam permitted the use of floating equipment almost exclusively. The equipment could be removed quickly if flood or ice threatened (Jansen 1948:28).

The cofferdam used arch web steel piling with timber sets at sufficient frequency to provide adequate strength. The cofferdams at Dam No. 23 were built in lengths of 160 feet with an additional transition section of 16 feet. Each cofferdam was 42 feet wide. Dravo Corporation spokesmen noted that although one rise of the river filled the cofferdam completely with chunks of ice and twice the coffer was half filled with river deposit, the steel pile cofferdam held (Dravo 1947:16-17).

At the same time when new cofferdams were under development increased use was made of caissons (Figure 1-41). For example, the contract for Dam No. 32 was awarded to the Dravo Corporation in 1922. The dam was to be constructed using pneumatic caissons. When the first caisson was sunk to the level where rock was supposed to be foundation, there was no rock, only compact sand and gravel and boulders. To accommodate site conditions, Dravo constructed the entire dam with the exception of the beartraps with steel floating caissons sealed under compressed air (Miller 1950:28-29; See Figure 1-38). These thirteen caissons were designed and assembled by Dravo in Pittsburgh and towed to the dam site, 372 miles downriver. The size of

Figure 1-40. Typical section through a steel sheet pile cofferdam (Dravo 1947).

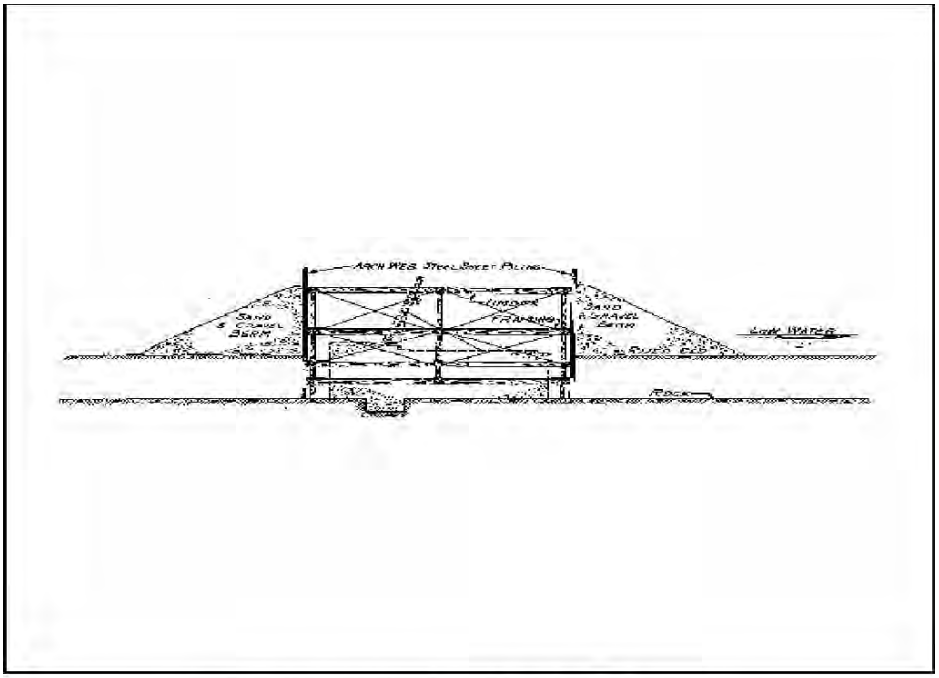


Figure 1-41. General layout of caissons and cofferdams. Ohio River Lock and Dam No. 32 (Dravo 1947).

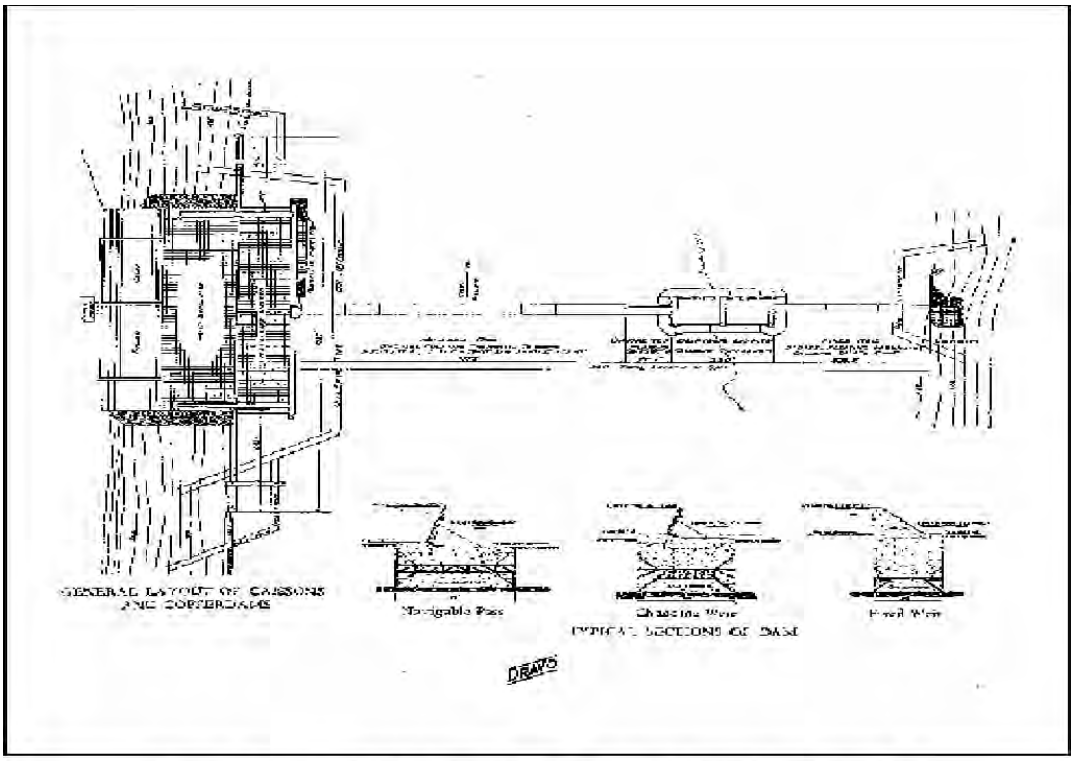


Figure 1-42. Section through navigation pass caisson (Trippe 1924).

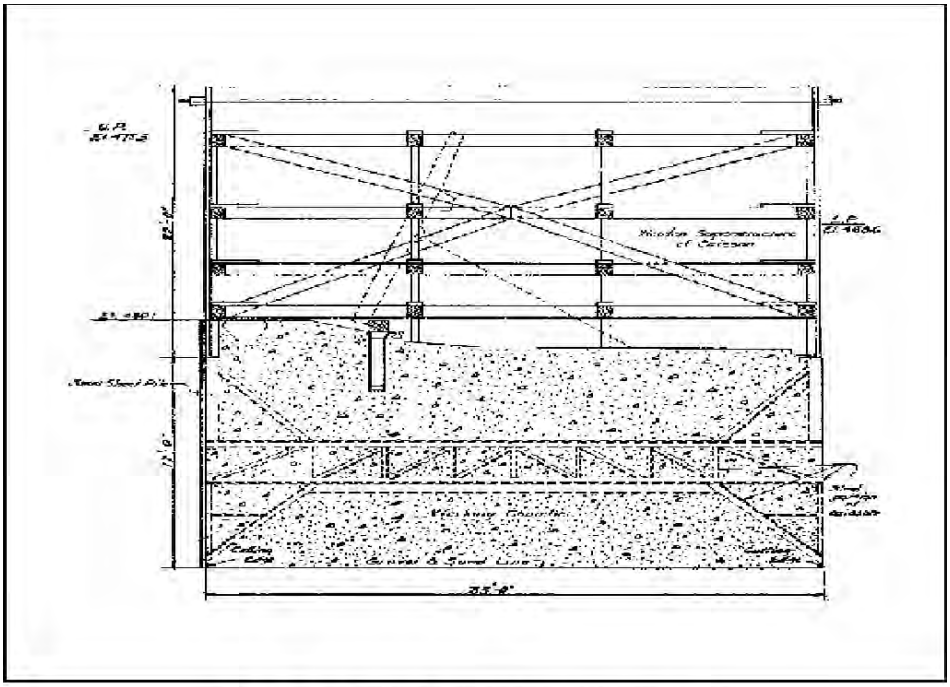
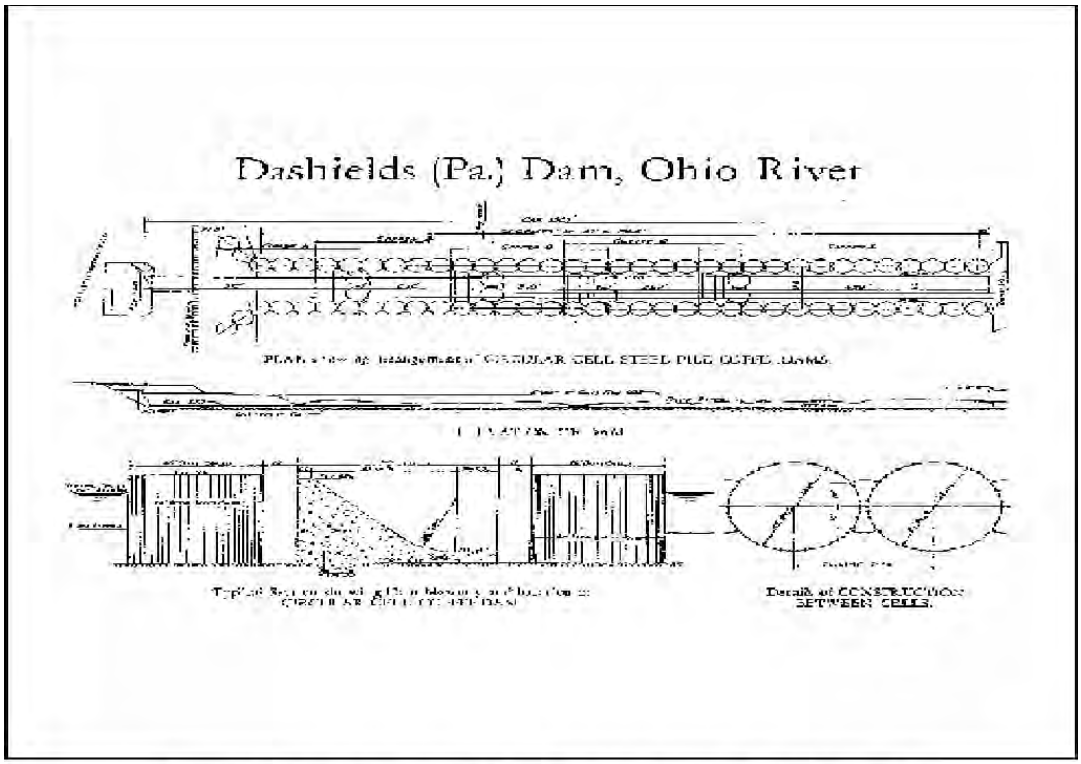


Figure 1-43. Plan, typical section, and details of circular cell steel pile cofferdam used at Dashields Dam (Dravo 1947).



the caissons varied from 35 feet by 75 feet for one section of the navigable pass to 20 feet by 111 feet 4 inches for the fixed weir (Dravo 1947:19; Figure 1-42).

The first caisson was sunk adjacent to the river wall of the lock. Excavation within the caissons was done by open dredging until the caisson had been sunk to an elevation supposedly near rock. Air locks were attached to the dredging tubes, compressed air was supplied, and the sinking continued through compact boulders and gravel. In the absence of rock, the first two caissons were carried down to a fire clay strata and then sealed (Dravo 1947:20). The pneumatic caissons were sunk independently along the lines of the dam with a concrete seal placed between sections using the tremie method. This approach enabled the use of a relatively small plant and made all parts of the work accessible to floating equipment (Jansen 1948:28).

On Dam No. 32, caissons were impractical for construction of the piers and beartrap weirs. The shallow foundations of the beartrap piers and the absence of rock on which to found the caissons did not permit the addition of sufficient weight to hold the caissons in place (Dravo 1947:20). This led to the use of a cellular type of interlocking steel cofferdam in which the bases of the piers and weirs were placed by submarine concrete bucket. Steel pile cells were filled with sand and gravel to provide stability. This type of cofferdam allowed floating equipment to handle practically all the work including the erection of the beartrap steel (Jansen 1948:28).

The first use of a cellular steel cofferdam for the entirety of dam construction occurred at Dashields Dam (Figure 1-43). The cellular steel cofferdam has been developed to raise the battleship *Maine* in Havana Harbor. (Miller 1950:54) and was first successfully used in the construction of the Black Rock Lock on the Niagara River in Buffalo (Jansen 1948:29).

The Dashields Dam was constructed in 1928-1929 within five sections of cofferdam, using cells 40 feet in diameter, spaced 42 feet from center to center. The 2-foot spaces between the cells were closed by two short arcs of sheeting connected to T-piles in the walls of the cells. Five sections of cofferdam each enclosed an area 80 feet wide and varying from 210 to 498 feet in length (Dravo 1947:29-30). Carl Jansen discussed the success of this cofferdam at Dashields:

> The Dashields cofferdam was looked upon by some as an experiment, uncertain of success. Nevertheless, actual experience proved its practicality. The cofferdam, which was driven to rock, provided for a 40-ft. head of water and permitted continuous work within the cofferdam until the river exceeded a level 8 ft. above normal. Full-revolving whirlers mounted on top of the concrete-decked cofferdam had uninterrupted access to the work (Jansen 1948:29).

The cofferdam was exceptionally watertight. After unwatering the 80 by 489 foot section under a 32 foot head, one 15-inch centrifugal pump kept it dry (Dravo 1947:30). Subsequent dam construction projects involved development and adaptation of this type of cofferdam.

As a result of cofferdam failure during the construction of the Cannelton and Uniontown locks and dams, the Stage 1 cofferdam for Hannibal Dam was redesigned during construction. It was anchored, using prestressed cable anchors more than 45 feet long grouted into rock and using concrete thrust blocks placed against the base of steel sheet pile cell walls. In addition, 63 pressure relief wells were installed at the base of the cofferdam cells and frequent testing of the underlying clay was made.

The Stage II cofferdam was also modified based on experience at Cannelton and Uniontown. The distance between the upstream and downstream arms was increased and the cofferdam was strengthened by berming the inside of the cofferdam 8 to 12 feet in height behind a seepage control wall. Instrumentation was installed to monitor site conditions (USACE-Pittsburgh 1973:5).

The contractor for Newburgh Locks and Dams, whose construction began in 1965, implemented an innovative cofferdam technique because bedrock lay a hundred feet below normal river level. A complex of subcoffers were used inside the main cofferdam for the pier foundations. The large cofferdam was constructed and dewatered and then more cofferdams were built inside to get deeper into the riverbed with safety. One of these cofferdams was in a unique figure-eight configuration to eliminate the need for internal bracing. Additional pier stability was gained by the first Louisville District use of prestressed rock anchors, steel cables up to 123 feet in length (Johnson 1984:41).

One of the engineering problems faced by Louisville District staff was building locks and dams on a sandy foundation, characteristic of the riverbed of the lower Ohio River. The solution they developed consisted primarily of driving round timber piles, generally about thirty feet long, to the rock substrata and building the concrete foundation for the lock or dam structure around the tops of the piles. Wooden and later, interlocking steel sheet piling, was driven down on the upstream side of the structure to form a curtain protecting the foundation. Riprap stone was placed on the downstream side to prevent scour and further stabilize the structure (Johnson 1975:183).

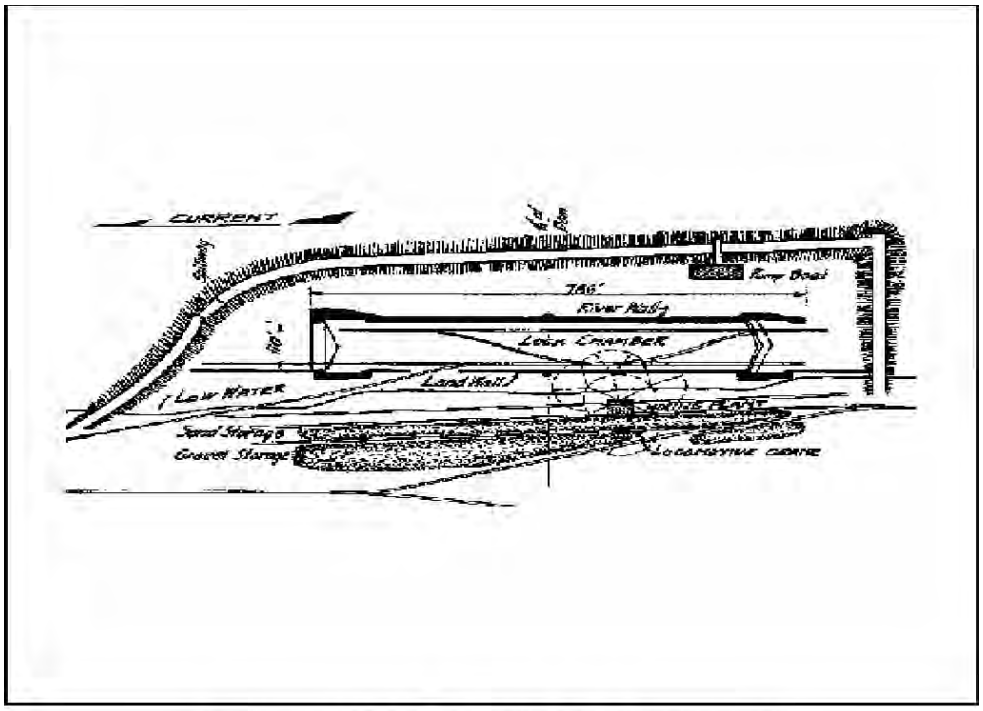
Construction Methods

To transport materials to and from the cofferdam construction sites, cableways were generally used. For example, at Lock and Dam No. 37 near Cincinnati, Ohio, two cableways of 300-ft. span were erected. These cableways were used to remove excavation material, deliver concrete, handle material, and erect the steelwork of the rolling lock gates. All work on the dam was done by stationary derricks in the pit and at the concrete mixing plant and by traveling derricks that ran on the cofferdam (Anonymous 1909b:238).

A *Military Engineer* article by Captain W.F. Heavey described the concrete mixing and placement at Lock No. 45. The project included pouring of 40,000 cubic yards of concrete to form two walls, a land wall of 1,100 feet and a river wall of 785 feet. Construction at this lock was accomplished using a movable gravity plant for concrete mixing and distribution. Heavey described the track system:

> The mixing plant moves on two standard gage tracks laid on 20-foot centers, the one next to the lock being six feet lower to conform to the slope of the bank and thus reduce the grading necessary for the road-bed. A third track was laid on top of the bank, and 30 feet from the upper mixer track, for a locomotive crane which is used for feeding the sand and gravel bins from storage piles on the bank….The upper mixer track is connected to the yard tracks thus allowing the cement in the railroad cars to be moved, as received, directly to the mixer and unloaded on an inclined belt conveyor which carries the cement to the mixing platform of the concrete plant (Heavey 1924:144; Figure 1-44).

Figure 1-44. Layout of lock coffer, Dam No. 45, Ohio River (Heavey 1924).



The mixing plant, designed by engineer H.G. McCormick, used materials already on hand. It consisted of a wooden tower, 50 feet high, supported by an A-frame, resting on a platform of I-beams that rested on a standard flatcar. The lower lifts of the river walls, the upper and lower miter sills, the land wall, and sections of the guide walls, were poured directly from the plant by chute. The concrete for the upper lifts of the river wall needed to be rehandled by a locomotive crane and bottom dump buckets (Heavey 1924:145).[4]

Booth & Flinn, the contractors for the Montgomery locks introduced three long-span cableways of 1,510 feet in their construction site (Figure 1-45). The firm had pioneered the use of these long-span cableways in their early George Westinghouse Bridge construction near Pittsburgh. 150 foot high head towers and 110 foot high tail towers supported the Montgomery cableways. Each had a capacity of 25 tons. The cableways handled much of the excavated material and backfill, placed all of the concrete, aided in erecting forms, and transported miscellaneous supplies and materials. A central mixing plant was erected on the cofferdam which discharged concrete into the five-yard cableway buckets set on flat cars on a dinkey line (Anonymous 1934:515, 518; USACE-Pittsburgh 1972b:9).

Lieutenant W.E. Potter's article on Montgomery Locks provided additional information about the construction procedures. Describing concrete mixing, he wrote:

> The aggregates were delivered in barges which were anchored below the lower arm of the cofferdam. They were transferred as needed from the barges to the bins over the mixers by means of an American Whirley. Cement was delivered by barge and was air-blown to its bin over the mixer.
>
> The bin batchers and mixers of Blaw-Knox construction were housed in one structure, centrally situated on the lower arm of the coffer. Bins for the three aggregates and cement were in the upper part of the structure and were arranged to dump into the proper weighing hoppers….
>
> The mixer unit was composed of two horizontal 2-yard Rex mixers, end dumping. Mixing time was specified as 2 minutes for the 2-yard mix. An electric clock regulated the mixing time and prevented dumping before the specified time had elapsed (Potter 1935:106).

Montgomery Locks used two types of concrete forms, the rolling gantry and panel types. The gantries were steel structures, approximately 50 feet high, capable of forming a single monolith (Potter 1935:106).[5]

The Markland Locks and Dam construction project was notable in the amount of construction activity that took place on water. Bulk materials for construction were moved to the site by barge. In addition, three derrick boats and a mixer boat were used to drive piles and place concrete for the guide walls (Anonymous 1958).

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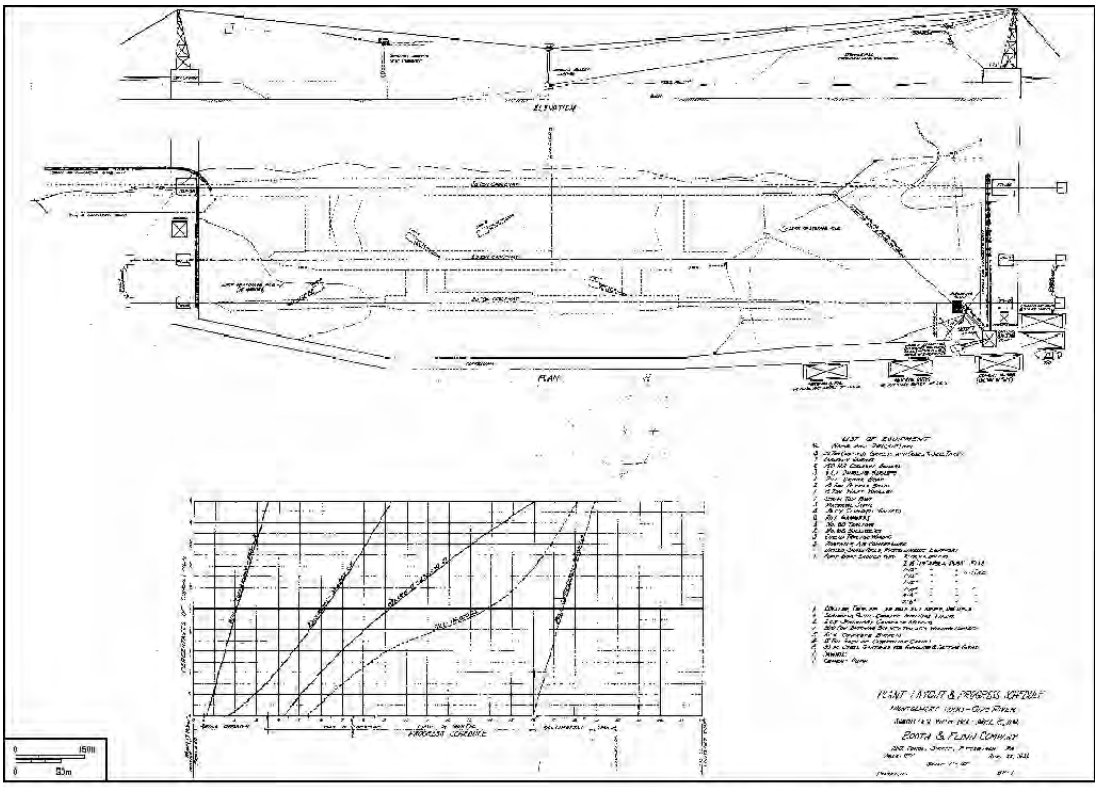
[4] The Heavey article cited in the references describes the concreting procedure at Lock No. 45 in detail.
[5] The Potter article cited in the references describes the concrete mixing and placing procedure used at Montgomery Locks in complete detail.

Figure 1-45. Montgomery Locks – Ohio River. Plant layout and progress schedule (Booth & Flinn Company 1932). From Cartographic Branch, National Archives.



HISTORIC ENGINEERING EVALUATION

This report summarizes the engineering characteristics of all the navigational structures of the Ohio River Mainstem system. To determine the engineering significance of these structures, they are compared to those of other similar navigational systems. The systems chosen for comparison are the Allegheny River, the Monongahela River, the Kanawha River, and the Mississippi River.

The Allegheny River navigation system consists of eight single lock and dam structures. All locks are 360 feet in length and 56 feet in width. All of the dams on the river are fixed crest concrete weirs. The oldest of the locks opened in 1927, while the most recently constructed opened in 1938.

The first lock chamber of the Monongahela River locks, Lock No. 1, was completed under contract to the Monongahela Navigation Company in 1841. Eventually, the MNC system consisted of seven lock and dam complexes. The last of these, MNC Lock and Dam No. 7, was completed in 1883. The first locks measured 158 feet long and 50 feet wide while the last of the locks measured 277.5 feet long and 56 feet wide. Beginning in the late nineteenth century, the U.S. Army Corps of Engineers began to rebuild existing locks and extend the navigation system further upriver. The system presently consists of nine navigational complexes. Lock sizes range from 360 feet long by 56 feet wide to 720 feet long and 110 feet wide. Construction on the earliest surviving complex, No. 2, was originally completed in 1906. Its lock chambers were later rebuilt. Lock construction at the newest complex, Grays Landing, was completed in 1993. Monongahela River dams include both low concrete weirs and high-lift, gated dams using either tainter or Sidney gates.

The Kanawha River navigation system was initially developed in the period from 1875 to 1898. The navigation system presently has three navigational complexes. One, Winfield, has three lock chambers, while the other two, Marmet and London, each have two lock chambers. With the exception of one of the chambers at Winfield, each lock is 360 feet in length and 56 feet in width. The third chamber at Winfield is 800 feet in length and 110 feet in width. With the exception of the large Winfield chamber, all the present locks on the Kanawha were constructed in the 1930s. The large chamber opened in January 1998. Each Kanawha River complex has a non-navigable, high-lift, gated dam with roller gates.

The Mississippi River has a total of 28 navigational complexes, six of which have dual locks. Locks range in size from 400 feet long and 56 feet wide near Minneapolis to several 1,200 foot long and 110 foot wide chambers further south. The oldest of the present locks, Auxiliary Lock 14, opened in 1922, while the most recently constructed, the auxiliary Melvin Price lock, opened in 1994. All dams are high-lift, non-navigable structures. The older dams employed roller gates, while the more recently constructed dams employ Tainter gates.

Locks

The earliest locks on the river systems of the Ohio Valley were constructed on stone. As concrete technology developed, it replaced stone as the favored lock wall material. Now all the locks of the five systems are constructed of concrete.

Most locks on the five river systems studied use miter gates, the most frequently used lock gates in the United States. Each gate consists of two leaves of equal size. Each leaf is hinged at the top

by means of a gudgeon pin, a fixed part of the leaf, which seats in a gudgeon or eye connected to the wall by adjustable anchorage bars. Directly below the gudgeon pin, on the bottom of the gate leaf, is a socket called the pintle bushing in a heel casting. The gate is suspended in position by the gudgeon and the pintle, the two points about which it pivots when in movement. Modern miter gates are fabricated of structural steel with horizontal, vertical, and diagonal members (Engineer School 1940:57).

Some of the larger miter gates were vertically framed while the smaller and all of the more modern gates are horizontally framed. The older vertically framed gates consisted of a large horizontal top girder and several smaller vertical beams. Load transmitted to the vertical beams was resisted by the top girder at the top and the gate sill at the bottom. The top girders reacted against one another and against the top of the lock walls.

Other gates that have been used or are in use at slackwater navigation systems of the United States include rolling gates and lift gates. As noted, rolling gates were pioneered at Davis Island Lock and Dam on the Ohio River and were later used in many of the numbered locks of the original system.

Lift lock gates resemble the vertical lift gates used at some non-navigable, high-lift dams. The lift gate is opened by either raising or lowering it between two piers or uprights on which vertical supporting tracks are laid. Lift gates were used for some locks on the Mississippi River, as well as locks on some of the western rivers.

While early locks were filled and emptied by use of valves or wickets contained in the gate, most modern locks now use a culvert system with valves to fill and empty the chamber. Culverts used on the rivers have been of two basic types. The more common arrangement has culverts extending lengthwise through the lock walls with side passages to filling and emptying ports in the lock chamber walls. Less frequently used was a design where individual filling and emptying culverts extended laterally through the river wall and allowed each port to fill from or empty to the river. The most common valve type of earlier locks was the butterfly valve, a typically circular valve that pivots on either a horizontal or vertical axis. The most common modern valve type is the Tainter valve. Less commonly found are cylindrical valves and Stoney valves.

All of the Allegheny River locks use miter gates. All are single locks constructed in the 1920s and 1930s. Each of these locks is similar in construction. All have concrete walls with filling and emptying culverts placed within them. Filling and emptying of each lock is controlled by a series of butterfly valves. For example, Lock No. 2 has eight filling ports on each wall, two eight by ten foot butterfly valves placed in each culvert, and one emptying and one filling valve, both eight feet by ten feet. Lock gate machinery is of the “Ohio River type” similar to that used on all the Monongahela River and upper Ohio River locks. The gate machinery is of the standard rack and sector gear type used throughout the Pittsburgh District. Both the lock gates and valves are hydraulically operated.

The earliest locks of the Monongahela River Navigation System were constructed of coursed, tooled stone, the typical material for mid-nineteenth century locks. Beginning with Lock No. 10, started in 1897, locks on the Monongahela River were constructed of concrete. As a result, Lock No. 10 was one of the earliest concrete locks in the Pittsburgh area. Thomas and Watt note in their book, *The Improvement of Rivers*, that the use of concrete for river works was “practically untried” in the United States until 1892, although it had been used for other hydraulic works for many years. The authors cite the Illinois and Mississippi Canal (1894) as one of the earliest uses

of concrete for river work (Thomas and Watt 1913:430, 432). By the twentieth century, concrete had supplanted stone masonry as the building material of locks.

The locks on the Monongahela River use several types of valves, depending largely on date of construction. One lock, the river chamber of Locks and Dam No. 3, still uses cylindrical valves. These valves were installed at the same time in several other lower river locks, but the other locks have either been eliminated or reconstructed. Other older locks, including Locks 2, Locks 4, and Morgantown, use butterfly valves. The most recently constructed locks on the Monongahela use reverse tainter valves. In addition, the river chamber of Locks No. 3 uses compressed-air powered wickets in its gates to supplement the cylindrical valves, while Locks No. 4 also uses compressed-air powered wickets to aid in filling and flushing out the chamber.

With the exception of the land chamber at Locks and Dam 3, all of the locks on the Monongahela River use a longitudinal culvert system for filling and emptying the chamber.[6] Most of the locks use hydraulically operated lock gate mechanisms and valve mechanisms. The oil in the hydraulic system is pumped by hydraulic pumps located in a central control building through a network of pipes to the machinery. The two newest locks, Grays Landing and Point Marion, eliminate the need for a network of hydraulic pipes by using self-contained, packaged hydraulic systems to operate each of the lock gates and valves. The gate machinery itself, which uses a rack and sector gear powered by a hydraulic piston, is standard throughout the Pittsburgh District, except for Grays Landing and Point Marion.

The initial locks on the Kanawha River were constructed using stone masonry lock walls (Johnson 1977:88). A typical early Kanawha lock was Lock and Dam 6, completed in 1886. The lock was 410 1/2 feet long on the outside and 342 feet long and 55 feet wide inside the chamber. Lock gates were constructed of white oak and turned on heavy steel pivots. Five valves were built into the lock gates. The 1930s-era locks of the Kanawha River were of concrete construction and used steel mitering gates. The side filling locks of the Kanawha are provided with 8 by 10 foot main culverts, five by eight fopot intake ports, four by five foot and five by eight foot discharge ports and ten lateral ports (Kemp 2000:255). The London, Marmet and Winfield locks were each constructed with four Stoney gate valves. These valves remain in use (Kemp 2000:103). These locks use a gate jack mechanism including a hydraulic cylinder with the piston rod connected to a rack, which in turn was meshed to a tooth sector wheel (Kemp 2000:255). The operation of this mechanism is described in *Great Kanawha Navigation*, prepared by the West Virginia Institute for the History of Technology:

> The gate jack consisted of a hydraulic cylinder with the piston rod connected to a rack. The rack was meshed to a sector arm of a tooth wheel having an attached arm, with a connecting arm which was attached to the valve. The valves were opened and closed by a single stroke of the piston. The operation machinery was set in a recess in the lock walls, shimmed to grade, aligned and adjusted to the gates and concreted into place (WVU n.d.:109).

The locks and dams constructed on the Mississippi during the 1930s were 110 by 600 feet in size. These locks employed monolithic reinforced concrete walls. The locks of the upper Mississippi constructed in the 1930s used tainter valves. The valves were raised and lowered from above by

[6] The 56 foot by 720 foot land lock at Locks and Dam 3, Monongahela River, fills through the wall. The filling valves fill from a covered flume or flumeway which draws water from the upper pool. This filling system is a transitional hybrid between the round valve culverts perpendicular to the lock wall and the modern longitudinal culvert system.

electrically driven cable hoists. Seals on the sides and bottom of the valves enabled them to close off the culverts in the lower position (O'Bannon 1989:54). Vertically-framed miter gates, pivoting on steel pintles and supported, when closed, upon steel beams embedded in the reinforced concrete gate sills, also operated electrically (O'Bannon 1989:26, 53; O'Brien et al. 1992:87).

Lock No. 27 of the Mississippi, whose construction began in 1947, employed double-leaf, vertical lift gates for the upper gates. With the lock emptied and the lower miter gates fully opened, the downstream leaf of the lift gate may be lowered until it nests behind the upstream leaf. Ice may then pass freely through the lock chamber. The lift gates are raised and lowered by electrically operated, counterweighted chain hoists (O'Bannon 1989:59).

In the upper Mississippi locks, the small culverts used on the Ohio were replaced by large longitudinal culverts located in the base of the lock walls controlled by only four valves. Intake and discharge openings were located in the lock walls, respectively above the upper gates and below the lower gates. A series of small ports branched off the main culverts and flooded or emptied the lock chamber (O'Bannon 1989:53). In post-World War II locks, the intake ports for the filling culverts are located in the floor immediately above the upper gates. For discharge, a complex discharge manifold was installed that releases water through the floor of the lock below the lower gates. This discharge system was designed to reduce turbulence (O'Brien et al. 1992:128).

Among the most notable elements of the early Ohio River locks and dams was the introduction of the rolling lock gate used to span the unprecedented 110 foot width of the Davis Island Lock chamber. Rolling gates were used until miter gates capable of spanning a 110 foot wide opening were developed. The first of these wider miter gates were installed at Emsworth Lock in 1922 and represented a pioneering use of gates of this width.

The Ohio River rolling lock gates were supported on ten sets of axles with fixed wheels that ran on a plate and channel track embedded in the concrete lock gate sill. Each axle was about 13 feet long and eight inches square and weighed about 2,100 pounds. On each end was a cast steel flanged wheel of 33-inch tread diameter and 7-inch tread width. The wheels and axles suffered corrosion due to pollution of the Ohio near Pittsburgh, and in the 1950s, the wheel and axle units of locks 7 to 13 were replaced (Combs 1954:440-441).

The numbered locks on the Ohio River were also the site of the first use of steel wall armor to protect concrete lock walls from the impact of vessels. This wall armor is now a standard feature in most United States navigation locks. While wall armor used on other locks such as those on the St. Lawrence Seaway is vertical, that used on the Ohio River is horizontal.

The Ohio River navigation system is also notable in showing the evolution of lock filling and emptying technology. Early locks were filled and emptied by valves in the gates and by valves and culverts in the river wall. In general, 17 individual filling and 17 individual emptying culverts brought water from the river and discharged water to the river. Synchronization of valve opening and closing was provided by hydraulic jacks. In the next generation of locks, the individual culverts were replaced with larger longitudinal culverts in each lock wall. These culverts, variously controlled by Stoney, butterfly, tainter or reverse tainter valves, permitted a more rapid filling and emptying of the lock chamber. Intake and outflow of water was through ports in the lock walls. To reduce turbulence in the lock chamber, more recently constructed locks have

incorporated deflection ports and culverts underneath the lock floor that discharge directly into the river.

Dams

Dams are critical elements of slackwater navigation systems. By allowing water to pool behind them, these dams provide the depth of water needed for safe navigation of the river. The earliest dams on slackwater navigation systems had fixed crests and were generally of timber crib construction filled with stones. Such construction was used in nineteenth century dams on the [Kanawha,] Allegheny and Monongahela rivers. These wood crib dams were prone to damage and failure due to flooding, debris, and ice floes. In several instances on the Monongahela, large sections of these dams washed away, and in other cases the crests were severely damaged. The dams also tended to leak badly and underseepage posed problems. As concrete technology improved, newer dams were constructed of this more durable material. Existing timber crib dams were sometimes capped or partially reconstructed in concrete.

Fix crest dams had their disadvantages. During dry periods, the insufficient amount of pooled water sometimes required suspension of lock operation. Because of the inability to change crest height, these structures are not navigable. In addition, in a complex with a fixed crest dam, high flood levels can cause cessation of lock operations more frequently than in one with a gated dam.

As noted, the first distinct type of movable dam was the beartrap, erected in 1818 on the Lehigh River of eastern Pennsylvania. It consisted of two wooden gates revolving on horizontal axes at the floor level. The downstream gate points upstream, and the upstream one pointed downstream, the latter resting on the edge of the downstream gate when raised. The dam was operated by water running under the gates through culverts and forcing them up (Thomas and Watt 1913:II:538).

The needle dam, the first movable navigational dam, was developed in France by M. Poirée in 1834 (Thomas and Watt 1913:538). An improved movable dam was invented in 1852 by Jacques Chanoine, Chief Engineer of the French Corps, and first used on the Seine River near Paris. The Chanoine dam consisted of a masonry foundation to which boards, called wickets, were hinged. When the wickets were down, boats passed over them in a navigable pass. When the river level dropped, threatening navigation, the wickets were manually pulled up. The channel was closed and water was backed up forming a slackwater pool. With the river level low, boats navigated slackwater pools and were moved from pool to pool by locks. When the river rose, the wickets were dropped, and the channel was again opened to traffic (Johnson 1977:84).

Colonel William E. Merrill pioneered the use of movable dams on American rivers. In 1874, he proposed to use Chanoine wicket dams on the Ohio River navigation (Johnson 1985:40). A colleague, Godfrey Weitzel, who collaborated with Merrill on movable dam studies, used several European systems later in the century on the Louisville and Portland Canal and the Sault Ste. Marie Canal (Johnson 1985:133).

Movable crest dams were introduced to the Ohio River area on the Ohio and Kanawha rivers. Among the early types of movable crests were Chanoine wickets, Bebout wickets, Boulé dams, and beartraps. The Bebout wicket is similar to the Chanoine wicket except that it is designed for automatic tripping. The Boulé dam consists of a series of collapsible trestles which support movable shutters. To install the dam, a maneuver and a shutter boat was needed. The remainder of these types of movable crest dams, developed in Europe, were first used in the United States

on either the Kanawha or Ohio River systems. Only the beartrap was used on the Monongahela River and that in lock chambers, not on the dam.

The Great Kanawha River Navigation was the second lock and dam system of the Ohio River area to employ movable dams. These dams, erected in the last quarter of the nineteenth century, were composed of a long line of wickets, each 3 feet 8 inches wide and hinged on the bottom that could be dropped to allow navigation over them in high water or raised to pool water during dry periods.

Leland Johnson, in his history of the Huntington Corps of Engineers District, described Dam 6, a typical dam of the Great Kanawha navigation:

The masonry foundation of the dam was 568 1/2 feet long and 50 feet wide. The navigation pass through which river traffic passed at high water was closed with 62 Chanoine wickets, each 3 feet and 8 inches wide and 13 and 5 1/2 inches long. The weir, which regulated the depth of the slackwater pool, was 310 1/2 feet long, closed by 69 Chanoine wickets smaller than those in the navigable pass. A metal service bridge, on which men stood when moving the wickets, extended across the dam above the wickets; the bridge also could be collapsed on the dam foundation at high-water stages (Johnson 1977:89).

This same type of dam was also used at Davis Island on the Ohio River.

The Monongahela River made early use of automatic movable crest dams. Neither of the two types used on the river, the Chittenden drum or the Betwa wicket, proved successful from a maintenance and durability standpoint. Where these devices proved unworkable, they were replaced, and the dams were permanently raised with a concrete top.

The present dams on the Monongahela River are a mixture of fixed concrete weirs and gated structures. One of the concrete weirs, Dam 3, is particularly interesting because of the survival of its middle pier. According to a lock employee, this pier is expected to contain remaining machinery from the Chittenden drum operating mechanism installed in the dam at the time of its original construction. The other two remaining fixed concrete weirs range in date of construction from 1905 (Lock No. 2) to 1996 (Grays Landing Lock and Dam).

During the twentieth century, modern, high-lift, adjustable crest dams were developed. These types, each of which is still in use include the roller gate, the tainter gate, the Sidney gate, and the vertical lift gate. As mentioned, use of the roller gate was pioneered on the Kanawha River, and these gates are now used on the upper Mississippi River and at Gallipolis Dam on the Ohio (Engineer School 1940:35).

The tainter gate is an internally framed sector of a cylinder with a system of radial bracing (end frames) at each end which carries the gate load to a trunnion pin. The trunnion pin is anchored to the pier, and the arm and gate rotate about this pin (Engineer School 1940:35). Tainter gates were pioneered on the Mississippi River and are presently used at all the Monongahela River movable crest dams and at movable crest dams on the Ohio. In the 1930s, electrically driven chain-hoist machinery was introduced on the upper Mississippi replacing the earlier gates lifted by a service bridge-mounted crane. This improvement allowed the simultaneous raising of all the gates, when necessary (Kemp 2000:104).

The Sidney gate is a special type of tainter gate with movable or sliding trunnion pins. The gate was designed to overcome the disadvantage of limited maximum clearance of other Tainter types (Engineer School 1940:42). A Sidney gate is used in the back channel section of the Emsworth Dam on the Ohio River, as well as at Dam No. 4 and Point Marion Dam on the Monongahela River.

The vertical lift gate is framed with trusses or built up girders which support the watertight skin plate or sheathing. The gate contacts the sides of the piers with fixed rollers that move in vertical recesses in the piers (Engineer School 1940:44). The vertical lift gate is used at the Emsworth and Montgomery Island dams on the Ohio. The Emsworth lift gates could be lowered some three feet below upper pool and could function as overflow gates.

All of the extant dams on the Allegheny River are fixed crest concrete weirs. The earliest of these dams, constructed in 1927 and 1928, are of concrete construction resting on a stone-filled wooden crib and wood bearing pile foundation with a steel sheet pile cut-off wall on the upper side of the dam and a 20 foot wide stone-filled crib on the lower side (Dravo 1947:26).

The replacement dams on the Great Kanawha navigation use non-navigable roller gate dams. The roller gate dams on the Kanawha were among the first in the United States. Dravo Corporation held American rights to the gates and the gate hoists of the roller-gate dam and was awarded the contract for construction of roller gate dams at Marmet and London (Johnson 1977:137) in 1932 (Miller 1950:58). The London and Marmet dams consist of five roller gates, each 100 ft. 3 ½ inches in length between piers and 26 feet in diameter. Four are standard roller gates, while the fifth has a flap to allow for ice and debris discharge (Kemp 2000:253). The Winfield Dam employs six roller gates including one with a retractable flap (Kemp 2000:257).

Roller gate dams were subsequently constructed elsewhere on the Kanawha and on the Ohio. In 1937, the Winfield Locks and Dam on the Kanawha was completed, and the following year, the Gallipolis Locks and Dam on the Ohio was finished (Johnson 1977:139). As of March 1939, a total of 146 roller gates had been installed in dams in the United. The longest of these gates were the 125 ½ foot gates at the Gallipolis Dam. The major proportion of these gates had been installed on the Mississippi River. In addition to Ohio and Kanawha river gates, these gates were used on reservoir and irrigation dams including installations in Colorado, Pennsylvania,[7] Idaho, Massachusetts, California, Washington and Maine (Martin 1939:67).

As mentioned, the early Ohio River dams introduced the movable dam to the United States, using dams and weirs of Chanoine wickets (Johnson 1977:92). These early dams were also notable for the use of beartrap gates, initially installed to pass drift without lowering wickets, and later used for passing minor rises and maintain pool levels without lowering wickets (Johnson 1977:95). Most of these beartraps were of the two-leaf type except at Dam No. 13, where two gates of the Reverse Parker three-leaf type were installed (Altstaetter 1914:504).

Beginning in the 1920s, a series of higher lift dams were constructed on the Ohio River to replace the earlier wicket dams. The oldest extant dam on the Ohio, Dashields, dates from this period. Dashields has the only remaining fixed crest concrete dam in the Ohio River navigation system.

During the 1930s, the first in a new generation of movable crest dams were constructed on the Ohio River. The Emsworth Dam, constructed in 1935 through 1938, replaced an earlier fixed

[7] The Pennsylvania installation was at Lake Wallenpaupack, a reservoir in the Poconos

crest concrete dam. The Montgomery Dam, constructed between 1932 and 1936 eliminated the original Ohio River Dams 4, 5 and 6. Both of these dams use vertical lift gates. In 1940, other vertical lift gates were used at the Bonneville Dam on the Columbia River; at Dam No. 17, Warrior River; and at the Savannah Bluff Dam (Engineer School 1940:I:45). More recently constructed Ohio River dams, including New Cumberland, Pike Island, and Hannibal, use Tainter gates to vary the dam crest height with New Cumberland and Pike Island using both non-overflow and submergible tainter gates, and Hannibal only non-overflow tainter gates.

The hydrological characteristics of the upper Mississippi River and the Ohio River are different, precluding the use of a first generation of dams modeled after the navigable wicket dams already in use on the Ohio (O'Bannon 1989:26). In their study of the Mississippi River Nine-Foot Channel, the authors of *Gateways to Commerce* contrast the Ohio River and the Mississippi:

> The Ohio River experienced extended periods of high water that permitted long periods of open river navigation, but necessitated dams capable of passing large amounts of water. Wicket dams, such as the Chanoine wicket dam constructed at the Davis Island site on the Ohio River, accomplished both of these ends….
>
> The non-navigable dams of the Upper Mississippi offered several advantages over the navigable wicket dams on the Ohio. Wickets had to be either fully raised or fully lowered. But the Corps could set the gates on the Upper Mississippi dams to any desired opening, permitting accurate regulation of pool heights. The high sills of non-navigable dams also ensured a minimum pool level, an advantage in a shallow river such as the Upper Mississippi (O'Brien et al. 1992:41).

Dams of the upper Mississippi nine-foot channel project were of the movable, non-navigable type. These non-navigable dams consisted of a series of reinforced concrete piers, supported on concrete foundations, with movable gates that close the openings between the piers (O'Bannon 1989:30). The earliest constructed dams of the upper Mississippi nine-foot channel employed roller gates, while a majority of the dams constructed on the upper Mississippi used tainter gates (O'Bannon 1989:39). Initially, because of limitations on tainter gate size, the main channel at each dam used roller gates, while the other portions used smaller, simpler Tainter gates (O'Bannon 1989:41). As construction of the nine-foot channel progressed, tainter gate design was refined, and wider and more efficient gates were practicable (O'Bannon 1989:45-46). By the end of the 1930s, 80-foot submergible gates had been perfected (O'Bannon 1989:47). Beginning with the construction of Lock and Dam 24, only tainter gates were used on the river (Kemp 2000:104).

An important area of engineering significance for the Ohio River is the evolution of dam technology. As noted, at Davis Island and the subsequent numbered locks, a navigable pass and movable and fixed weirs were employed. Much of the technology was imported from Europe, while the beartraps used represented the improvement of technology developed in early nineteenth century Pennsylvania. When completed, the original Ohio River Navigation System represented the most extensive complex of navigable pass dams in the United States.

As replacement of the navigable pass dams occurred, and non-navigable, high-lift dams were constructed, the Ohio River continued to be in the forefront of dam technology. Among the significant Ohio River landmarks were the construction of the largest roller gates in the United States at Gallipolis Dam, and the first use of a Sidney gate in the back channel dam at Emsworth.

The Ohio River engineers also contributed to tainter gate technology by the installation of wide-width gates and the development of submergible and non-submergible tainter gates.

Power Systems

The oldest locks of the Ohio River Valley were operated by hand. For instance, the earliest lock gates of the Monongahela River Navigation were opened and closed by chains attached to hand-powered capstans. By the 1870s, however, mechanized lock operation had begun to be developed in the Ohio River area. In 1876, Superintendent George W. Lutes of the Monongahela Navigation Company installed a waterwheel to take advantage of the current that passed over the dam at Lock 3. The power generated operated a series of drums, shafting, clutches and gearing and allowed the mechanized opening of a lock gate in 30 seconds. Soon after, this system was installed in Locks and Dams 1 through 4.

Steam engines were later used to provide power for the lower river locks on the Monongahela. For instance, at Monongahela River Locks No. 1, the gates were operated by steam power, excepting in the river wall of the river chamber where power was derived from a waterwheel placed in the dam. The machinery for the lock gates on the shore and middle walls was worked by steam power. A steam engine was located on each wall. The steam for the engine on the middle wall was carried from boilers on shore by an overhead steam pipe supported by an iron framework.

In the early twentieth century, compressed air became the motive power of all new or reconstructed Monongahela River locks. For example, in Locks and Dam No. 5, a water turbine was connected by bevel gears to an air compressor. Air, at 100 pounds pressure, was piped from the reservoirs to all the engines operating the valves and gates. One stroke of the cylinder opened or closed one of the miter gates in 40 seconds.

Davis Island Lock and Dam, the earliest navigational complex on the Ohio River, employed a turbine to operate lock machinery with a steam engine used as backup. Other early Ohio River locks used either steam or turbine power or a combination of both.

The Deadman Island Locks and Dam (now Dashields) on the Ohio River, constructed beginning in 1927, had gate and valve operation powered by hydraulic turbines, using oil pressure transmitted through oil lines to the gate- and valve-operating machinery. An electrical generator, also turbine driven, furnished current for light and power (Casey 1929:444).

Control valves were provided on the three walls of the Deadman Island locks for several combinations of operations. The controls for the valves were located at the middle of each lock wall. The controls for the large lock gate were located just downstream and upstream respectively from the upper and lower gate recesses, while those for the small lock gate were located at the gate recesses (Casey 1929:446).

Turbine power has been eliminated at all locks and dams on the Ohio River. All presently use electric power from the outside power grid to run hydraulic pumps. These hydraulic pumps, in turn, operate the lock gates and valves. This system is similar to that used on the Monongahela River.

Post-World War II locks on the Monongahela River, beginning with the Morgantown Lock and Dam, were constructed using oil-fed, hydraulic power to operate the gates and valves. Older locks

retained the compressed air system until renovations occurred. For example, Locks and Dam No. 3 were converted from compressed air to oil-fed hydraulic operation in 1978.

The first generation of Allegheny River Lock and Dam complexes were completed in the first years of the twentieth century. Initially, the Herr Island Lock and Dam (No. 1), the first to be completed, was to be operated hydraulically, using a turbine to supply power. To cut down on cost, it and the other first generation Allegheny River locks used hand-powered capstans to operate the lock and its wickets (USACE-ChE 1902:1905).

Locks and dams on the Allegheny River presently use two types of power generation. The older power system uses from one to three hydraulic turbines to power the hydraulic system operating the lock gates and valves. The original turbine system at Lock and Dam 4 has been replaced with an electrical system similar to that used presently at all the locks and dams on the Monongahela. The system at Lock and Dam 5 is scheduled to be replaced in the near future. This system is significant as among the oldest operating turbine power system in the Ohio valley area.

The first generation of Kanawha River locks, constructed in the final decade of the nineteenth century, were also hand powered using capstans and wickets. The second generation of locks on the Kanawha, constructed in the 1930s, used hydraulically operated gates and valves.

The locks of the Mississippi River Nine-Foot Channel Project, constructed in the 1930s, used electrically operated locks and valves. The gates, as typical of modern locks, were opened and closed by means of steel sector gears and struts, while the mechanisms of the tainter valves were cable-driven (O'Bannon 1989).

The upper Mississippi Lock No. 27, constructed between 1947 and 1953, incorporated departures from earlier construction practice. Six separate control stations replaced the single central control station used at earlier installations. These control stations were located at both ends of the east and intermediate lock walls, the upper end of the west wall, and the mid-point of the intermediate wall. Bulkheads, placed by stiffleg derricks, are provided to close off the upper gate bays of the locks for repairs. Unwatering pumps, located within the lock walls, are then used to completely empty the lock chambers (O'Bannon 1989:59). Mississippi River locks are also powered by electric-hydraulic systems.

The authors of *Canalization* cite factors affecting the decision to use either electrical or hydraulic machinery:

> Perhaps the chief factor influencing the choice of type is the likelihood of submergence of the machinery. If the lock walls are to be periodically overflowed, electrical machinery will have to be removed and replaced several times a year in order to avoid danger thereto, whereas hydraulically actuated machinery is not affected by completed submersion. This last consideration accounts for the fact that hydraulic lock operating machinery is standard on the Ohio, whereas electrical operation is standard on the Upper Mississippi (Engineer School 1940:389).

The Ohio River Navigation System is significant for its role in the evolution of power generation in navigational complexes in the United States. As noted, the earliest locks and dams on the river used either a steam engine or turbine system for power generation. Initially, machinery was operated by either steam or compressed air. With the extension of the power grid, the complexes

began to use electrical power for operation. Because of the potential for flooding, direct electric operation of lock machinery was not employed. Instead, electricity is used to power a hydraulic system that operates both gate machinery and lock valves.

Emergency and Maintenance Closure

Except when a lock is filling or emptying, when both gates are closed, one gate of a lock is generally closed and withstanding full hydrostatic head, while the other gate is open. Should the closed gate fail, the river would at once flow through the lock. Such failure of a gate has occurred either through structural defects or as the result of one gate being rammed before the other gate could be closed behind the entering vessel. The effect of such a failure and its consequent rush of water can be disastrous to the lock and nearby vessels. To prevent this from occurring, methods of closing the lock and stopping the rush of water have been devised. These same devices, if installed both above and below the chamber, may also be used for periodic unwatering of the chamber and gates for maintenance and repair (Engineer School 1940:65-66).

Emergency and maintenance closure devices have included the Poirée dam, the needle dam, a massive gate of structural steel, constructed to span the forebay from wall to wall, and double lock gates. The Poirée dam is used exclusively for maintenance closure. The sills, trestles or trestle boxes and anchorages for the Poirée dam are installed during lock construction. To close the lock, the trestles, if the hinged type, are raised; if the box type, are installed by a diver. The crosspieces and needles, stored at the site, are then placed by crane. When needle dams are used, the supporting frames may be installed during construction and left collapsed on the foundation until needed, or they may be made portable and moved from site to site where they are fitted to a specially prepared sill. Emergency needle dams are ordinarily used only on the downstream side of the installation to be unwatered where the head is relatively low. Steel or aluminum bulkheads are used above the dam to support the upper pool head. The structural steel gate is stored on a bank beside the lock and can be swung out and lowered into position by a crane. Double lock gates are less common but were installed at St. Marys Falls and on the Welland Canal (Engineer School 1940:22, 66).

The earliest locks on the Monongahela River Navigation System used beartraps for maintenance closure. When the upper beartrap leaf was raised to a level with the surface of the upper pool, the miter gates could be thrown open and fastened back.

At Monongahela locks No. 2, Boulé dams are used for maintenance closure (Rockovich 1999). A Boulé dam is permanently installed in the bottom of the chamber and consists of a number of collapsible trestle which support movable shutters. Each trestle is a structural steel A-frame placed at right angles to the dam. Needle dams are used for maintenance closure at Locks 3 and 4 of the Monongahela. The present Poirée dams consist of removable A-frame trestles, standard to the Pittsburgh District. Poirée dams are used for maintenance closure of the lower ends of the chambers at Morgantown, Hildebrand, and Opekiska. The newer Monongahela River locks, and those recently rehabilitated, each have a bulkhead system to close off the lock chamber. In most of the complexes, separate bulkheads are used for the lock and the dam, while the width of the Opekiska and Maxwell dam gate bays was designed to allow the use of the same bulkheads for both lock and dam, The Lock 2 (56 foot chamber) overhead “garage door” emergency bulkhead system is believed to be innovative and is found only at that lock and at Grays Landing on the Monongahela River.

Emergency and maintenance closure of Ohio River and Mississippi locks is provided by

bulkheads similar to those used on the Monongahela, except for Emsworth, Dashields, Montgomery, and New Cumberland. These first three complexes use Boulé dams similar to those used at Monongahela River Locks No. 2 for maintenance closure. The latter uses Poirée dams in the downstream end. The Allegheny River locks lack emergency closure systems and most use needle dams for maintenance closure (Rockovich 1999).[8]

The tainter gate Dam No. 4 has an emergency closure system typical of the Monongahela River. It is equipped with two steel bulkhead sections that are dogged between piers. The bulkheads ride in slots on the sides of the piers and are placed by the lifting beam of the traveling bulkhead hoist on the service bridge. Opekiska and Maxwell are designed to use the same bulkheads for lock and dam.

The Ohio River movable dams use an emergency closure system similar to that of the Monongahela. For example, the lifting beam used at Opekiska is similar to that used at the New Cumberland Locks and Dam on the Ohio. Upper Mississippi River dams constructed in the 1930s used temporary blocking units of structural steel girder construction to block gate openings during periods of emergency or repair of the Tainter gates. These emergency bulkheads were stored on land and were moved into place by locomotive cranes located atop the service bridge.

Closure above the Upper Mississippi and Kanawha River roller gate dams was accomplished by lowering a series of specially designed girders called “stop logs” that bear in slots in the piers. The girders were handled and placed by a traveling hoist. The downstream closure was accomplished by a series of Poirée trestles and needles (McAlpine 1934:423).

The use of Poirée dams, Boulé dams and bulkheads for maintenance and emergency closure of locks and dams is common in the Ohio River, Mississippi River, and Monongahela River systems. Therefore, the use of these methods of closure does not appear to add to the engineering significance of the Ohio River Navigation System.

Construction Methods

As noted, early United States river locks were constructed from mortared stone. This technology was used in the original locks on the Monongahela, Lock No.1 (Davis Island Lock) on the Ohio, and the original Kanawha River locks. According to the 1894 *Annual Report of the Chief of Engineers*, the first locks in the United States believed to have been constructed entirely of concrete were begun in 1892 and 1893 on the Illinois and Mississippi Canal. These locks were designed by Captain William L. Marshall of the Corps of Engineers (as cited in Black 1929:206). All of the present locks on the Ohio, Mississippi, Monongahela, and Allegheny rivers are of concrete construction.

Among the main technological innovations in lock and dam construction methods in these slackwater systems were in cofferdam construction. The earliest cofferdams used in lock and dam construction in the United States consisted of a dike of earth. Later, these dams were made more watertight by the installation of a central cutoff wall of wood sheeting and the covering of the dike with riprap to prevent scour. These dams suffered severe damage during periods of high water (Jansen 1948:26).

[8] Lock and Dam 2 on the Allegheny River has no permanent provision for maintenance closure on the downstream side. Closure is accomplished by a construction of sheetpile box cofferdam.

In the early twentieth century, the Ohio River-type box cofferdam was developed during the construction of navigational structures on that river. This type of cofferdam consisted of two rows of wood sheeting spaced 16 feet to 20 feet apart, with timber wales on the outside, held together with steel rods passing through the wales and sheeting (Jansen 1948:27). This cofferdam required two kinds of plants on each job, a floating plant for use on the outside of the cofferdam and for building the cofferdam itself, and a land plant for work inside the cofferdam. This cofferdam was low in height and occasionally suffered heavy damage from high water (Jansen 1948:28).

To address the perceived disadvantages of the Ohio River-type box cofferdam, the internally braced, interlocking steel sheet pile cofferdam was developed and was first successfully used at Dam No. 23 on the Ohio River in 1928-1929.[9] This type of cofferdam permitted the use of floating equipment almost exclusively. Further development of the interlocking steel sheet pile cellular cofferdam occurred in the construction of the Dashields Dam on the Ohio River in 1928-1929. This fixed dam was constructed in five sections of cofferdam, using cells 40 feet in diameter spaced 42 feet from center to center. This type of circular cell cofferdam permitted continued work in flooded conditions (Jansen 1948:28-29).

The most recently constructed locks and dams, such as Grays Landing on the Monongahela River and the recently constructed Ohio River complexes continue to use circular cell, sheet pile cofferdams in construction. In some cases, such as the reconstruction of Locks No. 2 on the Monongahela River, a diaphragm type, cellular cofferdam was used to mount cranes and other construction machinery (Larkin 1950:35).

The first generation of Allegheny River locks and dams were built in the early twentieth century. The lock walls and dam were constructed within Ohio River box cofferdams (Dravo 1947:8). The second generation of locks and dams were constructed beginning in the late 1920s. For example, Allegheny Dam No. 5 (Miller 1950:56) and Lock No. 7 was constructed within a double wall steel pile type box cofferdam that consisted of two rows of piling 20 feet apart, held together by steel rods and filled with sand and gravel. The plant for Lock No. 7, operated by Dravo Corporation, included a 2-yard land mixer to which cement was fed by a belt conveyor (Dravo 1947:31). Allegheny River dams 5 and 6 marked the first use by Dravo Corporation of steel piles in a box type cofferdam. The tie rods used to hold together the steel piling were spaced about ten feet apart longitudinally and about three feet vertically. Floating equipment used in construction included Dravo whirler boats and mixing boats (Dravo 1947:26). Lock No. 6, atypically for Allegheny River locks, used a cofferdam formed from a single line of sheet piling, bermed on both sides. Contractor for this project was the John F. Casey Company (Miller 1950:56).

The oldest of the present Ohio River locks and dams, Emsworth, was constructed by Dravo Corporation in the early 1920s. The lock was constructed within three sections of Ohio River box cofferdam de-watered by a motor-driven pump boat. Other equipment used in lock construction included a steam shovel, drag line excavator, and whirler cranes. A movable mixer was used for placing concrete in the land wall and middle wall, while the river wall used a floating mixer plant. Concrete was transported to the walls from outside of the cofferdam by chutes (Dravo 1947:22).

As mentioned, the original Dashields dam on the Ohio River, a concrete, fixed crest structure, was erected by Dravo Corporation in 1928-1929 within a circular cell type cofferdam. The Dravo

[9] Other early uses of this cofferdam type included Black Rock Lock on the Niagara River, Browns Landing Lock on the Cape Fear River in North Carolina, and the Forty-Sixth Street Pier in New York City (Black 1929:206).

engineers found this new type of cofferdam exceptionally water-tight and quite superior to the Ohio River Type box cofferdam (Dravo 1947:29-30). This dam is still in service today as a fixed crest dam.

The Gallipolis Locks and Dam on the Ohio were constructed by Dravo Corporation in the 1930s. A cellular steel sheet pile cofferdam was constructed to enclose the entire 2,158 feet of lock, using two lines of sheeting, connected with cross walls at 35 foot intervals. The cofferdam was filled with sand and gravel and the whole was capped with concrete (Dravo 1947:43). The type of cofferdam used is generally termed a diaphragm type, cellular cofferdam.

More recent projects on the Ohio have continued to modify existing cofferdam types to suit the particular construction situation. For example, at Newburgh Locks and Dam, cofferdams were constructed inside a main cofferdam to allow for deeper excavation for founding of piers. After the failure of cofferdams at Canneltown and Uniontown locks, the Stage I cofferdam for Hannibal Dam was redesigned with the incorporation of prestressed cable anchors and concrete thrust blocks.

The three extant Kanawha River navigation structures date to early 1930s modernization of that navigation system. The dam cofferdams for the Marmet, West Virginia, Lock and Dam complex were constructed in two consecutive units and were of the cellular type, consisting of a series of circular cells connected on both sides by short arcs, all filled with sand and gravel and paved with concrete. Dravo whirlers were used for excavation and for handling forms, concrete and steel. The floating plant consisted of a mixer boat, derrick boat, and barges (Dravo 1947:36).

The London twin locks and dam used cellular steel, sheet pile cofferdams similar to those used at Marmet dam. The construction plant used Dravo whirlers, a double 2-yard mixing plant, a 2-yard mixer boat, and derrick boat (Dravo 1947:38). The Winfield twin locks were constructed within a box cofferdam, consisting of two rows of arch web steel sheet piling, tied with cross roads and filled with sand and gravel. The dam cofferdam was of cellular steel sheet pile construction similar to that used at the Marmet and London dams (Dravo 1947:40-41).

Mississippi River Locks and Dam No. 26, constructed in the 1930s used a cofferdam constructed of cloverleaf steel sheet pile cells filled with dredged material. This cofferdam represented a modification of the circular, sheet pile cofferdam developed on the Ohio River. Y-connection piles, connected to two structural frames, tied the individual cells together at the panel points (O'Bannon 1989:74). Concrete was mixed on shore and was placed using a network of belt conveyors (O'Bannon 1989:78).

The Ohio River Navigation System is significant for its role in the evolution of cofferdam technology. As mentioned, the Ohio River box cofferdam was developed for use in construction projects on the river. Later, Dravo Corporation made the first successful use of a cellular steel cell cofferdam in lock and dam construction at Dashields Dam. Innovation continues as evidenced by the use of interior cofferdams at Newburgh Locks and Dam.

As mentioned previously, other construction techniques were also introduced on the Ohio River. The Louisville District engineering staff developed pile supported concrete foundations for locks and dams on the sandy bottom of the lower Ohio River. The contractors for Montgomery locks had previously made extensive use of long-span cableways to deliver material to the construction site, an early use of that technology.

RECOMMENDATIONS

The Ohio River Navigation System is recommended eligible for the National Register of Historic Places under Criterion C for significance in engineering. Criterion C states that "properties may be eligible for the National Register if they embody the distinctive characteristics of a type, period or method of construction."

The present Ohio River Navigation System is eligible both for its individually notable engineering features and as a complex that shows the evolution of lock and dam technology from the 1920s to the present. It possesses significance at the national level. Several specific areas of significance are applicable.

- Development of Dam Technology

From the earliest numbered locks to the presently on-going construction at the Olmsted complex, the Ohio River Navigation system has pioneered important developments in dam technology. Davis Island Dam was the first navigation dam in the United States to incorporate a navigable pass, a technology that had been developed in France. The Gallipolis Dam was one of the early uses of roller gates in high-lift, non-navigable dams and has the longest roller gates in the United States. The Sidney gate, a combination of a vertical lift and tainter gate, was first used in the back channel dam at Emsworth and remains in use in that structure. Early tainter gates on the Ohio River were among the largest used at the time of installation. The present dams 52 and 53 with their Chanoine wicket navigable pass represent a survival of an earlier technology, now almost superceded on the Ohio River and elsewhere in the United States. The present Olmsted dam will include a modern, improved version of the navigable pass, the only such structure built on a major American waterway in recent years.

The present dams and the remains of earlier locks and dams possess significance as tangible examples of changing dam technology. In its variety of dam types and dam technology, the Ohio River Navigation System is unmatched among waterways of the United States.

- Development of Lock Technology

The existing locks in the Ohio River Navigation System exemplify the evolution of lock technology. Early structures, such as Emsworth and Locks 52 and 53, employ through the wall filling and emptying with separate culverts for each individual filling and emptying valve. Later locks show the evolution of lock technology with the use of longitudinal culverts controlled by a smaller number of larger valves. The most recently constructed locks show the results of laboratory testing. Discharge systems are used to prevent turbulence in the lock chamber and scour of the lock walls.

The existing locks also demonstrate the use of steel wall armor in the interior of the lock chambers. This armor, now used on most navigation locks in the United States, was first introduced in the numbered locks on the Ohio River.

The variety of construction periods represented by Ohio River locks is matched by the variety of lock valves. The most recently constructed locks use tainter valves in a reverse configuration. Older locks use standard tainter valves, butterfly valves, or in the case of the inactive McAlpine chamber, Stoney valves. The presence of the variety of valves and filling systems provides

significance in lock technology. The Ohio River system is also significant for its role in the development of valve operating machinery. Several complexes on the Ohio were sites of early successful use of wire rope operating machinery for reverse tainter valves.

The locks of the Ohio River Navigation System demonstrate changes in twentieth century lock, culvert and valve technology. Only a few other navigation systems of the United States, notably the Monongahela River, clearly illustrate this technological evolution. The Ohio River Navigation System achieves national significance for its lock technology.

- Construction Technology

The significant role of the Ohio River Navigation System in the evolution of cofferdams is clear. As mentioned, the Ohio River box cofferdam was developed for use on the river. After the effort to recover the *Maine* from Havana Harbor showed the potential of the cellular steel cofferdam, the cofferdam was successfully used at Dashields Locks and Dam. Subsequent projects illustrate the continued evolution of cofferdam and caisson technology on the Ohio River. As mentioned, the construction of the Newburgh Locks and Dams included the use of sub-cofferdams within a main cofferdam to permit safe excavation for piers in the sandy river bottom.

Other potential aspects of significance in construction technology include the first use in American lock and dam construction of long-span cableways to move construction materials to the project site and the development of timber pile construction techniques to firmly anchor locks and dams in the sandy bottom of the lower Ohio River.

The Ohio River Navigation System played a critical role in the twentieth century development of lock and dam construction technology. Technology pioneered on Ohio River projects later became the norm for lock and dam construction elsewhere. Its role in the development of construction technology also gives the navigation system national significance.

- Emergency and Maintenance Closure

Because of the varying ages of the Ohio River's locks and dams, the system illustrates the evolution of closure technology from the emergency closure Boulé dam and maintenance closure Poirée dam to modern lock and dam bulkheads. Although other rivers, including the Monongahela, show a similar evolution of closure technology in their present locks and dams, the variety of existing closure systems on the Ohio River Navigation System contributes to its engineering significance.

To summarize, the Ohio River Navigation System achieves significance as a living laboratory of twentieth century lock and dam technology. It clearly meets National Register Criterion C for its significance in the area of engineering.

ESSAY ON SOURCES

In the course of writing the historic engineering evaluation for the Ohio River Main Stem Study, research was conducted at most of the major archival collections with primary and secondary source material on the Ohio River Navigation System. Collections visited included the Pittsburgh, Huntington, and Louisville district offices of the U.S. Army Corps of Engineers; the Still Photographs and Cartographic and Architectural branches of the National Archives in College Park, Maryland; the Mid-Atlantic Regional Branch of the National Archives (Philadelphia); the Library of Congress; the University of Louisville Library; the Filson Club in Louisville; the Marshall University libraries in Huntington, West Virginia; the Historical Society of Western Pennsylvania; the Carnegie-Mellon University libraries; the Carnegie Library of Pittsburgh; the University of Pittsburgh Library; the Free Library of Philadelphia; the University of Pennsylvania libraries; the Office of History, U.S. Army Corps of Engineers; and the U.S. Army Corps of Engineers Library. In addition to reviewing construction and inspection reports and studying historic photographs and engineering drawings at each of the Corps offices, the investigator met with engineers on the staff of each district.

The initial scope of work for the study called for visits to the Chicago and Atlanta regional branches of the National Archives. After discussing the holdings of these facilities with Martin Reuss of the U.S. Army Corps of Engineers Office of History, the investigator decided the lack of organization of these collections would make it difficult to ferret out useful information from the large amount of retained records.

Several other archival collections with holdings on the Ohio River were also not visited. These included the Inland Rivers Collection of the Cincinnati Public Library, the Mercantile Library of the University of Missouri at St. Louis, the library of the American Concrete Institute (suburban Detroit); and the Waterways Experiment Station, Vicksburg, Mississippi. The published catalog of the Inland Rivers Collection was studied. Few sources related specifically to the engineering of the navigation system and those that did were available elsewhere. The remaining three collections may prove to be useful repositories in any future research. The Mercantile Library has a complete indexed collections of the *Waterways Journal*, as well as historic files maintained by that publication. The library of the American Concrete Institute may contain publications that would help clarify and elucidate the early use of concrete in navigational lock and dam construction. Some reports of the Waterways Experiment Station were found and used at other repositories. The WES has, of course, a complete run of their reports, and additional reports may provide information on relatively modern technical innovations on the Ohio River Navigation System.

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Table 1-1. Ohio River Locks and Dams

Name	Location	River Mile	Locks Placed in Service	Removed from Service	Lock Sizes	Lift of Lock	Valve Number/Type	Dam Type
Davis Island (#1)	Border of Avalon and Bellevue, PA	4.7	October 7, 1885	1921	50 x 158	3.1 feet	14 filling and 14 emptying butterfly valves	1,223 foot navigable pass dam with 559 ft. Chanoine wicket pass and bear-trap weir. Stone-filled, timber crib back channel dam.
Emsworth	Emsworth, PA	6.2	August 13, 1921	n/a	110 x 600 (main) 56 x 360 (aux.)	18.0 feet	16 filling, 16 emptying; vertical butterfly	Movable crest; 13 vertical lift gates, **eight in main dam, five in back channel dam**; one Sidney gate **in back channel dam**
#2	Coraopolis, PA	9.0	October 13, 1906	1921	110 x 600	7.8 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with Chanoine wickets and bear-trap weir.
#3	Glen Osborne, PA	10.9	February 1, 1908	1929	110 x 600	7.7 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with Chanoine wickets and bear-trap weir.
Dashields	1.6 miles below Sewickly, PA	13.3	August 1, 1929	n/a	110 x 600 (land) 56 x 360 (river)	10.0 feet	horizontally mounted butterfly valves	Fixed crest dam (only one on the Ohio River).
#4	Legionville, PA	18.6	February 1, 1908	1936	110 x 600	7.6 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with Chanoine wickets and bear-trap weir.
#5	Freedom, PA	23.9	November 21, 1907	1936	110 x 600	8.5 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 700 foot long navigable pass, 96 foot long Chanoine weir and two 93 foot bear-trap weirs.
#6 (Merrill)	Beaver, PA	28.8	August 3, 1904	1936	110 x 600	5.7 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 600 foot navigable pass, 120 foot Thomas A-frame weir and two 120- foot bear-trap weirs.
Montgomery	1.4 miles above Industry, PA	31.7	June 25, 1936	n/a	110 x 600 (main) 56 x 360 (aux)	17.5 feet	6 horizontally mounted butterfly valve	Non-navigable movable crest with vertical lift gates.
#7	Midland, PA	36.5	September 16, 1914	February 15, 1961	110 x 600	6.9 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 600 foot navigable pass, 72 foot Chanoine weir and two 91 foot bear-trap weirs.
#8	Newell, WV	46.4	July 14, 1911	November 5, 1960	110 x 600	6.4 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 700 foot navigable pass, 200 foot Chanoine weir and two 91 foot bear-trap weirs.
New Cumberland	Strattonsville, Ohio	54.4	November 11, 1959	n/a	110 x 1200 (main) 110 x 600 (aux.)	20.5 feet	reverse tainter valves	Non-navigable movable crest with 11 tainter gates each with a clear span of 110 feet.
#9	New Cumberland, WV	56.1	November 2, 1914	November 28, 1960	110 x 600	7.4 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 600 foot navigable pass, 224 foot Chanoine weir and two 91 foot bear-trap weirs.
#10	Steubenville, OH	66.2	October 31, 1915	July 27, 1965	110 x 600	8.4 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 600 foot navigable pass, 256 foot Chanoine weir and two 91 foot bear-trap weirs.
#11	2.3 miles below Wellsburg, WV	76.9	August 1, 1911	December 26, 1964	110 x 600	7.3 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 700 foot navigable pass, 120 foot Chanoine weir and two 91 foot bear-trap weirs.
Pike Island	2 miles above Warwood, WV	84.3	November 29, 1963	n/a	110 x 1200 (main) 110 x 600 (aux)	21.0 feet	steel reverse tainter valves; two in the small chamber; four in the large chamber	Non-navigable dam with five submergible and four non-submergible tainter gates.
#12	Warwood, WV (2.3 miles above Wheeling)	87.4	January 16, 1917	August 19, 1959	110 x 600	8.4 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 200 foot Chanoine weir and two 91 foot bear-trap weirs.

Table 1-1. Continued.

#13	McMechen, WV	96.1	August 1, 1911	February 6, 1960	110 x 600	7.3 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 632 foot navigable pass, 160 foot Chanoine weir, and two 83 foot bear-trap weirs.
#14	Woodland, WV	114.0	August 20, 1917	July 1961	110 x 600	8.3 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 136 foot Chanoine weir and two 91 foot bear-trap weirs.
Hannibal	1.6 miles above New Martinsville, WV	126.4	August 1971	n/a	110 x 600 (landward) 110 x 1200 (riverward)	21.0 feet	reverse tainter valves	1,098 foot non-navigable dam with 8 fixed trunnion non-submergible radial gates.
#15	New Martinsville, WV	129.1	July 1, 1916	1972	110 x 600	7.8 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 208 foot Chanoine weir and two 91 foot bear-trap weirs.
#16	Bens Run, WV	146.5	August 16, 1917	1972	110 x 600	7.8 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 160 foot Chanoine weir and two 91 foot bear-trap weirs.
Willow Island	2.7 miles above Waverly, WV	161.7	January 1972	n/a	110 x 1200 (main) 110 x 600 (aux)	20.0 feet	reverse tainter valves	Non-navigable, high-lift, gated dam with eight 28-foot high tainter gates, and 110 foot fixed weir.
#17	4.5 miles above Marietta, Ohio	167.5	August 1, 1918	1972	110 x 600	8.2 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 352 foot Chanoine weir and two 91 foot bear-trap weirs.
#18	4.7 miles above Parkersburg, WV	179.9	May 1, 1910	1965	110 x 600	6.2 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 300 foot Chanoine weir and two 50 foot bear-trap weirs.
#19	Little Hocking, Ohio	192.2	October 16, 1916	1965	110 x 600	7.7 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 688 foot navigable pass, 304 foot Chanoine weir and two 91 foot bear-trap weirs.
#20	Belleville, WV	201.7	January 16, 1917	1965	110 x 600	7.5 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 192 foot Chanoine weir and two 91 foot bear-trap weirs.
Belleville	.3 miles below Reedsville, Ohio	203.9	October 12, 1965	n/a	110 x 1200 (main) 110 x 600 (aux)	22.0 feet	reverse tainter valves	1,206 foot non-navigable, high lift, gated dam with 8 tainter gates and 189 foot fixed weir.
#21	1.4 miles above Portland, Ohio	214.6	September 5, 1919	1967	110 x 600	5.6 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 388 foot Bebout weir and 100 foot fixed weir section.
#22	Ravenswood, WV	220.9	December 1, 1918	1967	110 x 600	7.8 feet	17 emptying and 17 filling butterfly valves	navigable pass dam with 600 foot navigable pass, 240 foot Bebout weir, 91 foot bear-trap and 81 foot fixed weir.
#23	Millwood, WV	231.4	September 26, 1921	1967	110 x 600	8.1 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 240 foot Bebout weir, 91 foot bear-trap weir and 49 foot fixed weir.
Racine	1.5 miles below Letart Falls, Ohio	237.5	December 16, 1967	n/a	110 x 1200 (main) 110 x 600 (aux)	22.0 feet	reverse tainter valves	1,160 foot non-navigable, high-lift, gated dam with eight tainter gates.
#24	Graham, WV	242.0	August 27, 1919	1937	110 x 600	7.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 240 foot Bebout weir, 91 foot bear-trap and 65 foot fixed weir.
#25	5 miles above Pt. Pleasant, WV	260.0	1922	1937	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 252 foot Bebout weir, 91 foot bear-trap and 39 foot fixed weir.
#26	Hogsett, WV	278.0	August 1, 1912	1937	110 x 600	7.5 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 272 foot Chanoine weir and two 91 foot bear-trap weirs.

Table 1-1. Continued.

Gallipolis (present Robert C. Byrd)	.7 miles below Hogsett, WV	279.2	1937 replacement locks: January 1993	n/a	110 x 600 110 x 360 replacement locks: 110 x 1200 110 x 600	Original: 26 feet Present: 23 feet	Original: tainter valves Replacement: reverse tainter valves	Non-navigable dam with eight roller gates, each measuring 134 feet 11 inches wide and 22 feet in inside diameter.
#27	3.6 miles above Proctorsville, Ohio	301.0	1923	1959	110 x 600	6.4 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 652 foot navigable pass, 288 foot Bebout weir, 91 foot bear-trap, and 97 foot fixed weir.
#28	3.3 miles below Huntington, WV	311.6	March 1, 1915	1959	110 x 600	7.1 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 296 foot Chanoine weir, two 91 foot bear-traps, and 70 foot fixed weir.
#29	2.7 miles above Ashland, KY (3 miles below mouth of Big Sandy River)	319.9	December 1, 1916	1959	110 x 600	8.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 124 foot Chanoine weir, and two 91 foot bear-traps.
#30	3.3 miles below Greenup, KY	339.4	1923	1959	110 x 600	7.5 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 120 foot Bebout weir, 91 foot bear-trap, and 144 foot fixed weir.
Greenup	4.9 miles below Greenup, KY	341.0	November 27, 1959	n/a	110 x 1200 (main) 110 x 600 (aux)	30.0 feet	reverse tainter valves	1,287 foot non-navigable high- lift, gated dam with 245 five weir and nine tainter gates.
#31	3.3 miles below Portsmouth, Ohio	359.3	October 22, 1919	1962	110 x 600	7.5 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 160 foot Chanoine weir, and two 91 foot bear-traps.
#32	1 mile above Rome, Ohio	382.6	1926	1962	110 x 600	7.5 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 100 foot Chanoine weir, two 91 foot bear-traps, and 340 foot fixed weir.
#33	3.5 miles above Maysville, KY	405.1	October 28, 1921	1962	110 x 600	7.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 216 foot Chanoine weir, and two 91 foot bear-traps.
#34	Chilo, Ohio	434.1	1925	1962	110 x 600	5.6 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 100 foot Chanoine weir, two 91 foot bear-traps, and 535 foot fixed weir.
Capt. Anthony Mendahl	2.2 miles above Foster, KY	436.2	November 1962	n/a	110 x 1200 (main) 110 x 600 (aux)	30.0 feet	reverse tainter valves	1,756 foot non-navigable dam with 12 tainter gates and 372 foot fixed weir.
#35	1 mile below New Richmond, Ohio	451.0	September 3, 1919	1962	110 x 600	6.4 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 208 foot Chanoine weir, two 91 foot bear-traps, and 255 foot fixed weir.

Table 1-1. Continued.

#36	9.3 miles above Cincinnati, Ohio	460.9	1925	1962	110 x 600	7.9 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 100 foot Chanoine weir, two 91foot bear-traps, and 250 foot fixed weir.
#37	Fernbank, Ohio	483.2	1911	1959	110 x 600	7.8 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 200 foot fixed weir, and 3 bear traps of 78 feet each.
#38	McVille, KY	503.3	1924	1959	110 x 600	7.3 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 100 foot Chanoine weir, two 91 foot bear-traps, and 259 foot fixed weir.
Markland	1 mile above Markland, IN	531.5	Locks in operation: May 1959 Dam: June 1964	n/a	110 x 1200 (main) 110 x 600 (aux)	35.0 feet	reverse tainter valves	1,395 foot non-navigable dam with 12 tainter gates, 7 originally submergible, 5 non-submergible.
#39	1 mile above Markland, IN	531.7	October 1921	1959	110 x 600	6.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 800 foot navigable pass, 200 foot Bebout weir, two special wickets, 91 foot bear-trap, and 277 foot fixed weir.
Falls of the Ohio Locks (first)	Louisville, KY		December 23, 1830	1872	3 locks: 50 x 170			
Falls of the Ohio Locks (second)	Louisville, KY		February 26, 1872	1885	two locks: 80 x 348		hand operated butterfly valves turning on vertical axis	Movable dam with 11 sections of Boule gates, Chanoine wickets, and permanent masonry weirs.
#41	Louisville, KY	604.4	July 1885		110 x 600 56 x 300		hydraulically operated butterfly valves turning on a vertical axis	Movable dam with 1952 feet of Boule gates, 648 feet of Chanoine wickets and 2246 feet of masonry fixed weir.
McAlpine	Louisville, KY	Dam: 604.4 Lock: 606.8	Main lock: 1961 Intermed.: 1921 Aux.: 1930+ Dam: Sept. 1964	n/a	110 x 1200 (main) 110 x 600 (intermed.) 56 x 360 (aux.)	37.0 feet	reverse tainter valves	7,590 foot concrete fixed weir with nine tainter gates in 1,065 foot dam.
#43	3.3 miles below West Point, KY	633.2	June 13, 1921	1966	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 320 foot Bebout weir, and one 91 foot bear-trap weir.
#44	Leavenworth, IN	663.2	September 12, 1925	1966	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 140 foot Chanoine weir, 140 foot Bebout weir, and two 91 foot bear-trap weirs.
#45	Addison, KY	703.0	September 12, 1927	1996	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 800 foot Chanoine pass, 200 foot Chanoine weir, 100 foot Bebout weir, and two 91 foot bear-trap weirs.
Cannelton	3 miles above Cannelton, IN	720.7	Locks placed in operation: Dec. 1966 Dam completed: 1974 Official opening: November 2, 1974	n/a	110 x 1200 (main) 110 x 600 (aux)	25.0 feet	reverse tainter valves	Non-navigable dam with 12 non-submergible tainter gates in 1,395 ft. gated section; 195 foot fixed weir.

Table 1-1. Continued.

Newburgh	16 miles above Evansville, IN	776.1	Locks placed in operation: Dec. 1969 Dam completed: 1975. Official opening: July 2, 1975	n/a	110 x 1200 (main) 110 x 600 (aux)	33.0 feet	reverse tainter valves	Non-navigable dam with nine non-submergible tainter gates in 1,140 foot long gates section and 1,300 foot fixed weir.
#46	Owensboro, KY	757.3	1928	1969	110 x 600	11.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 300 foot Chanoine weir, 100 foot Bebout weir, and two 91 foot bear-trap weirs.
#47	Newburg, IN	777.7	1928	1969	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 400 foot Chanoine weir, two 91 foot bear-trap weirs.
#48	5.8 miles below Henderson, KY	809.6	January 1, 1922 Dam: July 20, 1922	1969	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 800 foot Chanoine pass, 296 foot Chanoine weir, 304 foot Bebout weir.
#49	2.4 miles below Uniontown, KY	845.0	August 3, 1928	1969	110 x 600	11.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 200 foot Chanoine weir, 100.1 foot Bebout weir, and two 91 foot bear-trap gates.
Uniontown (John T. Myers)	3.5 miles below Uniontown, KY	846.0	Locks placed in operation: December 1969 Dam completed: 1977 Officially opened: October 4, 1975	n/a	110 x 1200 (main) 110 x 600 (aux)	22.0 feet	reverse tainter valves	1,265 ft. gated section with 10 non-submergible tainter gates and 2,239 ft. fixed weir.
#50	1 mile below Weston, KY	876.8	October 16, 1928	l979	110 x 600	10.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 300 foot Chanoine weir, 100 foot Bebout weir, and two 91 foot bear-trap weirs.
#51	.6 miles below Golconda, IL	903.1	July 30, 1929	1979	110 x 600	8.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 300 foot Chanoine weir, 100 foot Bebout weir, and two 91 foot bear-trap weirs.
Smithland	2 miles above Smithland, KY	918.5	Locks placed in operation: 1979 Dam completed: November 1980	n/a	110 x 1200 110 x 1200	22.0 feet	reverse tainter valves	Non-navigable dam with 2,140 ft. gated section with 11 non-submergible tainter gates and 1,375 ft. long fixed weir.
#52	1.4 miles below Brookport, IL	938.9	October 27, 1928 110 x 1200 foot chamber: 1969	n/a	Main lock: 110 x 1200 Aux: 110 x 600	12.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass of 1,248 feet, 540 feet of chanoine weir, 160 feet of bebout weir, three 91-foot beartraps, and 725 feet of fixed weir.
#53	10.8 miles above Mound City, IL and 10.8 miles below Joppa, Illinois	962.6	August 27, 1929 110 x 1200 foot chamber: 1980	n/a	Main lock: 110 x 1200 Aux: 110 x 600	9.6 feet	17 emptying and 17 filling butterfly valves	Navigable pass of 932 feet, two 91 foot beartraps, 340 feet of chanoine weir, 160 feet of bebout weir, 302 feet of fixed weir, and 2,000 feet of fixed weir.
Olmsted	Olmsted, IL	964.6	Under construction (began 1993)	n/a	110 x 1200 110 x 1200	Reverse tainter valves		Navigable dam with 2,200 foot long navigable pass section made up of steel wicket gates; non-navigable section of 6 tainter gates.

CHAPTER II

POLITICAL FACTORS AND MILITARY INFLUENCES ON THE DEVELOPMENT OF OHIO RIVER NAVIGATION IMPROVEMENTS

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INTRODUCTION

The political debates surrounding Ohio River Navigation improvements reflect changes in the national temperament. The evolution from untamed river to navigation system mirrored the transformation of political and popular thought of the nation, growing in sophistication, complexity, and scope as our government matured.

The debates and theories surrounding the U.S. Army Corps of Engineers' development of Ohio River Navigation present a microcosm of broader national trends and issues. National events figuring prominently into the discussion and development of river improvements included debates over the constitutionality of internal improvements in the early-19th century, Jacksonian Democracy's tendency to emphasize state's rights and authority, sectional issues that lead up to the Civil War as well as those in the post-war period, the agrarian and Granger movements, the Progressive Era, economic depression, and both World Wars. The successful completion of the Ohio River system of locks and dams by 1929 was never a sure thing, and owed its success largely to political maneuvering (often derided as "pork barrel politics"), fortuitous events including floods, wars, and timely political issues. Local Ohio Valley political and business organizations took advantage of these opportunities to pressure Congress, and slowly gained power enough to become a significant political force in the form of such organizations as the National Rivers and Harbors Congress and the more locally oriented Ohio Valley Improvement Association.

Alignments on the debate over river and harbor improvements tended to be more sectional than political, with the only possible exceptions being the Granger movement, which argued for better waterways and railroad regulation, and the early part of the Progressive Era, when Congressmen, predominantly the Progressive Republicans, used the conservation initiative to promote river navigation.

River improvements, especially those on the Mississippi, Ohio, and Missouri rivers, were nationally important concerns during the early twentieth century. The nature of the debate experienced a shift from issues over the constitutionality of federally sponsored improvements, to those of scientific answers to problems associated with rivers and harbors. The Progressives had a heavy reliance on science to solve these problems. This was a time of shifting roles for Congress, the Corps, and others involved in the debates over river and harbor improvements. Sometimes this change was so fast and drastic, that it left the players confused. All sides sought to use the findings of experts to strengthen their agenda. With its emphasis on conservation and trust regulation (mainly of the railroads), the movement became a vehicle for promotion of waterways improvements, and actually became part of the party platforms of the three major parties: Democrat, Republican, and Progressive Republican, or Bull Moose party. One may speculate as to whether the Ohio River Navigation System would have ever been a reality if not for the Progressives.

The history of the political debates over canalization of the Ohio River, and especially its link to flood control issues, largely supports Samuel P. Hays' theories concerning the professional nature of the Progressive movement. Professionals with expertise in soil and water conservation, navigation, and flood control rose to positions of power and respect as legislators looked to them for scientific answers to the issues before Congress. These professionals disagreed over the links between flood control and navigation, and the usefulness of locks and dams on the Ohio. These experts confused both Congress and the public, and many political leaders selected expert opinions that supported their political agenda.

Historians continue to debate the role of the Corps of Engineers within this political fray. Often, Corps leaders saw potential changes in national River Navigation policy as threats to their agency. Some historians, such as Samuel P. Hays and Frank E. Smith, have concluded that the Corps wielded too much power and criticized the Corps as obtuse, obstructionist, and self-serving as it fought potentially beneficial legislation such as that represented by the Newlands Bill of 1907. Although the Corps did struggle against what may have been useful legislation, and often contradicted itself in its professional opinions regarding the river and harbor projects it reviewed for Congress, this criticism appears harsh. The Corps' leaders were but one player in the political fray that included diverse forces of local and national politics as well as agency rivalries. The Bureau of Reclamation, the Forest Service, the USGS, and the Department of Agriculture all made attempts to wrest control of the rivers and harbors from the Army engineers. Although constantly arguing that it was a technical body and not political, the Corps excelled in this political game, eventually taking on the tasks of flood control, conservation, and river navigation.

HISTORICAL CONTEXT OF OHIO RIVER NAVIGATION IMPROVEMENTS

The politics of Ohio River Navigation improvement cannot be understood outside of the larger political debate during the 19th century on internal improvements. Accordingly, this study will begin with an overview of that debate in the context of Ohio River Navigation.

Between the American Revolution and the so-called "Era of Internal Improvements" of the early-19th century, private enterprise undertook most transportation projects. Some states, such as New Jersey, Maryland and Virginia provided aid through tax exemptions and purchase of stock. Most early improvements were roads. Turnpike companies constructing roads commonly raised money through the issuance of stock. Two companies, however, did construct early canals built without any public aid in the first decade of the 19th century. The Santee Canal, extending from Charleston, South Carolina, opened in 1800, and the Middlesex Canal connected Boston to Lowell Massachusetts on the Merrimack River in 1803. The Potomac Company, funded by both state and private funds, began river and canal improvements to the Potomac River in the same period. On the Ohio River, Kentucky and Indiana both began plans for a canal around the Falls of the Ohio at present-day Louisville (Goodrich 1960:20-21).

Serious thought to improving navigation on the Ohio River started at the beginning of the 19th century when in 1807, two waterway navigation improvements came before Congress: the Chesapeake and Delaware Canal and the proposed canal at the Falls of the Ohio. Henry Clay [Plate 2-1](Repub., Whig), Senator from Kentucky, introduced the bill for the Falls of the Ohio project. In a tactic not unlike the later omnibus river and harbor bills, he had joined Senators from Delaware in support of these two canal projects. John Quincy Adams (Plate 2-2) strongly opposed these measures as local projects that were unconstitutional. He warned that it was "fraud and collusion" for men to create a combination of interests to get their local issues through Congress. Adams instead introduced a resolution to have the Secretary of the Treasury submit a general plan for road canal and river improvements before approving singular projects. Congress agreed, defeating the two projects, and instead directed the Secretary of the Treasury to prepare a report on these projects for its next session (Goodrich 1960:27-28).

In 1808, Albert Gallatin (Plate 2-3) then Secretary of the Treasury, presented to Congress a "Report on Roads and Canals" (Gallatin 1808). In the report, he made observations on various completed and anticipated improvements. His conclusion: although many projects had been started, a large percentage had stalled for various reasons including mismanagement, personal problems, and above all, lack of available funds. He recommended federal government aid for the construction of over fifteen specific roads and canals, ranging from a turnpike from Maine to Georgia, Great Lakes inland navigation, and a canal around the Falls of the Ohio. He also stated that Congress should fund some local projects out of "justice". Gallatin estimated the total cost for all these projects at $20,000,000. He even suggested that the fund could be a revolving one, if Congress decided that the nation could not afford the debt (Goodrich 1960:30-31).

Gallatin had a strong understanding of American geography and an instinct for the country's future needs. Nearly all of his proposed improvements were eventually completed in the 19th century. Although his insight into the need and usefulness of the projects was remarkable, his thoughts on the ability of the nation to either finance or agree politically on any one improvement proved naïve. Gallatin did not see any issue about the constitutionality of the projects, and he assumed that the conflict of local versus national interests could be easily settled through what he termed "justice and policy" (Goodrich 1960:33). In fact, these two issues, constitutionality and

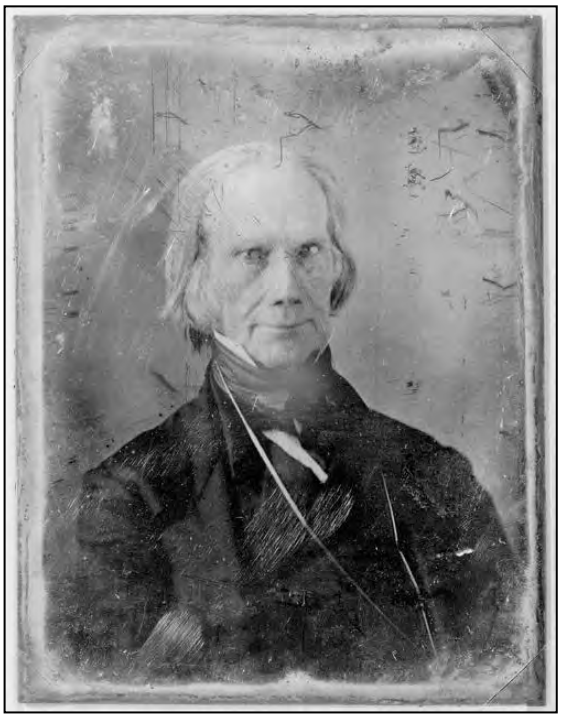

Plate 2-1. Henry Clay

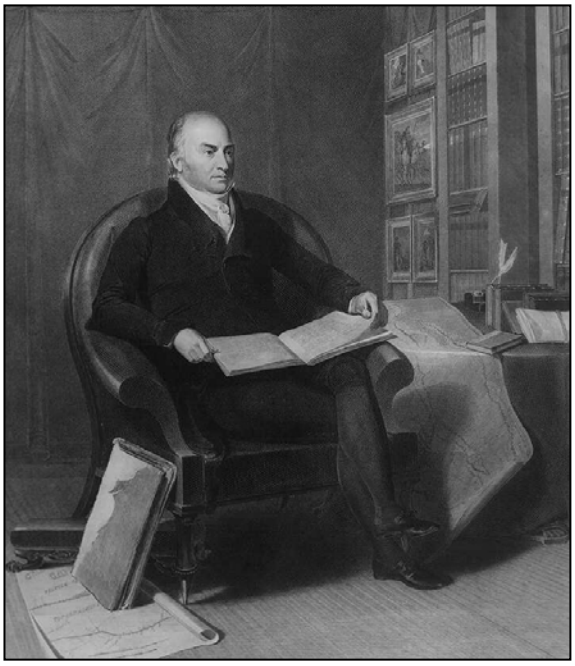

Plate 2-2. John Quincy

sectional rivalry, became the two chief impediments to almost every transportation improvement proposed well into the 20th century.

Gallatin's plan also assumed no other major government expenditures or financial problems in the near future, but interruptions in trade resulting from the Embargo Act of 1807 and the increased military expenditures leading up to the War of 1812 made funds scarce. The only federal appropriation for internal improvements came in 1809 with aid to construct the Carondolet Canal at New Orleans as a defense measure (Goodrich 1960:36). Upon the conclusion of the War of 1812, Congress once again took up the topic of internal improvements. John C. Calhoun [Plate 2-4](Dem.) of South Carolina submitted a bill to set aside federal income from the newly chartered Second Bank of the United States as a fund for internal improvements. National vs. state interests immediately came into play. Although conceived as a measure giving Congress the authority to decide where the money was spent, as passed, the money went directly to the states in proportion to their population, thereby almost ensuring that little of national interest, other than by pure chance, would come of any project. Clay, hoped to secure money for the canal around the Falls of the Ohio, since such a project would benefit his region. To that end, he added a proviso to the Act that a state could request that its share of the appropriation be given to a border state. This would give Kentucky the advantage of combining its money with that of the future state of Indiana when constructing a project of common interest such a the canal. Ultimately, however, the bill failed under a veto from President James Madison (Goodrich 1960:37-38).

In 1819, Calhoun, as Secretary of War, presented a plan of internal improvements stressing military importance. Although similar to Gallatin's plan, it extended farther west. Eventually, these recommendations evolved into the General Survey Act of 1824, but the question of whether the federal government had the authority to improve and regulate waterways remained open. Todd Shallat, in his book *Structures in the Stream*, explains that the 1824 Supreme Court case *Gibbons v. Ogden* became an important factor in the passage of the General Survey Act. This case involved the legality of a state to control exclusive rights to a ferry operation between New York and New Jersey. Daniel Webster, council for the steamboat operator, argued that no state monopoly could infringe upon the authority of Congress to regulate trade, and by inference, Congress had jurisdiction over all inland navigation. This case, according to Shallat, sent the message to Congress that legislation such as the General Survey Act of 1824 was constitutional (Shallat 1994:125-126).

The General Survey Act gave the President power to order surveys for canal and road routes having national importance. Specifically, this law authorized the President of the United States to "cause the necessary surveys, plans, and estimates to be made of the routes of such roads and canals as he may deem of national importance, in a commercial or military point of view, or necessary for the transportation of the public mail" (4 Stat. L., 22 as quoted in Holt 1923:5). This law also provided for civil engineers, as well as officers of the Corps of Engineers to carry out the work. Although Congress repealed the Corps' authority to employ civil engineers in 1838, the Army engineers continued in this work.

To carry out the General Survey Act, Congress formed a Board of Engineers for Internal Improvements within the Corps. The board consisted of General Simon Bernard and Colonel Joseph G. Totten (Plate 2-5) of the Corps of Engineers, and John L. Sullivan, a civil engineer. The Board initially tried to think and act on a national scale, but due to already growing sectional interests and local political power, Congress approved appropriations on a haphazard basis with no consistent or comprehensive plan. The earliest works on the Ohio River were piecemeal contracts to remove snags on the river (Holt 1923:7). The Board served as the nation's planning instrument for internal improvements until 1831 (Hill 1957:57).

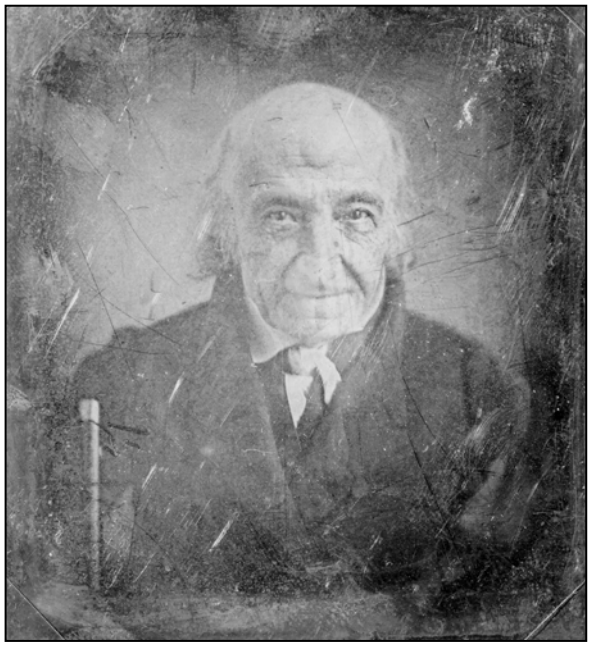

Plate 2-3. Albert Gallatin

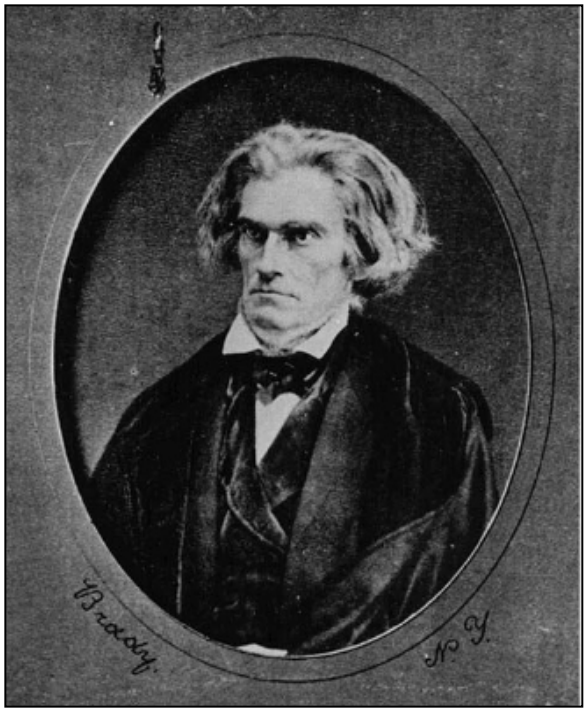

Plate 2-4. John C. Calhoun

In 1824, Congress also passed the first river-improvement bill and a separate harbor improvement bill, but legislation specifically directed at rivers and harbors improvements did not come until two years later, when in 1826, Congress passed the first "River and Harbor Bill" (Holt 1923:5-6). As with the General Survey Act of 1824, much of the money appropriated under the 1826 River and Harbor Act found its way to local and secondary projects as sectional pressures became dominant. As the country expanded, the task of satisfying all requests for aid became impossible. The Army engineers had an increasingly difficult time distributing the work in a way that would not cause sectional jealousy or charges of favoritism. Conflicts of state and sectional interests not only increased the demand placed upon the engineers, but also caused the work to become more fragmented. The army began to emphasize smaller, more scattered improvements to satisfy these factions, and as a result, the improvements ceased to be national in scope. Congressmen tended to support appropriations only if advantageous to their own sections, and the army engineers generally supplied the needed services (Hill 1957:76). Congress received a great deal of criticism for its piecemeal approach to these appropriations, and the Army engineers often complained about small and late appropriations. Logrolling, sectionalism, inefficient and useless projects were common complaints (Hill 1957:179).

More effective aid for the Ohio came from Congress in the form of federal subscription to stock of private improvement companies. Many in Congress felt that the government's money would be spent more wisely if private investors also had a stake in the outcome. The privately owned Louisville and Portland Canal received funding from Congress in this manner in the amount of $100,000 in May of 1826 (Goodrich 1960:40). The canal, completed in 1830, permitted vessels to bypass the treacherous Falls of the Ohio, was a major cause for Louisville's success (Bigham 1998:84-89).

Federal internal improvements studies focused more on surveys for canals and roads than river improvements in the early years. The engineers made surveys for the Chesapeake and Ohio, the Ohio and Lake Erie, and other canals, as well as routes for the new national road. In 1827, the Topographical Engineers began to survey a route for the Baltimore and Ohio Railroad under the justification that the proposed railroad was of national importance (Hill 1957:58-60, 70). During this period, both James Monroe and John C. Calhoun proposed an increase in the number of Army engineers available to assist in internal improvements. President John Quincy Adams and Secretary of War James Barbour supported the call for government sponsorship of increased aid to internal improvement planning (Hill 1957:62). In 1829, Major John J. Abert, head of the Topographical Bureau of Engineers, criticized the Board of Internal Improvements for inefficiency. As a result, Abert managed to get himself placed on the Board to coordinate its operations. Between 1831 and 1838, the Topographical Bureau of Engineers, which was in general responsible for internal improvements, administered the General Survey Act. Still being geared toward aiding local and private enterprises, the General Survey Act soon lost its Congressional support and authority. During the 1830s, the emphasis on canals decreased and focus turned to roads and railroads while public aid justification became increasingly military due to westward expansion (Hill 1957:80).

President Andrew Jackson supported a river and harbor development policy for any improvements that were of national scope. For that reason, he favored works on the Ohio and Mississippi since they could aid foreign trade. Although Jackson agreed in principle to aid for national improvements, he renounced his power under the General Survey Act to initiate such studies, leaving it up to Congress. In addition, struggles between those who believed that only military engineers should work on improvements under the Act prevailed against those who believed that civil engineers should also work on national internal improvements. Thus, civil

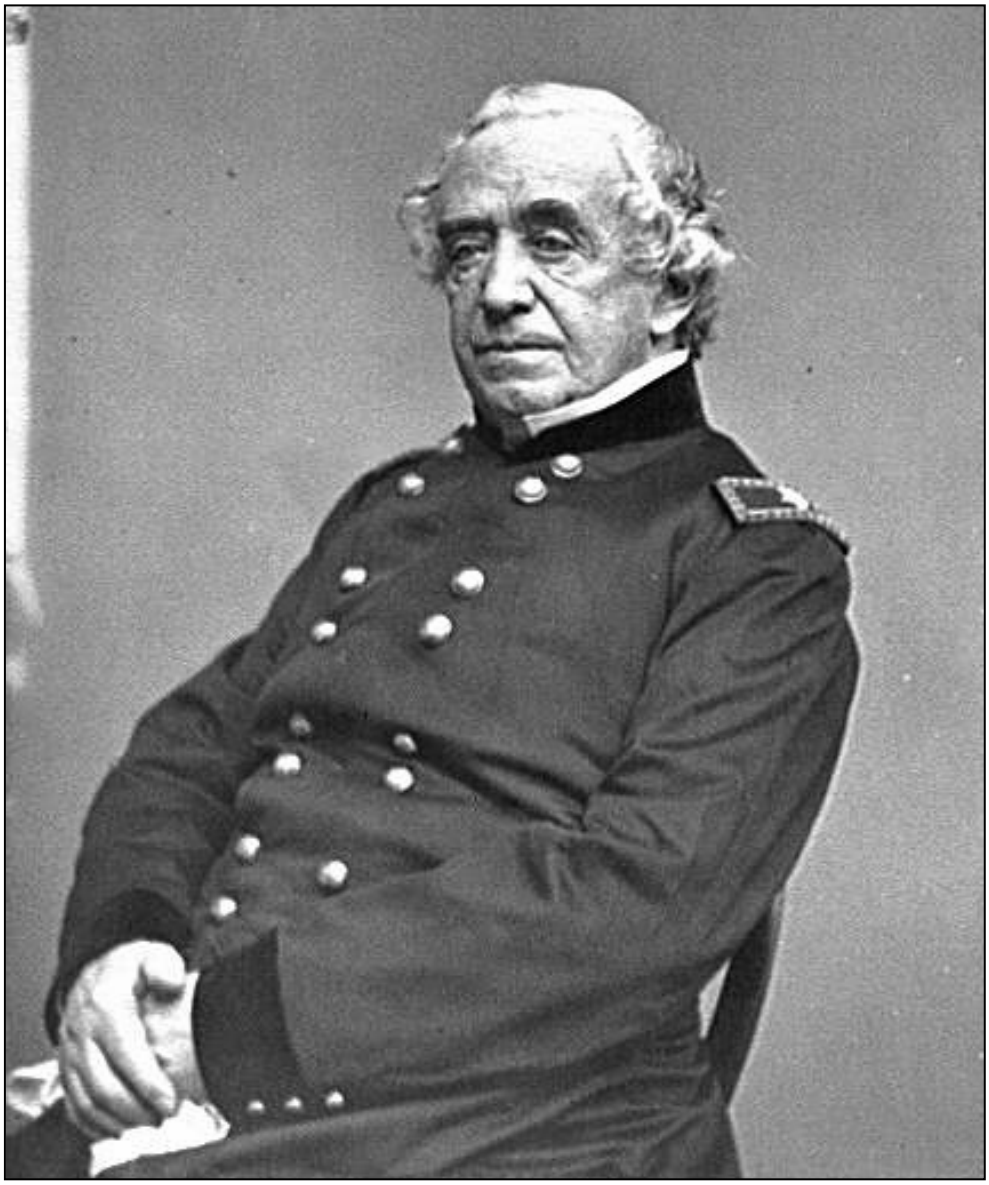

Plate 2-5. Col. Joseph G. Totten

engineers were barred from employment under the Act. Additionally, the Department of War restricted the Army engineers from aiding private and state enterprises when time permitted after 1836 (Hill 1957:83). In 1838, Senator James Buchanan summarized this sentiment when he argued that engineers were no longer scarce and Army engineers employed by canal and railroad companies had profited, while government projects had suffered (Hill 1957:92-93).

The doctrine of states' rights, sectional controversies, the loss of the planning functions under the Act, the growth of the railroads, rivalries between the President and Congress, Jackson's veto of federal aid to non-federal transportation projects, the financial panic of 1837, inadequate funds, increasing availability of civil engineers for private and local enterprises, and new military needs all contributed to the decline of Congressional support of the General Survey Act during the 1830s.

Jackson believed that the states could best administer funds for improvements. Congressional debates centered around the constitutional issues of the limits of federal power and state sovereignty. States generally opposed yielding on matters that would threaten their power base. Power to control the purse was the heart of the issue. Every state wanted money for improvements, but under their own control. Each Congressmen looked for the supreme benefit for their state. The ensuing rivalries between the states created inflexibility and impasse, paralyzing Congress and preventing major action. Congressmen complained that they could not obtain votes for their projects from outside of their region. This was doubtless exacerbated by the realization that funds were scarce and if one measure was approved, another state's issue would have to wait.

Although Jackson generally disapproved of federal action, other politicians from the West, including Senators Henry Clay and James Breckinridge of Kentucky, and Andrew Stewart (Repub., Whig) of Pennsylvania all argued strongly for improvements to the Ohio and were somewhat perturbed that the Congress constitutionally created "banks for the accommodation of the merchant" but would not "construct canals for the benefit of the farmer" (Goodrich 1960:46).

Additionally, those states that had already spent their own funds for improvements did not want to see states that had not had such expenses get federal money. New York, and the New England states had already funded their own projects. The North and South also had sectional disagreements, which grew on account of the slavery issue, splitting the Whig Party and diminishing solidarity on the internal improvement issue (Shallat 1994:153). The result of these rivalries was that the only money appropriated for many years was that which was secured as special acts or riders to other legislation (Hill 1957: 195-196).

After 1838, appropriations for river and harbor improvements decreased due to increasing political and constitutional criticism. In 1839, the War Department ordered the Engineers to restrict, and if possible suspend all improvements due to the lack of Congressional appropriations (Hill 1957:181). Congress passed no general river and harbor bill between 1838 and 1844. After 1838, legislators could not reach a consensus on the constitutionality or expediency of internal improvements. Congress never agreed on the scope of the river and harbor work, or how to define national vs. local work. Although Whigs were more apt to support and Democrats to oppose large improvements to the rivers and harbors, this cannot be stated as a general rule, as sectional differences often overruled party doctrine in the internal improvement debate. Western state Democrats favored major federal involvement for rivers and harbors. With so many opposing views and rivalries, Congress either defeated or the president vetoed most appropriation bills (Goodrich 1960:266; Holt 1923:9; Hill 1957:57).

Ohio River improvements remained at a virtual standstill during the administrations of Van Buren, Polk, and Pierce. In 1842, Congress made limited appropriations in the amount of $100,000 for the improvement of the Ohio, Mississippi, Missouri, and Arkansas rivers for the removing of snags, rocks, and wrecks, as well as some surveying. President Tyler and his Secretary of War William Wilkins recommended large improvements to western rivers and harbors with the condition that these be of demonstrably national character (Hill 1957:183). Disagreeing with Congressional efforts to fund small, sectional projects, Chief of Engineers Colonel John Abert refused to oblige Congress' requests for estimates on small projects, as he felt them to be inefficient and uneconomical. This situation continued during the war with Mexico. The new president, James K. Polk, held the opinion that all internal improvements were unconstitutional. Combined with the lack of consensus in Congress, this ensured no river and harbor appropriation bills through the year 1851 (Hill 1957:185-186).

Renewed appropriations came under President Millard Fillmore who approved of federal aid for internal improvements. He even approved of projects that appeared local in scope, such as the ship canal at Sault Ste. Marie, since he considered it to have national benefits. In 1852, Congress appropriated over $2,000,000 for over one hundred projects (Hill 1957:186).

At this time, the War Department divided the river and harbor works between the Topographical Engineers and the Corps of Engineers, with improvements to the western rivers and Great Lakes going to the Topographical Bureau, and the Atlantic and Gulf coasts being under the supervision of the Engineer Department. Chief Engineer Joseph Totten directed both groups to categorize each project based upon its national importance and to provide estimates and plans. Totten also assumed that his engineers had the power to originate estimates for new projects and present them to Congress.

In the 1850s, Secretary of War Jefferson Davis ruled that each project must be completed with existing appropriations, and that projects should not be planned with the expectation of future monies. This decree severely limited the size and scope of improvements. Davis also forbade improvements to commercial harbors and limited navigable river improvements to those "washing several states" as they alone had national importance. He expected local sources to fund local projects (Hill 1957: 190-191).

EARLY COMMUNITY GROWTH AND LOCAL POLITICAL INFLUENCE

From the earliest days of settlement in the Ohio Valley, merchants, manufacturers, and other more wealthy townspeople controlled the political leadership of their communities. The more successful merchants exercised the strongest control, while newspaper editors, lawyers, and doctors tended to have a lesser degree of control (Wade 1959:78). These community leaders understood that a town's growth depended upon its reputation for healthfulness, susceptibility to floods, their perceived future, as well as their natural resources. This knowledge caused them to be strong supporters of internal improvements (Bigham 1998:84). Secretary of the Treasury, Albert Gallatin, author of the "Report on Roads and Canals," had strong business interests along the Monongahela River that would benefit from efficient navigation of the Monongahela, Ohio, and Mississippi Rivers.

In these early days, professional men, including doctors, lawyers, ministers, teachers, and journalists, also held places of respect and standing in the community. Many of these professionals also had business interests (Wade 1959:113). Generally, the wealthy grew wealthier, due to the availability of cheap land and opportunity. They were proud of their achievements, and were often ostentatious about it. These merchants were the spokesmen for Federalism in the West, even after the party had all but died out in the East (Wade 1959:112).

In the early years of settlement, wage earners enjoyed relatively good pay and working conditions due to labor shortages, although this tended to be the case more north of the Ohio where slavery was not an issue (Wade 1959:117-119). European immigrants tended to settle north of the Ohio due to the presence of Slavery in the South. Among all immigrants, Germans were by far the most numerous (Bigham 1988:109). Transient workers, including wagon drivers, boatmen, and others, tended to be rough, causing trouble, and having no lasting interest in the community. In the early years of settlement of 1800-1820, this group was a prevalent, troublesome component of the population, but their numbers declined during the early 1820s, however, a new group of transient workers appeared on the scene with the construction of the Louisville and Portland Canal. By 1827, the transients comprised almost 10-percent of the population of Louisville (Wade 1959:117-218). By the 1830s, the lower classes began to exercise some political influence, and their associations began supporting candidates (Wade 1959:216).

Steamboating increased between 1811 and 1830 due to improvements on the river that included snag removal, dredging, and the important bypass around the Falls, the Louisville and Portland Canal. The steamboat trade that so dominated the river influenced the character of growth of the river towns began to lose its momentum upon the arrival of the first railroads in the Ohio Valley (Reid 1991:120). Still in the heyday of the steamboat, cities and regions urged Congressmen to secure river improvements of local and regional benefit. In 1850, frustrated with the lack of support in Congress, a group of businessmen in Evansville passed a series of resolution requesting funds for federal aid. In 1857, this group, chaired by entrepreneur John Law, promoted the study conducted by Charles Ellet who proposed a series of reservoirs on the Ohio in order to provide a six-foot navigation channel year round. The convention stressed the national character of such improvements (Bigham 1998:118).

An example of how river towns acted to promote navigation improvements, Evansville increased their efforts to persuade Congress after the Civil War when industry was on the rise. In September of 1868, the Evansville City Council sent one of its members as a delegate to a Cincinnati meeting with a congressional delegation with interests in the Ohio and Mississippi Rivers. They laid the foundation for the 1872 Cincinnati Chamber of Commerce convention

which stressed the increasing development of coal and iron, and planned more meetings as a means of securing congressional aid (Bigham 1998:119).

The ability of towns and cities to have access to river transportation had profound impacts on their social and economic development. Both the railroads and river transportation were important to the economy and society of the river valley. The very railroads that began to supersede the river in importance in the latter half of the 19th century also owned much of their growth to the river, and for a while the two modes of transportation appeared to be truly complementary. As river transport became more efficient and reliable, new markets for goods opened up, changing the nature of both product and production. Along the Lower Ohio, Tell City became quite prosperous in the late 1800s, and Cannelton was moderately prosperous. Flooding, however plagued Tell City, Cannelton, Evansville, Paducah, Mound City, and especially Cairo, and limited each city's success at attracting industry. Flooding also gave a city a reputation for unhealthfulness (Bigham 1998:177).

Nineteenth century river trade peaked in the 1850s. The steamboat was in its golden age, and although the railroads threatened river trade, it also complemented river trade by bringing inland goods to the river ports. Steamboat service continued to have the advantage of capacity and cost. Even the minimal navigation improvements at the Falls of the Ohio accelerated growth of some towns. New Albany, for instance, was located just below the falls, and took advantage of this location to become an important shipbuilding center, while rail and road service gave the town access to the interior for manufacturing industries. Other towns, such as Newburgh, experienced little growth despite its location on the river (Reid 1991:151; Bigham 1988:111).

Despite the lack of river improvements, larger, better situated communities did grow. Evansville and Paducah became urban centers in the late 1800s. Evansville became a large shipbuilding center, and was responsible for a large number of "tin clad" ships used by both North and South during the Civil War. Among the many ships was the U.S.S. Indianola (Plates 2-6 & 2-7). Mount Vernon, the sixth largest city on the Lower Ohio, grew steadily since 1870, as did Metropolis. Railroads became a major catalyst for the growth of these cities, although barge traffic began to play a role at the end of the 19th century (Bigham 1998:192).

DECLINE OF THE RIVER TRADE AND GROWTH OF RAILROADS

The Ohio River trade declined as promotion and aid to the railroads increased. Railroads built lines parallel to the river and the brief but promising era of river improvements seemed near its end (Bigham 1998:177). In 1850, no railroad offered serious competition to the Ohio river, the Mississippi, or any tributary, but this did not last. In 1847, Cincinnati had a new rail connection with Lake Erie at Sandusky and within four years, another connection to Cleveland. By 1854, Cincinnati had a second direct link to the East with the opening of the Ohio Central Railroad. In 1850 rail lines connected Madison, Indiana to Indianapolis and to Lake Michigan by 1854. In the 1850s, railroad mileage of the entire country tripled, becoming serious competitors for Ohio River commerce. By 1860, Pittsburgh, Cincinnati, and Louisville all had competent rail service, signaling the demise of the steamboat era (Hunter 1949:484-485). One by one, lesser river towns obtained connections to the railroad network. By 1887, only three of thirty major towns between Pittsburgh and Cairo had no railroad connection (Hunter 1949:587). Railroads had the advantage of speed, whereas river freight had the advantage of lower cost, however the rates often approached nearly equal levels in times of restricted navigation, especially in winter and low water, and the railroads enjoyed the further advantage of uninterrupted service (Hunter 1949:493).

Plate 2-6. U.S.S. Indianola During Construction in 1862

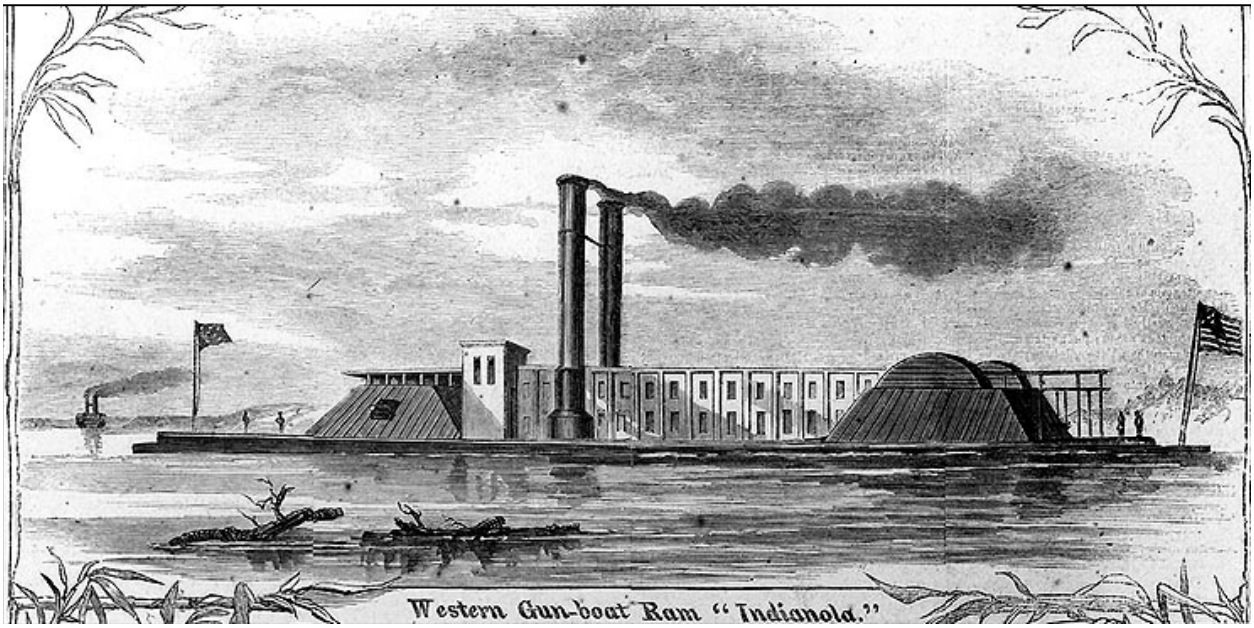

Plate 2-7. U.S.S. Indianola in 1863

POLITICS OF THE OHIO RIVER SLACKWATER SYSTEM: THE DAVIS ISLAND LOCK AND DAM

Samuel P. Hays, in his book *Conservation and The Gospel of Efficiency, 1890-1920*, argues that the Conservation Movement of the Progressive Era gained its momentum from a rising group of professionals who, as experts in their field, moved into positions of power in government and promoted their science. Hays argued that the movement was one of expert vs. expert, rather than a popular movement of workers against monied trusts and conservation minded people against wholesale destruction of our environment. According to Hays, professionals promoted conservation as an efficient use of resources, and not out of pure concern for the earth. In the process, professional rivalries and differing scientific opinions and theories often collided. The fervor with which these professionals pursued their vocations proved both an asset and liability. The conflicting expert opinions confused Congress and the public, and ultimately, both lost interest in the cause.

While the debate over canalization of the Ohio River, and especially its link to flood control issues, supports Hays' theories of the professional nature of the movement, the record also makes clear that there was a true grassroots movement component. Although it is true that the experts confused both Congress and the public, Congressional leaders, as well as local politicians and newspapers clearly selected expert opinions that would support their needs.

Hays indicts the Corps as an obtuse organization that fought comprehensive organized conservation. He argues that the Corps feared that an integrated water program that included conservation and reclamation would undermine their work and other agencies would usurp the Corps function. The Corps fought to block passage of the Newlands Bill of 1907 which sought to authorize comprehensive river development. Hays cites several articles appearing in *Engineering News* by Marshall O. Leighton of the U.S. Geological Survey, Brigadier-General Mackenzie, Hiram M. Chittenden, and others of the Corps of Engineers. While Leighton supported theories of reservoir and forest cover as important to flood control, the men of the Corps attacked the ideas. Part of the opposition stemmed from a desire for autonomy, but also from a desire to protect Congress' power to select public works projects rather than have a commission do the job. In the end, Hays asserts, the Corps entered the field of flood protection out of self-defense, forced to cultivate legislators and Congress used the guise of improvements to navigation to keep flood protection projects from appearing unconstitutional (Hays 1959:199-211).

The push for slackwater improvements to the Ohio River came from industrialists looking for cheap transportation alternatives to the railroads, and not primarily from river men. During the extreme seasonal dry spell and ensuing economic recession in 1871, Pittsburgh business interests began to organize a campaign for navigation improvements through year-round depth control of the city's harbor. The river became un-navigable from May until November of 1871. Coal shortages downstream in Cincinnati, Louisville, Evansville and Paducah became serious, driving up prices. In the winter of 1871 over ninety separate firms signed a petition to Congress for locks and dams. Signatories included General James K. Moorhead, who owned the Moorhead Iron Works. Moorhead was also president of the Pittsburgh Chamber of Commerce and the Monongahela Navigation Company (Johnson 1985:43).

The iron and steel industry promoted locks and dams but coal shippers opposed them. Due to this opposition, Colonel William E. Merrill could not seriously consider the problem from 1871 to 1878. After receiving the petition, Merrill asked for views of the coal shippers and rivermen in order to assess their objections to river improvements. He found many of their concerns

legitimate, including the request that the dam have a chute at least 300 feet wide to allow the passage of coal tows without lockage. In 1872, a convention of business associations organized by Felix R. Brunot and James Moorhead met in Cincinnati at which Captain Merrill described the proposed plans for the river navigation improvements to the Ohio. At this convention, the governors of seven states along the Ohio appointed a 35 member Ohio River Commission charged with keeping a vigilant watch on progress towards the improvement of the Ohio. James K. Moorhead became President and Chairman of the Commission (Johnson 1985:20-24).

After W. Milnor Roberts completed his report on canalization of the Ohio, state governments on the river made concerted efforts to gain congressional support for the project. On February 9, 1872, the Kentucky legislature instructed its Congressmen to support the matter. Kentucky, Pennsylvania, Indiana, Ohio, West Virginia, Illinois, and Tennessee all participated in the regional Board of Commissioners for the Improvement of the Ohio River (Ohio River Commission). The members studied the economic and transportation situation on the Ohio Valley, met with Army engineers, and lobbied Congress actively in support of the project (Johnson 1975:160). Coal interests who opposed the project cited that the dams might increase flood heights, that stagnant slackwater would foster disease, and that the river channels would fill with silt. The Monongahela slackwater system proved the first two concerns false. To the allegation of increased flood risk, the engineers proposed movable Chanoine dams similar to those constructed in France (Johnson 1975: 162).

Congress appointed General Godfrey Weitzel of the Louisville District of the Army Corps of Engineers and Colonel William E. Merrill of the Cincinnati District to a special Board of Engineers to report on the proposal in 1872. They recommended that Congress approve the project along with the offer of the Monongahela Navigation Company to pay for half of the experimental hydraulic gate designed by Felix R. Brunot of Pittsburgh. Due to opposition from coal shippers to the concept of restricting navigation with locks and dams, Congress did not act (Johnson 1975:162). These coal interests feared that the federal government might impede the coal industries use of the river and restrict access to their markets.

Engineers continued to argue the merits of water and rail transportation in professional circles. Captain F. A. Mahan published an article in *Transactions*, the journal of the American Society of Civil Engineers in 1893. The article, initially prepared for the International Engineering Congress of the Colombian Exposition of 1893, compared rail and water transportation with the object of showing that competition of water transportation kept railroad rates down, and would prove an efficient and economical mode of transportation if "brought up to date" like the railroads (*Transactions* Vol. XXIX, 1893. American Society of Civil Engineers, New York). In the next volume of *Transactions*, C. W. Raymond, Edward P. North, and F. A. Mahan published a discussion on Mahan's paper where Raymond and North take issue with Mahan's assumptions that water transportation is inherently cheaper than rail (*Transactions* Vol. XXX, 1893 American Society of Civil Engineers, New York) .

River transportation received national attention in 1872 at the request of President Ulysses S. Grant in his annual message. On the Congressional level, the Senate Committee on Transportation-Routes to the Seaboard (the Windom Committee) held hearings on the proposed Ohio River Canalization Project in 1873 and 1874 (Johnson 1975:165). The Senate formed the committee to set forth a planning policy for national waterway improvement. This Senate Select Committee on Transportation-Routes to the Seaboard was commonly called the Windom Committee since its chairman was Senator William Windom of Minnesota. Representing the Ohio Valley interests were Senator John Sherman (Repub.) of Ohio, Henry G. Davis (Repub.) of West Virginia, and John H. Mitchell (Repub.) of Oregon, a native of Western Pennsylvania

(Johnson 1985:30). The Committee's recommendations included a system of locks and dams on the Ohio that would maintain a depth of at least six feet, considering it "one of the most important works for which the National Government can appropriate money" (Johnson 1985:31).

Senator William Windom was originally from Mount Vernon, Ohio. Although chiefly interested in the Mississippi River and St. Lawrence, he supported all river and harbor improvements. He argued that the railroads could not effectively move cheap and heavy farm products as well as waterways. Before a bribery scandal forced him to resign in 1876, former Secretary of War William W. Bellknap had supported the idea of a "general system and plan" for improvements in Congressional hearings. He hoped to change the course previously set by Congress of funding small amounts for multiple projects. (Congressional Record, Senate, 45th 2nd 1878).

Proponents of the Granger Movement dominated the Windom Committee. This group had an interest in providing cheap transportation for agricultural products as a way to break the farmer's dependence on the railroads. Most farmers felt that the railroads discriminated against them in their pricing policies. Among the chief causes of the Granger Movement were the declining prices of farm products, a growing indebtedness of farmers to merchants and banks, discriminatory freight rates imposed on farmers by the railroads, and the acquisition by the railroads of public lands that formerly had served pioneer farmers as a source of new farmland. As a result, a number of political parties, bearing such names as the Reform Party and Anti-Monopoly Party, sprang up in several states during the 1870s and 1880s. These parties succeeded in electing several state officers and U.S. Senators. In a number of states, including Illinois, Iowa, Minnesota, Wisconsin, and California they contributed to the passage of laws regulating railroad rates and practices.

During the Windom Committee hearings, Colonel Merrill and Captain Milton B. Adams, deputy to General Weitzel testified. The Committee reported that although the railroads had been completed from the Ohio Valley to the Gulf, the waterways were still the "cheapest line of transport" and that the competition they provided would force rail freight rates down. The Committee recommended that Congress approve the Davis Island Dam project.

Congress approved $100,000 for initial land acquisition and construction at Davis Island in 1875, but the Pennsylvania legislature still needed to grant jurisdiction of Davis Island to the federal government. Local rivermen were not generally in favor of the measure, as it represented an unknown variable in the future of their business. Thus, few groups in the Ohio Valley promoted the improvement, although some, such as the City of Lawrenceburg, Indiana, petitioned the committee on Rivers and Harbors for river improvements (Congressional Record, House 48th 1st 1884). Outside of the Ohio Valley, the agrarian movement brought diverse interests together in support of river improvements, and Congressional supporters included Representatives Strother M. Stockslager (Dem.) of Indiana, William Breckinridge (Dem.) and Albert Willis (Dem.) from Kentucky, Thomas Bayne (Repub.) of Pennsylvania, and even Edwin Conger (Dem.) of Iowa and Richard Coke (Repub.) of Texas.

The political conflict between the iron and the coal interests had considerable influence on the engineering design of the Davis Island Dam, and by extension of that system to the other locks and dams. The conflict significantly altered the design of the entire navigation system. Frederick A. Mahan, Engineer in Charge, and Colonel Merrill investigated many systems in use both in the United States and Europe. In France, Merrill discovered the Chanoine system of rectangular panels called wickets that could be raised during low water periods, and lowered during flood stages in order to let boats through without using the lock. This was precisely what he needed on the Ohio to accommodate both the iron and coal interests (Johnson 1985:38-40).

Coal interests impeded construction of the dam despite the compromise in design. The U.S. Government needed to purchase a strip of land on the north bank of the river for a lock and lock house, as well as land for other structures associated with the dam. Coal shippers and their associates owned much of this land. Captain Thomas Mulvehill, a coal shipper owned one parcel. He used his property for barge moorage. Mulvehill demanded a high price for his land. David Davis, owner of the upper end of Davis Island, refused to sell altogether. Mrs. James Graham, who owned the land on the south bank also resisted. Eventually, Merrill settled with all parties, but at prices exceeding the value of the land, and at the loss of valuable time. Partly due to this delay, Merrill had to agree to construct only one dam at Davis Island, and wait for it to prove effective before continuing with the entire navigation system to Wheeling that he had originally proposed (Johnson 1985:50-52).

In their efforts against Ohio River canalization, the coal shippers tried to block the granting of jurisdiction over Davis Island in the Pennsylvania Legislature, and they were successful for several years from 1874 through 1877. In 1874, the Pennsylvania assembly passed the jurisdiction bill, but the Governor vetoed it, and in 1875, the legislation died in the state Senate. In 1877, the Pittsburgh Chamber of Commerce and the strong influence of the Ohio River Commission won out, and the enabling legislation passed (Johnson 1975: 165).

Joseph Stone (Repub.), Representative from Iowa gave a state of the Union speech on June 4, 1878, in which he derided the practice of granting land to the railroads (railroad subsidies) as "careless, wasteful and extravagant." Using the Mississippi Valley as an example, he asserted that the interests of the nation would be "more effectually promoted by improving . . . navigation." Harry White (Repub.) of Pennsylvania promoted a similar theme on May 11, but White continued by saying that this "mischief" of large companies combining to drive out all competition was rampant, extending to Standard Oil, the Southern Improvement Company, and others (Congressional Record, House 45th 2nd 1878). Although little concrete action came from this agitation immediately, it eventually led to the creation of the Interstate Commerce Commission in 1887, after the 1886 Supreme Court decision, *Wabash, St. Louis and Pacific Railroad* v. *Illinois,* ruled that the states could not regulate interstate railroads, effectively shifting the burden of regulation to the federal government.

Congress continued to struggle over successive river and harbor bills. In 1882, appropriations had increased over seven million dollars from the previous year. President Chester Arthur vetoed that year's appropriation bill (H. R. 6242) on the grounds that there were too many projects that appeared to be local in nature, and he could not approve measures that did not promote "the common defense or general welfare and . . . commerce among the States" (Chester Arthur's veto message as quoted in Congressional Record, Senate 64th 2nd 1916).

Where politics often failed, floods succeeded. When disastrous floods struck, Congressmen, eager to get money for flood control that many thought to be unconstitutional, linked the flood control projects to navigation improvements, making appropriations for navigation projects easier for Congress to agree on. Major floods in 1883 and 1884 caused Congress to appropriate funds for relief of flood victims and authorize some flood control projects, but many felt that it was time for Congress to authorize a study for a comprehensive system of flood control. *Engineering News*, in 1884, asserted that the Corps should undertake such a study, but Congress was not prepared to authorize it (Johnson 1975:192).

Congress did, however, allow for the study of levee projects for areas that had been severely damaged during the flood of 1884, and appropriated money for constructing a levee at

Jeffersonville as part of the 1884 Rivers and Harbors Act. Flood control was not specifically mentioned in the Act as it was not politically expedient, and the work was done under the guise of improving navigation (Johnson 1975:192). Other towns in Indiana and Illinois, including Lawrenceburg and Shawneetown had also been greatly effected during the floods, and Colonel Merrill of the Corps requested money for these towns despite the fact that the levee improvements would not aid navigation. Congress, although it would not commit to improvements for flood control, did approve monies for these improvements (Johnson 1975:192). Levees were often justified in terms of aiding navigation, such as when Congress funded embankment construction at Lawrenceburg, Indiana in 1886 to prevent the formation of bars which might obstruct navigation (Johnson 1975:192).

When the Davis Island Dam was completed in 1885, its successful operation transformed the coal shipper's previous objections into enthusiasm for extensive canalization. In July of 1888, this enthusiasm was reinforced, and virtually all opposition to slackwater navigation ceased when a record flood sent water down the Monongahela destroying coal tipples and over one hundred barges on the Monongahela, but shippers within the Davis Island pool did not lose a single barge (Johnson 1985:105).

The Cincinnati and Louisville District engineers held public hearings in 1888 in response to a Congressionally authorized study for extending the six-foot minimum depth slackwater project down the Ohio. These hearings made it clear that the coal and navigation interests who had previously opposed canalization of the Ohio were now unanimously in favor of additional slackwater improvements (Johnson 1975: 169). Senator Matthew S. Quay (Repub.) of Beaver, Pennsylvania presented resolutions for improvements of the Ohio between Davis Island Dam and Raccoon Creek, Beaver County, Pennsylvania "in accordance with Col. W. E. Merrill, engineer in charge" (Congressional Record, Senate, 50th, 1st 1888). His colleague Thomas M. Bayne was also active in presenting resolutions from organizations like the "Commissioners for the Improvement of the Ohio River and its Tributaries", calling for improvements to the Ohio, Monongahela, Green, and Barren Rivers (Congressional Record, Senate, 50th, 1st 1888).

POLITICAL AND SOCIAL MATURITY IN OHIO RIVER VALLEY TOWNS

Strong political leadership was essential to a town's success. Business associations for urban advancement in Evansville, Henderson, Owensboro, and Paducah in the 1880s formed a cohesive political front that brought such firms as Ken-Rad, Bucyrus-Erie, Mead-Johnson, and Hercules to the Ohio Valley. Eventually, these associations became Chambers of Commerce (Bigham 1998:219).

Evansville's population doubled between 1870 and 1890, and doubled again by 1920. At that time, about 85,000 people lived within the city limits (Bigham 1988:15). Part of this growth came from the annexation of localities like Independence and Howell. Other factors included a higher birth rate and lower mortality rate, but this growth also came about as a chain reaction of events. Industrialization attracted new workers to the city eager to find employment in the new industries made possible by the steamboat packet trade on the river and the rail lines of the Evansville and Terre-Haute and the L&N (Bigham 1988:16). The increased influx of people created a population composed increasingly of wage-earners dependent on the industry of the urban areas, and less independent, having less control over their working conditions. In 1900, 14,000 residents worked in manufacturing, but by 1920, this figure had risen to 18,000. (Bigham 1988:17). Increased industrialization also led to increased consolidation of the factories. Layoffs and other threats to job security led to organized labor, as well as the more extreme Socialist Party of America led by Indiana's Eugene V. Debs (Bigham 1988:17).

Social distinctions developed rapidly in the West. These lines were economically based, and to a lesser extent professional. Societies for different groups sprang up in the first decades of the 1900s, and included such memberships as the St. Cecilia Society for ladies in Cincinnati, and the Quintillion Literary Society in Pittsburgh, as well as professional and charitable associations (Wade 1959:106). In Evansville, the Men's Business Association coined the name "Gateway to the South" for Evansville in the 1880s, showing their pride and hope for the possibilities that these transportation routes opened up (Bigham 1988:17).

Cities such as Cincinnati, Pittsburgh and Louisville early competed against each other for economic and political supremacy. The issue centered on control of river commerce, as the Ohio was the main commercial artery of the West (Wade 1959:327). Cincinnati and Louisville were major rival cities on the Ohio. Louisville had a geographic advantage being situated at the Falls of the Ohio, being a natural gateway to the South. Both cities fought for the favor of southern markets. When Cincinnati was chosen as the northern terminus of a proposed railroad to connect Charleston, South Carolina, Louisville demanded a branch line in exchange for a franchise to cross the state of Kentucky, as well as other concessions from Cincinnati, ultimately dooming the project (Ambler 1931:232).

The fight between Wheeling and Pittsburgh over the construction of the Wheeling Suspension Bridge illustrates just how fierce this competition could be - it took a local bridge building dispute, and propelled it into a national issue. Although Pittsburgh had a distinct commercial advantage geographically, the aspirations of Wheeling to become the chief commercial city of the upper Ohio, and the imminent completion of the B&O railroad to Wheeling caused Pittsburgh's opposition to grow. Pittsburghers fought the construction of the Wheeling bridge from the start, claiming that it was an obstruction to navigation, as it required large steamboats to lower their stacks to pass under the bridge. In June of 1849, a large group of Pittsburgh rivermen met to appeal to Supreme Court Judge Robert C. Grier, to grant an injunction against the construction of the bridge, but the first cable had already been positioned. The Commonwealth of Pennsylvania,

representing Pittsburgh, then sued the bridge company (Ambler 1931:220; Kemp & Fluty 1999). Although Wheeling lost in court, they succeeded in having Congress declare the bridge a post-road in 1852, and thus, the bridge could not be ordered down (Ambler 1931:227).

For many years, there were no general laws or provisions regarding bridges, but in 1870, Congress allowed for the creation of a board of engineers specifically for the examination of bridges crossing the Ohio River to report whether they were an impediment to free navigation of the river (Holt 1923:42). The group most interested in the maintenance of free navigation of the Ohio was the Pittsburgh coal shippers. Other interests, local and sectional, were more concerned about railroads and railroad bridges across the river. In the 1870s, the only major proponents of free navigation of the river in the state of Ohio were at Cincinnati. As a result, many railroads constructed bridges that impeded navigation of the Ohio either by obstructions of height, or by piers that caused shippers to break up coal fleets to pass. Coal producers still managed to ship the majority of their product by river (Ambler 1931:311-312). It wasn't until 1884 that Congress gave the Corps the authority to regulate the construction of bridges, and put upon the party constructing any bridge to pay the costs necessary to ensure that it did not interfere with free navigation (Holt 1923:42).

At the end of the 19th century, the states along the Ohio River exhibited wide variations of social and economic sophistication. Kentucky's economy was relatively stagnant due to poor rural roads, limited railroad construction, predominantly agrarian values, and generally poor education standards. Illinois, by contrast rapidly became an industrial and urbanized state. More than half of its population resided in urban areas, and the state's economy largely depended on iron and steel, as well as coal. Public education expanded greatly, and in 1914, the state developed a highway plan.

Indiana experienced advancement in its northern and central regions, but less so in the south. Ohio was perhaps the most dependent on river trade at this time. Evansville, in particular remained a leader in the commerce of the Ohio River, although a fair number of railroads crossed the state (Bigham 1998:198-200). Other towns, such as Cairo, continued to lack strong political leadership and this town, despite its unique position at the intersection of the Ohio and Mississippi Rivers, as well as a terminus for many railroads, declined. Cairo always had the threat of flooding, but that too, was partly due to the lack of solidarity of opinion among leadership and the lack of will to act decisively to protect the town from such floods. Cairo, which struggled throughout the early 19th century, had only about 200 residents in 1850. When the Illinois Central railroad line was completed to Cairo in 1855, the town grew, having a population of 2,188 by 1860. The town continued, however to be plagued with the threat of floods (Bigham 1988:103).

Darrel Bigham examined the development of the Lower Ohio Valley from settlement through about 1930 as an effort, in part, to discover why so many towns and cities experienced decline beginning in the 1880s. He studied why some remained stagnant, and yet others, especially Evansville, Indiana, Ownesboro Kentucky, and West Point grew remarkably. Cairo's example proved that an ideal location was no guarantee. He concluded that nothing was inevitable about the growth of these communities, but that a mixture of location, resources, market economy, political culture, leadership, and luck determined their future. He specifically pointed out that the decisions made in state and national legislatures made a difference (Bigham 1998:251-253). Evansville had expanded rail service by the late 1800s, and it served much of the expanding industry. Local businessman David J. Mackey gained control of local railroads, including the Paducah, Decatur and Evansville Railroad, but the panic of 1893 left Mackey bankrupt, and most of the railroads consolidated under external control and ownership.

The growing coalition of interests favoring Ohio River navigation improvements did not mean that the coal, navigation, and manufacturing interests agreed on the nature and location of these improvements. In July of 1888, Senator Matthew S. Quay submitted a resolution adopted by the Pittsburgh Coal Exchange strongly in favor of navigation improvements on the Ohio, but just as strongly disapproved of the current Congressional legislation calling for the construction of the next lock and dam to be at Beaver Pennsylvania, instead asking for construction of a lock and dam just below Davis Island. They were, in effect stating that proper navigation of the Ohio River required four locks and dams between Davis Island and Beaver, and not one (Congressional Record, Senate, 50th, 1st 1888).

PROGRESSIVE ERA POLITICS AND NAVIGATION IMPROVEMENTS

The Progressive Movement had a major impact on the course of Ohio River navigation development. Characteristics of the movement included concern for the protection of the country's natural wealth in forests, minerals and river systems with a dominant theme on the careful use of these resources to insure that the economy would have a lasting supply of raw materials. Advocates looked to scientific and professional cooperation with large corporations to develop a coherent policy of government regulation. Others were more interested in the chance to revive a mythical agrarian society and reverse the urban and industrial trend of society. Regulatory agencies like the Interstate Commerce Commission and the Federal Trade Commission were some of the vehicles through which reformers hoped to effect these scientific changes (Gould 1974:4).

The Republican party dominated the political arena during the Progressive Era. The Democrats' reign effectively ended with the economic depression of the early 1890s. Although the Republicans advocated "Big Business", the party was careful to advocate government action that would promote economic growth, and the economic recovery of the early-20th century gave the party its strength (Gould 1974:5). Although the Republicans were dominant, the Socialist movement expanded during this period, with Indiana's Eugene V. Debs as its chief advocate and candidate (Bigham 1988:17).

The social movements of this time propagated a renewed interest in slackwater improvements on the Ohio and waterways development in general. One contemporary writer stated: "The present movement (for inland waterways) is regarded as a great awakening to the need of national economy, and the conservation as well as the development of our natural resources . . . while there may be now and then a lull in the storm, the waterways movement is nevertheless firmly rooted, and will command attention for years to come" (Moulton 1912:3-4). In 1895, Cleveland held an International Waterways Convention. In 1901, the first National Rivers and Harbors Congress met in Baltimore. In 1903, New York appropriated $101,000,000 for the improvement of the Erie Canal. In 1906 the Rivers and Harbors Congress held conventions in both St. Louis and Washington, and on March 14 1907, President Theodore Roosevelt appointed the Inland Waterways Commission (Moulton 1912:1-2).

Hays' theory that the Progressive Movement was largely a professional movement, propelled to the forefront of national debate by scientists and other experts explains much of the link between conservation and river navigation improvements. Hays does not do justice to the social aspects of the movement. Massive changes in production modes, brought about by industrialization, economic distress, visible changes to the environment, loss of individual worker autonomy, and other factors all played a role in the coming of the Progressive Era. What is unique to the period is that America sought scientific solutions from experts to combat society's ills. The period following the Civil War exhibited greater social and political awareness of the American public. Social injustices in the workplace, including child labor and long work weeks of over sixty hours were frequent complaints. Labor unions began to assert their power, and business, as well as government, which appeared too often on the side of business, fought back. The depression of the 1890s, beginning with the panic of 1893, dramatized the social problems of the day. Citizens groups rallied against poor public facilities, tax favoritism, corruption in government, and business privileges. Growing concern about business consolidation and "trustification" gave way to fears of diminishing opportunity for the individual entrepreneur.

By 1900, these concerns had begun to take the form of a political agenda that stressed the fear of business consolidation and a call for government regulation of corporations. During the 1890s, large-scale businesses had multiplied. Railroads and steel industries in particular had become large consolidated "trusts" (Gould 1974:1-2).

Although work on rivers and harbors increased each year between 1881 and 1901 including during the Spanish American War, commerce on the Ohio was dying. In both Cincinnati and Louisville, statistics of commerce on river and rail showed how bad it was. In almost every category, cotton, tobacco, whisky, lard, corn, wheat, potatoes, flour, ham and bacon, the railroads carried from 95 to 99-percent of all commerce. The only significant exceptions were coffee and sugar, for which the Ohio carried twelve and seven-percent respectively (Hunter 1949:602). This was the beginning of a long-term trend. The total percentage of decline in tonnage between the years 1870 through 1910 totaled over 75-percent for the Ohio River (Hunter 1949:637).

The Interstate Commerce Act of 1887 proved a disappointment to Ohio River interests. River men had high hopes that the Interstate Commerce Commission (ICC) would alleviate the problems of steamboat men by enforcing a clause in the Act that forbade the railroads to make a greater charge for short haul than long haul freight. Since railroads could not lower their rates across the board to levels in effect at river points, the river men believed that the water carriers would be able to obtain higher rates and eventually eliminate the competition of the railroads at river terminals. In a blow to all river men, the ICC declared that the long and short haul clause was only applicable "under substantially similar circumstances and condition," meaning that because water competition was so dissimilar to rail service, that rate differences were justified (Hunter 1949:593). River interests were further disappointed by the Commission's decision that the clause in the Interstate Commerce Act of 1887 that compelled the railroads to enter into joint arrangements with water carriers for through shipments at through rates was not mandatory, but optional. As late as 1910, the Commissioner of Corporations noted that on the Ohio there was still no coordination of rail and river facilities at any river terminal (Hunter 1949:597-599).

In the latter half of the 19th century, the Grange Movement continued to play an important part in Ohio River political battles. Although most of these so-called granger laws were repealed or drastically modified within a few years the U.S. Supreme Court upheld some, and they served as the basis for much later legislation in the field of railroad and public-utility regulation.

During the 1890s, the rise of agrarian protest hurt both major parties, but infighting proved most divisive among the Democrats; their collapse at the polls followed in 1896. Beginning in that year, increased voter strength made the Republicans the majority party in the country for a generation. Party factionalism continued. Beginning in the 1890s a group of Republicans known as the Progressives sought to balance the party's commitment to the industrial elite with the use of federal power to correct some of the worst excesses of the monopolies and trusts that dominated the economy.

Although Congress began to fund additional improvements after the success of the Davis Island Dam, appropriations were slow. It was not until 1890 that Congress made appropriations for the second lock and dam improvement, the Merrill Dam. In that year, Congressman Thomas J. Henderson (Repub.) of Princeton Illinois, introduced H.R. 9486 for the "construction, repair, and preservation of . . . rivers and harbors . . ." (Congressional Record, House, 52nd 1st 1890). The issues in the debate included those opposed to the general "pork barrel" tendencies of the river and harbor appropriations that gave money for what they felt were "improvements to creeks." Congressmen made the bill the butt of jokes and derided the waste of public money. Issues such

as these, combined with a general complacency among Congressmen, some sections continued to create a difficult, but not wholly unfruitful environment for appropriations.

During the early 1890s, Congressmen such as Senator David Turpie (Dem.), Arthur H. Taylor (Dem.) of Petersburg Indiana continued to submit petitions for Ohio River improvement from chambers of commerce and citizens groups, as well as sponsoring legislation for navigation improvements. During the 53rd Congress, Arthur Taylor was appointed to the Committee on Rivers and Harbors. Taylor, along with John Dalzell (Repub.) of Pittsburgh, and Bellamy Storer (Repub.) of Cincinnati in the House, and John Sherman of Mansfield, Ohio in the Senate, continued to submit petitions from chambers of commerce. They also sponsored bills and amendments for rivers and harbors in general. Local commercial and citizens groups became more powerful and prolific in their agitation for improvements during the 1890s. Typical was the petitions for "artificial freshet navigation" on the Ohio River from the Pittsburgh Chamber of Commerce, introduced by John Dalzell in the House and a similar petition by the Cincinnati Chamber of Commerce submitted by John Sherman in the Senate in 1894 (Congressional Record, House and Senate, 53rd, 2nd 1894).

Other special interest groups were organized and exerted influence, including the Mahoning Valley Industrial Council, the American Waterways Operators Inc., the Wabash Valley Improvement Association, and the Propeller Clubs of the United States. In response to the lack of enthusiasm in Congress, in 1895, local interests formed the Ohio Valley Improvement Association (OVIA) at Cincinnati to campaign for canalization of the river (New York Times October 29, 1961 Section 11, p.4). In 1896, OVIA took the House Rivers and Harbors Committee on a tour of the Upper Ohio to emphasize the need for river improvements. (Johnson 1975: 169).

President Grover Cleveland vetoed the river and harbor bill of May 1896. He explained that the appropriations of the bill were instigated by private interests and promoted "local or individual profits" and therefore "could not fail to stimulate vicious paternalism and encourage a sentiment among our people already too prevalent, that their attachment to our Government may properly rest upon the hope and expectation of direct and special favors . . " (Congressional Record, Appendix 56th 2nd House 1901).

In 1898, Mr. Theodore Burton (Repub.)[Plate 2-8], Chairman of the Committee on Rivers and Harbors introduced an amendment to the 1898 River and Harbor bill for a survey to report on the cost and feasibility of constructing a lock and dam at "Cullums Riffle" near Cincinnati. He pointed out that the survey had already been completed by Major Bixby and it would only require a small expenditure to produce the report. Jacob H. Bromwell, (Repub.) member of the House from Cincinnati, also endorsed the survey (Congressional Record, House, 55th 2nd 1898). Under the urging of Senators Joseph Foraker (R) of Cincinnati and James McMillan (R), the Senate passed the amendment the next day (Congressional Record, Senate, 52nd 1st 1898). McMillan, although he had been a purchasing agent for the Detroit & Milwaukee Railroad and held positions for the Michigan Car Company, and acted as president of the Duluth, South Shore & Atlantic Railroad, saw that there was a great deal of benefit to cooperating with waterway transportation, and he held a great interest in shipbuilding and lake transportation companies as well (Moore 1915). During the next session, in February of 1899, the Secretary of War transmitted the report to the Committee on Rivers and Harbors ." (Congressional Record, House, 53rd 1st 1899). Congress appropriated the first funds for Locks and Dams Nos. 13 and 18 for the ports of Wheeling and Marietta in 1899 (Johnson 1975:169).

The turn of the century saw some monumental shifts in the political arena with the sudden rise of Theodore Roosevelt (Plate 2-9) to the presidency upon the assassination of William McKinley in 1901. Roosevelt, in addition to being an ardent promoter of the conservation movement, had the popular reputation as the enemy of the monied "trusts". Previous to the presidency, he had rubbed shoulders with muckrakers like Jacob Riis. Although Roosevelt targeted these industrial monopolies, he was not concerned with breaking up the monopolies so much as with correcting their evils. Some of the legislation that resulted from this fervor was the creation in 1903 of the Department of Commerce and Labor and a Bureau of Corporations. They were authorized to investigate business combinations and to warn against practices harmful to the public.

In 1901 the Northern Pacific, the Great Northern, and the Burlington railroad systems were brought together under the Northern Securities Company. In 1903, through Attorney General Philander C. Knox, Roosevelt brought suit under the Sherman Anti-Trust Act of 1890 for the dissolution of the Northern Securities Company as a conspiracy in restraint of trade. The United States won the suit. Suits were also begun against the United States Steel Corporation, the Standard Oil Company, and other large combinations. In all, Roosevelt obtained 25 indictments during his two administrations, although some of the cases were not decided until he was out of office.

In addition to dissolving the Northern Securities Company, Roosevelt attacked railroad monopoly in two acts passed by Congress. The Elkins Act made illegal the granting or accepting of secret rebates; that is, repayment of shipping charges. The Hepburn Act gave the Interstate Commerce Commission the right to fix rates. It extended the commission's jurisdiction to include pipelines, terminals, ferries, and express companies. It forbade railroads to grant free passes to anyone but employees, and it forbade the railroads to carry commodities in the production of which they had an interest.

The 56th Congress labored over the River and Harbor bill for 1901 at great length. In the House, those in favor of the bill included Jacob Ruppert Jr. (Dem.) of New York, who supported all the appropriations made under the bill, but predictably stressed that the improvement of the New York Harbor was of greater commercial importance than most of the projects, although he suggested that more was needed for the Mississippi. Nicholas Muller (Dem.) of Staten Island was less verbose, but just as strong in his approval for improvements to improvements to channels surrounding Staten Island, New York. David E. Finley (Dem.) of South Carolina also unequivocally endorsed the bill (H.R. 13189). James R. Mann (Repub.) of Illinois suggested that those who opposed the bill were unfamiliar with waterways and could not understand the complex interrelationship of trade and waterways improvements (Congressional Record, Appendix, 56th^{d} 2nd 1901).

Republicans generally favored the bill, and Democrats, especially those from regions where waterways appropriations would be of little use, vilified it. William King (Dem.) of Utah opposed all the appropriations because to him it represented the epitome of pork, where each member of Congress felt obligated to "struggle for a portion of (the) booty" or face the wrath of their constituents. He opposed the deals that caused Congressmen from areas with worthy improvement projects to support unworthy projects to secure passage of the bill, saying that "to improve 'navigable' streams, millions of dollars are squandered on unnavigable ones." He also complained about private corporations that used their capital stock to subscribe a lobby to Congress and use previous bad precedents set by Congress as justifications for more appropriations. Along partisan lines, he stated "In my humble opinion, it is indefensible for any Democrat, even though he can succeed, to attempt to use the Treasury of the United States to aid in improvements that are personal or local. When Republicans are looting the Treasury and

Plate 2-8. Senator Theodore Burton

Plate 2-9. Theodore Roosevelt

seeking to employ the Government to benefit the few, the duty is, if possible, stronger than ever for the Democrats to defend the people and the Constitution and keep their hands clean. . . . Civil and political liberty are threatened by the Republican party, and industrial liberty is being destroyed by the power of wealth. Centralized power and aggregated wealth! These are the foes Democracy must challenge" (Congressional Record, Appendix, 56th^{d} 2nd 1901).

By the time the bill reached the Senate, the majority had agreed to support it, and a conference had found disagreement on only four amendments, however, a minority continued to present formidable opposition. Thomas H. Carter (R) of Helena, Montana, with previous careers in agriculture and railroading, entered into a long filibuster against the bill. His intentions to oppose the bill were directly related to the killing of a shipping bill, also known as the subsidy bill, that intended to re-establish the Merchant Marine system. Opposition to this bill centered around the idea that it was meant to subsidize the freight costs of Standard Oil, the Pennsylvania Railroad, and other large "trusts". This bill, which he supported, passed the House but died in committee. He made it clear that he would do his best to defeat the river and harbor bill just like those who through "repeated speeches . . . deprived the majority in this Chamber from casting their votes in favor of the measure for which the majority stood" (Roeder 1989:23-29; Congressional Record, 56^{d} 2nd 1901).

Carter argued that nine-tenths of the projects in the river and harbor bill for 1901 had no merit, and that the "rivers are not increasing in number; the harbors are not increasing; but Mr. President, we are starting out to make rivers where rivers do not exist." Carter saw the bill as a fraudulent attempt to extort money from the treasury for local, unconstitutional projects on creeks and swamps. He detailed projects in the bill that were easy to pick on, such as the harbor at Porcupine Island, Maine, and the Oak Orchard Creek work in New York, but steered clear of projects of more obvious merit such as the Mississippi and the Ohio. In Maryland, he noted that "every river, great and small . . . is remembered in this grab bag" (Congressional Record,, 56^{d} 2nd 1901). Improvements to navigation of rivers, including to the Mississippi and Ohio, became difficult to justify when seen in the context of river usage. Although the Ohio River Canalization project continued to be constructed, albeit slowly, during the first decades of the 20th century, waterborne commerce on the Ohio River was dead. Steamboat packet service dwindled rapidly, and coal shipments had virtually ceased. The sudden end of the coal trade on the river came about due to the formation of the Monongahela River Consolidated Coal and Coke Company - a company that had been formed from over 100 small coal operators on the Monongahela. The "Combine", as it was sometimes called, made the decision to stop the coal trade on the Ohio in 1916, due to competition from Alabama coalfields and Oklahoma oil in the New Orleans market, as well as an increased local market for coal for the steel industry, eliminating the need to ship coal down river (Johnson 1975:179).

The decreased tonnage on the river had grave political implications, as it provided heavy ammunition for those who opposed river improvements. Calculations, even those estimates provided by the Districts indicated that railroad transportation was cheaper per ton-mile. The Corps countered with arguments that the project, once completed, would prove profitable. Major Malcolm Elliott, former Assistant Engineer in the Louisville District, for example, compared the Ohio River Canalization Project to a railroad under construction, stating that it could not be a profitable venture until completed (Johnson 1975:180-181).

Congressmen found themselves walking a thin line between losing their share of the money and inviting ridicule for supporting useless projects. Many became more selective in their support. Benjamin R. Tillman (Dem.) of Trenton, South Carolina, for instance, was mixed in his support for navigation projects. Previous to his career in Congress, he had been a farmer, and Governor

of South Carolina from 1890 to 1894. Tillman argued that projects on his own state's Oconee and Ocmulgee rivers were not objectionable, but that he had little respect for the attempts of other Senators and Representatives seeking surveys of their areas under the guise of improving navigation when all they hoped to achieve was the possibility of lowering railroad freight rates through competition (Simpkins 1967). Tillman objected to the Mississippi improvements saying that "the Mississippi itself has quit having any steamboats on it . . . and the whole scheme of river improvement is a humbug and a steal, but if you are going to steal, let us divide it out and do not go to complaining." (Congressional Record, 56d 2nd 1901).

Thomas Carter challenged that the improvements had not created a regulation of freight rates or improved trade, proof of which could be seen in the perishing of the towns along the Mississippi River which, with few exceptions, constituted "a standing contradiction to that statement" (Congressional Record, 56d 2nd 1901). In mockery, Carter often called the projects "Swamp navigation" (Congressional Record, 56d 2nd 1901). Carter was curiously silent on the topic of the Ohio River improvements.

Steel and other manufacturing interests on the river continued to be at the mercy of the railroads for shipping their freight. Although cities like Wheeling had lost some of their industries, others grew. Wheeling, once a great nail producing center, had lost this industry, but Pittsburgh had become a great steel producer. The *Pittsburgh Chronicle* decried the "rapid development of the railroads that had destroyed the river commerce." The paper stated that the rivers were "still the most attractive means of transportation, citing the many thousands of pleasure boaters who crowded packets for Cincinnati, Morgantown, Charleston, and other river towns." This paper awaited the completion of work that had begun with the Davis Island Dam, and expected that soon the river would be navigable year round (*Pittsburgh Chronicle Telegraph* September 18, 1908).

After the drawn out controversy of 1901, the next few years of the 20th century brought little argument in Congress concerning navigation improvements. Legislators lacked enthusiasm to support navigation improvements, and the decrease in traffic on the Ohio and other river systems seemed to justify ending further expenditures rather than increasing them.

At the turn of the century, there were three major issues creating obstacles to continuation of Ohio River slackwater improvements: Should the improvements be continued to the Lower Ohio River; was there adequate benefits to justify the cost of increasing the pool depths to nine feet; and was the canalization project justifiable considering the decline of commerce on inland rivers. After 1902, due to accusations of "pork" Congress appropriated little money on the Ohio River or its tributaries. Generally Congress only approved funds for maintenance and operation, provided the projects assisted commercial traffic. Engineers desperate not to see the baby thrown out with the bathwater urged that it was the political system that was at fault, and not the Corps of Engineers or Congress. Many recommended that instead of a piecemeal system of appropriations instituted by Congressmen, that each project be reviewed and approved by the Corps of Engineers before Congress could appropriate funds. As a result, in 1902, the Corps created the Board of Engineers for Rivers and Harbors to review all projects, presumably independent of local politics. (Johnson 1975: 171). The "Lockwood Board," named after its senior member, Colonel Daniel W. Lockwood, grappled with these issues. All of the members of this commission were Ohio River District Engineers.

There were many factors that attributed to the decline in river traffic, including railroad competition and charges collected at city wharves, but the Board found that the chief cause of decline was the "unreliability" of the navigation of the river in its unimproved state (Johnson

1975: 170). Major William L. Sibert, recommended raising the first six dams to provide a nine-foot channel, since six foot was insufficient for modern barge towing. In 1906, the Lockwood Board recommended the construction of a nine-foot project from Pittsburgh to Cairo. There were many who did not agree with this recommendation, including the editors of *Engineering News*, who doubted that the project could ever pay for itself in increased river traffic. Congress approved the nine-foot depth for the first six dams in 1905 (Johnson 1975: 169, 172).

One could follow the public debate over river improvements in engineering journal articles and books written by professionals. Dr. Emory Johnson, professor of Transportation and Commerce at the University of Pennsylvania, author of several books on railway and waterway transportation, wrote a book in 1906 on inland waterway transportation, in which he promoted the completion of the Ohio River navigation slackwater system to a channel depth of nine feet as quickly as possible due to the importance of the great industrial interests in the region (Johnson 1906:381).

In Congress, representatives James Hughes (Dem.) of Huntington, West Virginia, Stephen Morgan (Repub.) of Oak Hill, Ohio, James Kehoe (Repub.) of Maysville, Kentucky, and Swager Sherley (Dem.) of Louisville all introduced bills for construction of locks and dams on the Ohio during 1903 and 1904, but little debate ensued. The same was true in 1905, when Sherley and J. B. Bennett (Repub.) of Greenup, Kentucky introduced bills for the construction of locks and dams again. There seems to have been a beginning of a coalition of interests among Congressmen from several regions beginning at this time. As legislators struggled to garner support for their projects, they found support with other regions looking for a piece of the pie. In 1905, James R. Mann (Repub.) of Chicago Illinois supported river and harbor bills with more fervor, not only for his area, but across the board. William Adamson (Dem.) of Georgia became active in the debate as well, but these new alignments were in their infancy (Congressional Record, House and Senate, 57th & 59th 1902-1905). In 1906, the Kentucky State Legislature memorialized Congress, asking that it adopt "a broad and liberal policy toward the waterways of our nation", rather than intermittent and inadequate appropriations (Congressional Record, Senate, 59th, 1st 1906).

J. McGee, founding member and one-time president of the National Geographic Society, has been credited with playing a major role in outlining the philosophy that became the Conservation Movement. In 1903, McGee, along with Senator Joseph Ransdell supported the Lakes to Gulf Deep Waterway. The Corps, charged with examining the feasibility of the waterway, initially discredited the entire project, but by 1907, had been pressed by Congress and others enough to state that the portion from Illinois to the Mississippi River may be feasible, but that the portion from Cairo to the Gulf was not. Theodore Burton, chairman of the Rivers and Harbors Committee supported the Corps' recommendation. Sentiment in the Mississippi Valley, however, was against the Corps. Frank Smith, in his book, *The Politics of Conservation*, suggests that McGee then came up with the idea of an Inland Waterways Commission (IWC) to bypass Burton and the Corps, whom Smith suggests was simply protecting itself (Smith 1966: 105). In the IWC, McGee suggested a multidisciplinary approach to conservation that required cooperation between the Army Corps, Forest Service, Reclamation Service, the USGS, and other agencies. McGee, either somewhat naïve to politics, assumed that these diverse agencies could cooperate without rivalry and dissent, or he expected that the Corps, having only one vote on the Rivers and Harbors Committee, would not be powerful enough to thwart his purposes.

Following in large part the recommendations of McGee, in 1907, Theodore Roosevelt created the Inland Waterways Commission. Composed of two Senators, two Representatives, the Chief of Engineers, the Chief of the Forestry Service, the Chief of the Reclamation Service, the Chief of

the Bureau of Corporations, and a representative from the Bureau of Soils, the Commission recommended sweeping changes in waterways policies. McGee obtained an appointment to the Bureau of Soils to make himself eligible to serve as chairman of the new commission. The IWC's findings stated: "Hereafter, plans for the improvement of navigation in inland waterways . . . should take account of the purification of water, the development of power, the control of floods, the reclamation of lands by irrigation and drainage, and all other uses of the waters or benefits to be derived from their control" (Smith 1966: 107-108).

Regarding the Ohio River, the IWC reported that the railroads hindered the development of river traffic by gaining control of much of the land available for landing and terminal facilities as well as occupying long stretches of land along the banks with tracks, making the river inaccessible to navigation. The Commission's report noted that railroad control of terminal facilities and their withdrawal from prorating arrangements with the river lines created serious problems. Other impediments to river commerce included wharfage charges at terminals largely owned by municipalities that often approached 25-percent of the carrier's profit. All the members of the Commission agreed with one exception: Chief of Engineers, general Alexander MacKenzie did not endorse these recommendations. McKenzie saw government involvement in hydroelectric power production, flood control, and anything else not directly related to navigation, as unconstitutional (Hays 1959:104-105; Inland Waterways Commission Report 1908:109). The final IWC report includes his letter of dissent. The 1907 Newlands Bill, introduced by Senator Francis G. Newlands (Plate 2-10), sought to implement the proposals of the IWC, but the combination of unwillingness in Congress to spend more public money, opposition from the Corps, and longtime opponents to waterways in general, defeated the measure repeatedly. Despite having the strong backing of Theodore Roosevelt, the bill died as a result of Corps opposition, and Taft's sympathy for the Corps as the Secretary of War (Smith 1966: 108).

During the 59th Congressional session of the winter 1906 to 1907, Ohio Valley legislators in both House and Senate actively garnered support. In the House, Augustus Stanley (D) of Henderson, Kentucky (and Governor of Kentucky from 1915-1919) supported a dredging and snag removal bill, while the Senate authorized work on locks and dams 9, 10, and 12 of the Ohio based upon the endorsement of the Corps of Engineers. Nathan B. Scott (Repub.) of Wheeling, West Virginia introduced this bill as S. 88 in the Senate (Congressional Record, House & Senate, 59th, 2nd 1907).

Writers continued to take up the subject of waterway commerce. One such author, Herbert Quick, published *American Inland Waterways* in 1909. The book's subtitle, *Their Relation to Railway Transportation and to the National Welfare; Their Creation, Restoration and Maintenance*, sheds light on the author's purpose. He explains at the start that "The country is humming with agitation for waterways . . . chiefly, I think, it comes from the collapse of the railways under the tremendous traffic of our last three years of flush times" (Quick 1909:29). Quick found that the railways were killing waterway commerce in an unfair manner (as many of his day had decided), and "having found the way by which the railways may be prevented from killing water-borne traffic, we must make our waterways fit for their work" (Quick 1909:V).

Quick advocated Theodore Roosevelt's connection of conservation to waterway navigation improvement, as well as Roosevelt's penchant for fighting the monopolistic tendencies of the railroads, but cautioned that waterways should only be promoted if they were economically feasible. As could be expected, Quick also promoted the recommendations of the original Inland Waterways Commission. His book elevated Senator Theodore Burton, Senator Francis Newlands, General Mackenzie of the Army, and Gifford Pinchot whom he called "one of the most potent men for good now living" (Quick 1909:131). He promoted the ideas of Chief

Plate 2-10. Senator Francis Newlands

Hydrographer for the U.S. Geological Survey, Marshall O. Leighton who studied flood control reservoirs for the Inland Waterways Commission. William Bixby and Leighton agreed that flood control reservoirs should be part of the greater system along the Ohio and other rivers, but Bixby did not think federal law provided for flood control, but strictly navigation (Johnson 1975:193).

Republican Senators and Representatives began to take advantage of the growing conservation and progressive movements that were gaining momentum under President Theodore Roosevelt to promote river navigation. The Progressive Era brought intense criticism of the "pork barrel" system of politics that favored local improvements based upon political power at the expense of nationally expedient planning. Therefore, supporters of conservation and river and harbors improvements found it expedient to merge. During the 60th Congress in the winter of 1907-1908, the issues of forest and water conservation merged with navigation interests in several bills. Supporters of waterways improvements gained momentum by linking the popular conservation movement, the relation of waterways to the reclamation of flooded lands, the development of water power, increased sanitation, the supposed cheapness of water transportation, and the monopolistic tendencies of the railroads in their attempts to gain Congressional support (Moulton 1912:447). All interests benefited from this linking of causes. There was no shame in such linkages, since, according to many scientific experts, preservation of forests prevented silting of rivers, thereby decreasing the cost of flood damage and needs for dredging. It appeared the most economical way to preserve mountain forests and the navigability of the rivers.

Some Congressmen supported the river and harbors bill of the 60th Congress because it promised to alleviate flooding. Democrat Edward Saunders of Virginia supported the proposition, saying that the recent flood at Pittsburgh left all wondering if science knew the cause and the solution, to which he replied: "science and experience are agreed on the causes, and the remedy. The most potent cause is deforestation, the remedy for which is reforestation." William Reeder (R) of Logan, Kansas cited a circular that concluded that all engineers agreed: "The fact is . . . there is absolutely no difference of opinion among scientific men" that deforestation was the cause of silting and flooding (Congressional Record, House, 60th, 1st 1908). Reeder, originally from Cumberland County Pennsylvania, had personal interests in irrigation and farming, and supported the Progressive Republican move to link resource conservation and navigation.

In a move strikingly similar to Henry Clay's provision in 1812 giving states the ability to share appropriations for internal improvements on their borders, Charles F. Scott (R) of Iola, Kansas introduced bill H.R. 21986 "to enable any State to cooperate with any other State or States, or with the United States for the conservation of the navigability of navigable rivers, and to provide for the appointment of a commission . . ." (Congressional Record, House, 60th, 1st 1908). Scott was chairman of the Committee on Agriculture from March 1901 until March 1911. This bill provided for the Secretary of Agriculture (where the Forest Service was lodged), to advise and determine the connection of forestry works with navigation, and to create a National Forest Commission. Scott, and most other legislators, felt that this connection to navigation necessary, since the Committee on Agriculture did not think that the United States could constitutionally purchase lands for creating forest reservations, unless specifically linked to navigation. (Congressional Record, House & Senate, 60th, 1st 1908).

Waterways engineers were often their own worst enemies when it came to garnering political support for Ohio River improvements. Experts would publicly disagree over runoff calculations, methods of flood control, the best lock and dam technology, and countless other issues. There was also a major rivalry between civil and military engineers, and between members of committees and commissions (such as the Inland Waterways Commission), and engineers who resented the members, who often knew nothing about engineering, making decisions on the best

methods to improve navigation. An example of such a controversy, Marshall Leighton published an article in *Engineering News* of May 7, 1908 on the topic of reservoirs for flood control and navigation. Captain W. D. Connor of the U.S. Corps of Army engineers dismissed his ideas as impractical and based upon false assumptions, contended that Leighton's cost estimates were way off base, and made other more technical arguments against Leighton's proposal as well. Many of the arguments pitted Army engineers against civilian engineers as well. These highly public forms of professional disagreement left many Congressmen confused, and although some simply used the arguments that best suited their purpose, others, wishing to get at the truth of the issues, found no comfort in such differences of opinion (Quick 1909:190-194).

The Governors' Conference on the Conservation of Natural Resources, organized by Gifford Pinchot (Plate 2-11) and held on May 13-15 of 1909 at the White House, propelled conservation issues into the forefront of public consciousness. The governors held a second Conference at the end of the year to receive the recommendations of the National Conservation Commission. The National Conservation Commission, appointed in June by Theodore Roosevelt and composed of representatives of Congress and relevant executive agencies with Gifford Pinchot as chairman, compiled an inventory of U.S. natural resources and presented Pinchot's concepts of resource management as a comprehensive policy recommendation in a three-volume report. Commonly known as the Gannett Report, the Commission submitted it to Congress at the beginning of 1909.

1908-1909 PARTY PLATFORMS

Both the Democratic and Republican party platforms of 1908 pledged support to the development of navigable waters and conservation of natural resources under a comprehensive plan. Roosevelt chose William Howard Taft (Plate 2-12) as his successor, and the Republican party named him as presidential candidate in the election of 1908, in which he defeated William Jennings Bryan. Taft, a Cincinnati lawyer, became nationally prominent as a figure in Republican politics in 1890 when President Benjamin Harrison chose him as U.S. Solicitor General. In 1904 his friend President Theodore Roosevelt appointed Taft Secretary of War. Taft became a close adviser to the President and was prominent in Latin American affairs, conducting the delicate negotiations attending U.S. intervention in Cuba in 1906. Roosevelt expected Taft to continue his policies, and to a large extent he did. He vigorously prosecuted the Trusts under the Sherman Anti Trust Act; the Mann-Elkins Act of 1910 strengthened the Interstate Commerce Commission; and Taft's Latin American policy, known as “dollar diplomacy,” was to an extent only an enlargement of Roosevelt's Panama policy and the Roosevelt Corollary to the Monroe Doctrine.

Members of the Republican party who favored Progressive policies became increasingly restive, and this Insurgent movement grew strong. Taft grew at odds with the Progressive elements in his party: he failed to support the Insurgents' attempt to oust speaker of the House, Joseph Cannon (R) and he favored the Payne-Aldrich Tariff, a high-tariff measure that was denounced by Progressive Republicans. The Senate altered the House's moderate Payne Bill so as to increase rates on manufactured goods, thus favoring the industrial Northeast and angering Midwestern Progressives. Taft also supported Richard Ballinger against Gifford Pinchot in the Ballinger-Pinchot controversy.

Pinchot was a rising star in the Roosevelt Administration and Progressive Party in the first decade of the 20th century. After Congress authorized the National Forest Commission in 1896, he served as a commissioner, and then from 1898 to 1910 as chief of the Division of Forestry (now the Forest Service) of the U.S. Department of Agriculture. During that period Pinchot filed charges against Richard Achilles Ballinger, then Secretary of the Interior, accusing him of abandoning the nation's conservation policies in his administration of coal lands in Alaska. President William Howard Taft supported Ballinger, and in 1910 dismissed Pinchot for insubordination.

The second Congressional session of the 61st Congress in 1910 attracted a great deal of debate focused on the Ohio Valley. Both the Democratic and Republican party platforms included a commitment to the development comprehensive planning and development of waterways in conjunction with natural resource conservation. The Republicans stated that they had inaugurated the reform of waterways and conservation with the impetus of Theodore Roosevelt. The Democrats specifically stated that the development of rivers should be combined with conservation, irrigation, drainage of swamp lands, and the utilization of water power.

The political climate that had previously necessitated a convergence of interests, seemed less important in 1910. In the Senate, Theodore Burton (R) of Illinois had just finished his 13-year service on the Committee on Rivers and Harbors. He had also been appointed by President Theodore Roosevelt as chairman of the Inland Waterways Commission in 1907-1908. He became chairman of the National Waterways Commission from 1908 until 1912. Burton reflected the frustration of Ohio Valley interests but was more particular about what he endorsed in the river and harbor bill, arguing that only those items that had a favorable report from the

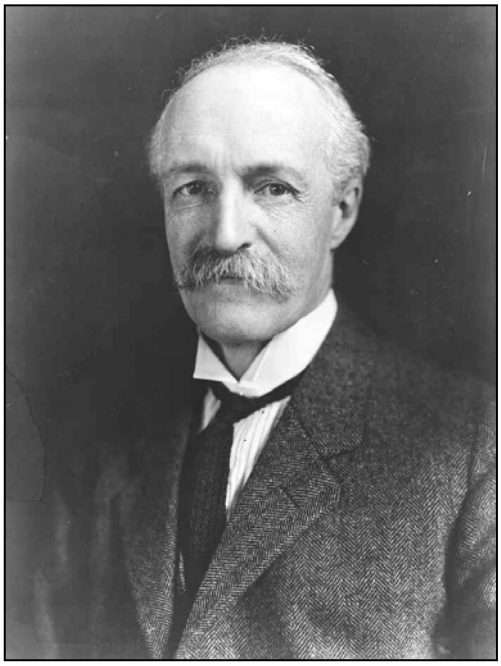

Plate 2-11. Gifford Pinchot

Plate 2-12. President William Howard Taft

Corps of Engineers should receive the greatest attention. Burton argued that the worst offense of the latest bills was the failure to "finish the great trunk lines" and as a result, tributaries had been finished, yet the main lines prevented these lines from being profitably used. "The Ohio is a great artery of commerce. Improvements have been made costing tens of millions of dollars for branch streams like the Big Sandy . . . . As a result there is a more uniform and at times a greater depth of water in the Big Sandy and the Green rivers than in the Ohio River where those rivers empty into it" (Congressional Record, Senate, 61st 2nd 1910). Any previous alliances he had with Congressmen of neighboring states were clearly foreclosed by his interest in gaining a lions share for the Ohio. He argued with Thomas Paynter (D) of Frankfort, Kentucky against completing Lock 14 on the Kentucky River, calling it a waste of government money. He advocated railroad transportation as a viable alternative to less important waterways, and stressed that instead of the piecemeal appropriations for the Ohio, Congress should approve larger sums in order to finish the work.

Burton, who previously had little objection to the argument of using waterway development to regulate railroad rates, now argued that it was an inefficient way to regulate freight rates. Burton now relied heavily upon organizations more in line with his interests, such as the Lakes to the Gulf Deep Waterway Association, which advocated deep water navigation improvements for the Mississippi and Ohio Rivers. Asked to rank the most important waterways of the nation, Burton replied: One . . . is the barge canal from Buffalo to the Hudson River, and down that river to New York. . . . The next, I would say . . . would be the Ohio River, from Pittsburgh down to Cairo. Why? Because there are great stores of coal and there is a busy, industrial country below it on the Ohio which is a great consumer of coal, of the mineral products, and of the finished iron and steel coming from Pittsburgh Then, again, there is a great deal of clay for brick along portions of the Ohio" (Congressional Record, Senate, 61st 2nd 1910).

Burton, along with Newlands of Nevada argued that from 1902 through 1909, Congress funded no projects without the recommendation of the Board of Engineers, but that the current bill departed from this practice. They advocated the policy of only appropriating funds for projects endorsed by the Board, and that any projects not so endorsed were likely scientifically and economically unwise. When confronted with the fact that despite expenditures in recent years, river traffic had declined steadily, they argued that one could not expect increases in tonnage until the entire work was completed, likening it to a half-finished railroad " (Congressional Record, Senate, 61st 2nd 1910).

Burton's speech on April 16, 1910 on the varying merits of waterways projects brought heated opposition from Senators William Warner (R) and William Stone (D) of Missouri, William Lorimer (Repub.) of Chicago Illinois, Frank Brandegee (Repub.) of Connecticut, and others. Burton also opposed the linking of conservation issues with navigation, as he saw it as a useless drain on funds that should be directly applied to completing the Ohio navigation system. He pursued a filibuster on June 24, 1910. Among his arguments, he contested the idea that all experts agreed that conservation helped navigation by quoting Brigadier-General William H. Bixby, Chief of Engineers, who supposedly stated that "he would not spend 5 per cent of (money for navigation) for any such purpose as is contemplated in this bill." Burton, who continued at length against the bill, bristled at the accusation of "filibuster" from other Senators, saying that the issue was too important to pass without careful consideration. Burton, a moderate Republican accused the muckrakers in journalism of indiscriminately attacking their Congressmen for not supporting large expenditures for public projects for the "uplifting" of the poorer classes (Congressional Record, Senate, 61st 2nd 1910).

The Lockwood Board had recommended the construction of a nine-foot waterway from Pittsburgh to Cairo. In 1905, Congress bought into the idea and Taft, a Cincinnati native, supported it. In 1910, Congress authorized the project for the entire length of the Ohio (Johnson 1975: 173). President Taft, although he made it clear that he strongly disagreed with the system of making numerous small appropriations rather than complete the most useful projects, signed the bill.

Progressive reformers generally believed that the railroads monopolized transportation of the country, charging extortionist rates. They pointed out that wherever railroads competed with waterways, railroad rates were substantially lower. Proponents of waterways argued that the Government should aid in waterway development to alleviate this unfair situation. President Taft, in a message to Congress on January 14, 1910, stated that "it is certain that the existence of such methods of traffic materially affects the rates which the railroads charge, and it is the best regulator of those rates that we have, not even excepting the governmental regulation through the Interstate Commerce Commission" (Moulton 1912:13-14). Speaking as the President of the National Rivers and Harbors Congress, Representative Joseph E. Ransdell (Dem.) stated: "I am convinced that waterway transportation in this country, under favorable conditions, costs about one sixth as much as the average cost by rail" (Moulton 1912:12).

In 1912, Harold Moulton, instructor in political economy at the University of Chicago, published *Waterways Versus Railways*, in which he attempted to present the arguments and facts for and against waterways improvements. He favored the railroads, but presented a remarkably unbiased analysis, admitting that the railroads were monopolies that had an unfair advantage due to the fact that almost all the boats on the Great Lakes and the Ohio River were either owned outright, or controlled by the railroad through majority stock ownership (Moulton 1912:28-29). This was a common accusation at the time. In areas where the railroads did not control waterways, he asserted that railroads adjusted rates near waterways to cause the traffic to prefer to use the railroads. He summarized the argument of the waterways block: "The knowledge that the railways have adopted such methods as these to defeat the waterways has raised a storm of protest, and developed the contention that, if the waterways were afforded protection from such crushing competition, they would speedily regain their former position in the transportation of the country" (Moulton 1912:84-85).

As was common in his time, Moulton reported in great detail the success of the waterways of Europe and the great extent to which these countries used waterways profitably. These he compared to the waterways extant in the United States, concluding that their success was based upon unique situations and history, and did not prove or disprove that all waterway projects in the United States could be profitable. He did decide, that in fact many proposed waterways, such as the proposed Chicago River and Drainage Canal - from Chicago to St. Louis, were not practical. Interestingly, despite his book's tendency to increasingly unfold his bias towards railroads, Moulton, asserted that the Ohio River was unique, as it alone had "retained a large traffic in recent years" (Moulton 1912:392).

Moulton stated that the recent approval in 1910 of a plan to improve the Ohio River, extending its depth to nine feet was practical and would be profitable since the Ohio had a number of industrial towns, that carried on trade with the Pittsburgh region, and had an excellent position in relation to trade routes. Especially important, he stated was the iron and steel industries in the region. Mouton makes extensive reference to the Ohio Valley Improvement Association and the efforts of the Governor to promote the project (Moulton 1912:394).

Concluding with support for the railroads, Moulton wrote that the evidence pointed strongly against the feasibility of most water transportation in the Unites States. In his view, the railroads had the clear advantage of not being tied to a valley or pre-determined route, but could go anywhere. He asserted that motives other than public service motivated the "second waterways movement." These motives, he asserted were a variety of private construction companies who hoped to receive contracts in return for political support, politicians who had financial interests related to waterway construction, and business interests who hoped to lower their shipping costs at the cost of the public purse. He specifically mentions the Ohio Valley Improvement Association which, in 1908 showed an expenditure of $11,232.79. They obviously hoped for a return on this investment (Moulton 1912:450).

THE POLITICS OF FLOOD CONTROL AND OHIO RIVER NAVIGATION

With the support of President Theodore Roosevelt and the creation of the Inland Waterways Commission, the issue of government aid for flood control received greater scrutiny. Congressional support, however was still weak. The 1911 report of the National Waterways Commission voiced a popular opinion that the "Federal Government has no constitutional authority to engage in works intended primarily for flood prevention or power development. Its activities are limited to the control and promotion of navigation and works incident thereto. The commission is one of the opinion that flood prevention is primarily a local problem " (Johnson 1975:193).

By 1912, Taft's relations with Roosevelt had deteriorated, and the former President joined the opposition. In 1912, Roosevelt fought vigorously for the Republican presidential nomination. When he failed and Taft got the nomination, Roosevelt ran in the election as the Progressive (popularly called Bull Moose) candidate. All three parties, Democrat, Republican, and Progressive, made a commitment to a comprehensive conservation policy including flood control, resource conservation, and waterway navigation. Recent devastating floods along the Mississippi and Ohio strengthened the weight of these issues. The Republican vote split between Republicans and Progressives, however, and the Democratic candidate, Woodrow Wilson, won.

As in the past, it took a disaster to effect changes, since in the throes of an emergency, a change in flood policy would have fewer political repercussions. The flood of 1913, popularly known as the "Dayton Flood", rose one foot above the 1884 flood, causing extensive damage in the Ohio River Basin. Damages at Louisville alone were estimated at a half a million dollars and 361 people had died in the disaster. Congress immediately organized the Miami Conservancy District to plan and construct flood control project for the Miami River basin. This results of this action created a pioneer flood control project, and more importantly, had great influence on future Congressional support for flood control projects when it proved effective in preventing damage far in excess of its cost (Johnson 1975:193-196). While the Miami Conservancy District was planning flood control works, the Secretary of War directed the Chief of Engineers to appoint a Board of Engineers to investigate methods for preventing flood damage through the construction of navigation improvement projects. The Ohio River Flood Board made a preliminary report in 1914, but opposed the linking of flood control to navigation improvements, stating that the issue should be addressed based on the benefits to the protection of life and property that would result. Congress was not prepared to take this leap (Johnson 1975:199).

Senator Francis Newlands, who had been promoting a bill for the regulation of navigable rivers through various means including reservoirs (Newlands-Bartholdt river regulation bill), saw the floods of 1912 and 1913 as a chance to re-submit his bill. Herbert Quick, in *American Inland Waterways*, argued in favor of the 1909 version of this bill which provided for a permanent Inland Waterways Commission vested with power for funding and coordinating waterways projects (Quick 1909:177).

Newlands, best known for what is known as the Newlands Reclamation Act of 1902 was a land speculator from Mississippi, who moved to Nevada. He recognized the need to build a reservoir to expand agricultural production within his holdings and personally hired his own engineers to determine where would be the best place to put a dam. He also ran for the U.S. Senate. Newlands won election and set out to convince Congress that the nation needed these dams. Rather than just limit the language to the State of Nevada, he ensured the wording of the legislation would allow the building of dams throughout the West. Newlands promoted the bill as

a comprehensive planning approach to the combined issues of flood control, conservation, and navigation. Much to the disappointment of State elected officials, and some speculate only as a result of the assassination of President McKinley in 1902, the Reclamation Act came into being. (Congressional Record, Senate, 61st 2nd 1913).

THE DEMISE OF THE PROGRESSIVE PARTY COALITIONS

There was little opposition to river and harbor improvements in 1913. Between the demise of the Progressive party and World War I, the alliances between various regions of the country that had been effective in garnering support for navigation improvements deteriorated. Despite a promise to support the conservation initiative, a new era of political debate concerning river improvements came as hostilities in Europe approached, and some Republicans, in a break with the dying Progressive Party, found less reason to support navigation improvements.

Other representatives found reason to support navigation improvements based upon the need for adequate river transportation in war time. Representatives proposed bills for the survey and selection of a site for a naval armor plant in the Ohio Valley. William B. Francis (Dem.) of Martins Ferry, Ohio hoped to locate it in the Steubenville Manufacturing District near Lock and Dam number 10 on the Ohio, whereas Howard Sutherland (Repub.) of Elkins, West Virginia hoped to locate it in the Parkersburg Manufacturing District of West Virginia. Sutherland, having been engaged in the coal, timber, and railroad businesses had personal as well as political reasons to support the site (Casdorph 1974:1-25). Matthew M. Neely (Dem.) of West Virginia advocated yet another site in his district near Moundsville in Marshall County, West Virginia. Of course, the construction of such a plant was certain to decrease opposition to improvements on the Ohio. (Congressional Record, House, 63rd 2nd 1913).

Renewed protest against the river and harbor bill erupted in 1914. With a Democratic majority in power, Republicans used the river and harbor issue as a rallying cry against the Democrats. Led by James Frear of Wisconsin, Republicans generally opposed the river and harbor bill of 1914 as a sign of the wastefulness of the Democratic regime. Frear, as in previous sessions, championed himself as the enemy of "pork" and strongly opposed all river and harbor appropriations. 1914 also brought a bill to increase taxes for war preparations. Republicans linked this tax to the excesses in the river and harbor bill, and Frear reasoned that spending existing unspent money and defeating the new river and harbor appropriation would make a "war tax in time of peace" unnecessary. Frear's Republican colleagues, Frederick Britten (Repub.) of Chicago, Illinois, and Franklin Mondell (Repub.) of Wyoming, lamented that the Democratic majority would likely pass the bill even though it was, in their eyes, extravagant. Mondell, a businessman with interests in mining, railway construction, and coal and oil property development, may have had personal reasons for opposing appropriations, as well as coming from a region with strong isolationist tendencies. Democrat John Charles Linthicum of Maryland, on the other hand, challenged the Republicans to point out which items they considered "pork" (Congressional Record, Appendix, 64th 1st 1914).

Charles Lieb of Indiana promoted continued appropriations for the unfinished 9-foot Ohio River system. He likened the Ohio to the Panama Canal in importance, and reasoned that industrial growth would follow the completion of the project. He read letters of petition from a variety of industries in Evansville promoting completion of the work (Congressional Record, House, 64th, 1st 1914). In his remarks, he presented a letter from Samuel L. May, president of the National Contract Company of Evansville, contracted to construct Dam No. 10 at Steubenville, Ohio. May explained that he would most likely have to lay off 206 employees and lose an investment of over $150,000 if new appropriations did not come through Congress to complete the work. The Senate struck down the original House bill for $53,000,000, and passed a substitute measure for $20,000,000 (Congressional Record, Appendix, 64th, 1st 1914).

The experience of 1914 brought caution to the 1915 appropriation debates, as well as an increased competition for limited funds. The cooperation that had existed in times of large appropriations continued to break down. Stephen Sparkman (Dem.) of Florida supported the 1915 bill. He objected to the Congressmen from the Ohio, Mississippi, and Missouri River valleys suggesting that the appropriations for any but these three rivers constituted unnecessary "pork". In response, he stated that those three rivers alone took up half of all the proposed appropriations, suggesting that it would be much easier to fund a good many projects with the sacrifice of these three (Congressional Record, House, 64th, 1 1915).

In 1915, Senator George Oliver (Repub.) of Pittsburgh submitted an amendment to the River and Harbor bill to give the Chief of Engineers the option of constructing one lock and fixed dam on the Ohio River to replace Locks and Dams Nos. 1 and 2 if studies proved this to be desirable. Duncan Fletcher (Dem.) of Florida strenuously objected. He had previously been reminded that Congress agreed to avoid new expenditures in the bill for 1915. The disagreement between Oliver and Fletcher created discord in the chamber. Debate during this session nearly became violent as Senators Theodore Burton, James Reed (Dem.), Knute Nelson (Repub.) and William Kenyon (Repub.) of Ohio fought for diminishing funds. Theodore Burton, who had previously supported most river and harbor projects while on the Committee on Rivers and Harbors, became highly selective, opposing those that he felt were not reasonable, and especially those projects outside of the Ohio Valley. In 1915 he threatened to obstruct the bill indefinitely if Congress did not remove appropriation amendments for the Missouri and other rivers (Congressional Record, Senate 63rd 2nd 1915).

Despite the rivalries, the majority of Congressmen seemed to accept the notion that among river improvement projects, the Ohio, Mississippi, and perhaps the Missouri rivers were truly worthy of appropriations as national projects. Representative Thaddeus Caraway (Dem.) of Arkansas summed up this generally accepted viewpoint: "In passing I wish to say appropriations for the Mississippi and Ohio Rivers are not discussed in these remarks, because the Ohio River is cared for . . . and the Mississippi has been declared to be a national project by the platforms of both the great parties" (Congressional Record, House 63rd 2nd 1915).

In the House, men such as William Gordon (Dem.) of Ohio (Owner of Gordon Lumber of Cleveland, Ohio) tried to use rational arguments, but political arguments went beyond the rational or even the tendency to secure a portion for their portion of the river and harbor expenditures. Western Representatives like Nicholas Sinnot (Repub.) of Oregon were annoyed with those mid-western associates who had killed the "Apple Box" bill (H.R. 11178). Majority Leader Oscar Underwood (Dem.) of Alabama, (who grew up in Louisville, Kentucky) kept this bill from coming up for a vote. As the bill was vital to the apple industry of the West and Northwest, Sinnot made it clear that he would oppose the river and harbor appropriation bill in return (Congressional Record, House 63rd 2nd 1915). The River and Harbor bill for 1915 contained no new projects. Starting out at $50,000,000, it shrank to $25,000,000.

Most agreed that river traffic continued to decrease, but Robert Switzer (Repub.) of Gallipolis, Ohio disagreed with figures presented by the opposition producing figures from the Board of Engineers that showed an increase of 2,000,000 to 4,000,000 tons of tonnage a year on the Ohio. (Congressional Record, House 63rd 2nd 1915). Others argued that value, and not tonnage was a better gauge of usefulness. Switzer reported that of the planned 53 locks and dams, 15 were complete, 18 were in process, and 20 not yet begun.

THE PATH TO WORLD WAR

Between 1905 and 1907, railroads experienced shortages of available cars for transport, causing crises among manufacturing and agricultural markets. Shortages again became acute during World War I. The inability of the railroads to expedite transportation needs demonstrated the importance of barge transport as an effective and necessary system for transporting freight. This prompted Congress to further regulate the railroads, and to continue to aid in the development of navigation of the Ohio.

Joseph H. Moore (Repub.) of Philadelphia, who had been a close ally of Theodore Roosevelt, revived the argument that waterway development could effectively compel railroads to charge reasonable rates. Concerning the current crisis of the railroads to meet increasing wartime demands, he stated: "If the railroad men are wise - and some of them in the East begin to realize it - rather than retard waterway development they will encourage it, because where they have been subjected to the congestion such as they have endured during the last few months, carrying the products of the West to the seaboard, they find that it is desirable to have relief, some auxiliary, such as Mr. James J. Hill - builder of the Great Northern Railway - who, back in 1907, indicated must be had if the railroads of the country are to give effective service." (Congressional Record, House 64th 2nd 1916).

Alben Barkley (Dem.) of Paducah and Simeon Fess (Repub.) of Yellow Springs, Ohio stressed that Congress had, in 1910, committed to finishing the Ohio navigation system by 1922, and Congress should not break a promise made to the people of the United States (Congressional Record, House 64th 2nd 1916). Representative Frear of Wisconsin spoke out against the 1916 river and harbor bill in his usual fashion. He pointed out that commerce on the Ohio continued to decrease. Frear took the tonnage predictions for future commerce on the Ohio as estimated by Chief of Engineers Kingman, and picked it apart in a mocking fashion, pointing out what he perceived as obvious overly optimistic numbers. Despite this skepticism, he conceded that if there was any worthy river project, the Ohio qualified (Congressional Record, House 64th 2nd 1916).

Cries of "pork" continued to reverberate with regard to the river and harbor bill of 1916. In 1916, the *Philadelphia Inquirer* stated "The 'pork barrel' known to Congress is an appropriation bill carrying immense sums in the aggregate, which sums are distributed among Congressional districts on the principle of 'you tickle me and I'll tickle you.' There are usually two barrels. One contains hunks of appropriation pork for rivers and harbors. The other contains pap for nice little congressmen who have influence enough to demand and receive all sorts of money for all sorts of public buildings in all sorts of towns of their districts." (as quoted in the Congressional Record, House 64th 2nd 1916).

In 1916, Senator Paul O. Husting (Dem.) was not willing to spend time picking at items in that year's bill to see what, if any merited funding. He openly stated that he opposed the bill altogether. His opinion was that the extravagance of "hit or miss" spending on river and harbor appropriations had gone on too long, and he would rather each project stood or fell on its own merit. After such an outspoken introduction, he discussed only three rivers, reasoning that if they were not worth spending money on, then it would stand to reason that none would be. These three rivers were the Mississippi, the Ohio, and the Missouri. He provided the chamber with figures that showed decreased tonnage on these rivers, and asked how Congress could justify continuing to spend money in such a case. (Congressional Record, Senate 64th 2nd 1916).

Generally, funding for the Ohio River navigation system experienced the same political and economic whims of the nation that all the other projects were, but in the case of the Ohio, Mississippi, and Missouri, even opponents of river improvements often agreed on the merit of these systems. Senator William Kenyon had a moderate approach, only attacking those elements that he felt had little merit, admitting that both parties had, as a rule equally opposed and supported the river and harbor bills, and that the disagreements were more regional or sectional than "political" He was clear that the "Ohio and Monongahela Rivers have proven more of a success commercially." He dismissed accusations that he was prejudiced against waterways because he had once been counsel for a railroad company (Congressional Record, Senate 64th 2nd 1916). In 1917, Ollie James (Dem.) of Marion, Kentucky addressed the Senate on the improvements of the Ohio. He dismissed Frear's accusation of "pork" because Frear opposed all waterways improvements, however, he lauded former Senator Theodore Burton as having sound opinions on river improvements. He cited Burton's statements that even though most waterways were unfit for navigation improvements, the Ohio was one of the few that had merit, while Frear called the Ohio "the most wasteful project of all" (Congressional Record, Senate 64th 2nd 1916).

Many, including James Frear, the enemy of all river and harbor improvements, and William Graham (Repub.) of Illinois, considered all omnibus legislation wrong because it bundled good legislation with bad, and forced people to vote for things that they were opposed to hoping to gain approval of other measures. Graham and Frear found it an "unconscionable wrong" to consider appropriations for "pork barrel" measures like rivers and harbors when the country was at the brink of war (Congressional Record, Appendix 65th 1st 1917).

For many years Frear had been the most outspoken opponent of omnibus river and harbor legislation. On March 3, 1917, he gave his final and most memorable speech against such legislation. The speech was, in large part an indictment against the Chief of Engineers and the Rivers and Harbors Congress. Frear began with of the Chief of Engineers. Frear questioned the ability of an Army engineer to make decisions regarding the economic feasibility of projects. "The Army engineer has been shown to be unfitted by lack of business training, environment, or experience from performing a service filled by experts in economics, waterways, and business management in other countries. His social and official life unfits him for such a responsibility" (Congressional Record, Appendix 65th 1st 1917).

First, he said, the Chief had ignored the law passed in 1916 that required a reexamination of the merit of all river and harbor projects. He accused the engineers of deliberately presenting Congress with inflated figures on river tonnage, and having unethical ties to the National Rivers and Harbors Congress. Frear specifically indicted former Chief Brig. Gen. William H. Bixby, and current Chief of Engineers Black.

Frear had spoken out against this lobby before, and had introduced resolutions to investigate this 'mutual bribery' lobby. He quoted from the secretary of the group, Captain J.F. Ellison: "We send Congressmen here to legislate for the Nation, theoretically, but actually to get all he can for us, and if he does not get our share, and then some, we do our best to replace him" (Congressional Record, Appendix 65th 1st 1917).

Frear was especially agitated with the appointments to the 1917 Advisory Commission on Waterways made by the Council of National Defense. They included Brig. Gen. William M. Black, Chief of Engineers, Captain J. F. Ellison of Cincinnati, former secretary of the National Waterways Congress, James E. Smith, president of the Mississippi Valley Waterway Association, Walter S. Dickey, president of the Kansas City Missouri River Navigation Company, and M. J. Sanders, president of the New Orleans Board of Trade. All of these men admittedly had expertise

in waterways, but also had interests, in Frear's estimation, that were in conflict with the execution of their duties on that committee (Congressional Record, Appendix 65th 1st 1917).

He also submitted evidence that the Dredge Owners Protective Organization, a powerful lobby, had "fraudulently and unlawfully secretly divided up Government contracts in the past," and asserted that "the Chief of Engineers is in supreme control and helps perpetuate the present indefensible "pork barrel" system." (Congressional Record, Appendix 65th 1st 1917).

The Transportation Crisis of World War I

The reality of war altered the character of debate on river and harbor improvements. During the first session of the 65th Congress in 1917, the majority of the House and Senate supported the river and harbor bill, justifying the bill as a "war measure," but an outspoken minority which now included Senator Lawrence Sherman (Repub.) of Springfield, Illinois continued to argue that due to the decline of commerce on the Ohio River, Congress should re-think the whole project. In that year, the Chief of Engineers recommended only emergency navigation projects or those that aided in national defense. In the House, John Small (Dem.) of Washington, North Carolina cited a memorandum from former representative Frederick C. Stevens (Repub.) of Minnesota. In this letter, Stevens alerted Congress to a severe railroad car shortage of 145,449 cars in May, which he said was a slight increase in a shortage experienced in April 1917. He reported that the shortages had been increasing since September 1916, and that Congress needed to take quick action on waterways improvements or face a crisis of national security.

Small also quoted Daniel Willard, chairman of the advisory commission for the Council of National Defense, who asserted that rail transportation had reached its capacity. Small reminded his colleagues that during the rail car shortage of 1907, railroad magnate James J. Hill had stated essentially the same thing, and argued for coordination of rail and water interests. Small also reminded Congress that Secretary of War Newton W. Baker had endorsed the bill as necessary for preparedness (Congressional Record, House 65th 1st 1917). The issue of car shortage, although its severity was debated, did exist, and upon discussion of food and fuel conservation during the war effort, Senator Atlee Pomerene of Ohio reported that the Committee on Interstate Commerce had found that the severe shortage of rail cars had caused an increase in the price of coal (Congressional Record, House 65th 1st 1917).

Federal subsidies in Paducah benefited the barge construction industry. Munitions and other war related contracts were let to Ohio River industries including Bucyrus in Evansville, which produced shells. This interest in navigation also benefited grain industries. The demand for flourspar in steel production stimulated growth of industry in Rosiclare and Tolu, Kentucky. In 1918, Tolu became the site of a federally funded hospital. Camp Young, established in 1903 in Hardin County near West Point, became the 100,000-acre Fort Knox (Bigham 1998:218). All of these federal undertakings stimulated population growth as well as economic expansion.

During World War I, military construction in the Ohio River Valley came under the control of the Cantonment Division of the Quartermaster Corps, later renamed the Construction Division for the duration of the war. General George Goethals was Acting Quartermaster General in 1917 (Johnson 1975:210). Two of the largest projects in the Ohio Valley included the construction of Camp (later Fort) Knox near Louisville, and Wright-Patterson Air Force Base near Dayton Ohio (Johnson 1975:210).

During the war, civil works construction in the Ohio Valley River Basin diminished in scope and pace. Guards protected all navigation structures to watch against sabotage. A crisis arose with

the increase in commercial shipments and the large movements of troops and military supply shipments that customarily had been transported by railroad. In 1917, the railroads proved utterly unprepared to handle the increased volume, whereas the inland waterways remained vastly underutilized (Johnson 1975:211).

As a result of the railroad congestion, in June of 1917, Congress commissioned a study of the feasibility of using the waterways to relieve the pressure. The study resulted in the first direct government owned water transportation facilities with the operation of barge lines on the New York State Barge Canal (Erie Canal), the Misissippi, and Warrior rivers. Government operation of such facilities continued after the war with the creation of the Inland Waterways Corporation (IWC) in 1924 (Armstrong et al. 1976: 46-47).

The shortage of rail transportation spurred a great renaissance in the shipyards on the Ohio River. Yards began a major construction effort to meet the increased demands for transportation, and the Corps actively aided in this expanded use of the waterways. In addition, the Corps put every possible idle vessel to use for the movement of freight (Johnson 1975:212). Many local businesses began to build boats, but most focused on the construction of barges. In 1918 alone, 245 barges constructed on the Ohio reached Pittsburgh (Ambler 1931:424). The Dravo Corporation exemplified the renaissance that took place in the shipbuilding industry as a result of the First World War. The company, originally organized as the Dravo Contracting Company in 1891, established a plant at Neville Island in 1906. During the war, the company, like several others in the area, built boats out of sheer necessity.

In 1918, with the United States in the thick of the war and the transportation problem having become more acute, Congress experienced less opposition to reasonable water transportation bills. John Small used the climate of cooperation to argue for water terminals on the river systems. Stressing the need on the Ohio River, he argued that although the project would give the people a 9-foot navigation channel, without terminals for the boats and barges the system would be useless. He reported that the Chief of Engineers expressed the opinion that not one suitable terminal existed on the whole river. The exigencies of war apparently altered Frear's response to waterway improvements. While he still objected to some items without merit, he admitted that "many real waterways need improvement, and several large harbor projects are needed for war purposes, so the bill is not opposed as a whole." Frear instead argued that harbors were fourteen times as valuable for commerce and war than rivers based upon a comparison of the appropriations to the ratios of expense and tonnage for the largest rivers, the Ohio, Mississippi and Missouri vs. the Superior-Duluth, Ashland, and Milwaukee harbors. He therefore found that the Ohio was an "extravagance" (Congressional Record, House 66th 1st 1918).

In reality, the Ohio River Canalization project greatly aided the war efforts by providing industries with low-cost, dependable transportation. "In the 1930s, the cost of moving non-metallic minerals on the Ohio was less than a third and steel products less than a quarter of the comparable rail rates" (Johnson 1975:227).

OHIO RIVER INDUSTRIAL GROWTH AFTER WORLD WAR I

Effects of the War on Ohio River Navigation

Ohio river commerce had declined steadily since the 1890s and work on locks and dams had virtually ceased. The statistics for the Annual Report of the Chief of Engineers for 1920 were disappointing, although a change in river use was imminent. The Chief of Engineers, no doubt feeling the pressure of Congress resulting from the discouragingly low amount of commerce on the Ohio River, stated that "The great benefit claimed for the improvement will be felt only when the slack-water system has been extended far enough downstream to permit continuous navigation at all times (except when interrupted by floods or ice) over a longer section of the river, connecting the large cities on the upper with those on the middle and lower sections. The commercial effect of the series of completed dams on the upper river is reflected in the marked increase in general traffic and in the amount of coal shipped from the mines along the Monongahela River to industrial plants on the Ohio River at Alquippa and Midland, Pa., and Steubenville Ohio. . . . This increased movement of freight is not shown in the commercial statistics, due to the fact that it occurred during the present calendar year, whereas the commercial statistics are for the calendar year 1919" (Report of the Chief of Engineers 1920: 1344-1345). General Lansing H. Beach, Chief of Engineers in 1920, pressed upon Congress the importance of improved waterways as was borne out by the recent war transportation shortage. Congress responded with the Transportation Act of 1920 (Johnson 1975:212).

In 1920, Representative John Small could finally report that large vessel use of the Ohio River had been on the rise, resulting in a "substantial increase in the amount of water-borne commerce" (Congressional Record, House 66th 2nd 1920). Locally, newspapers in the Ohio River Valley began promoting the navigation improvements with greater fervor as it neared completion. In February of 1923, the *Pittsburgh Sunday Post* headline read: "Ohio and Mississippi to Save the Nation Millions When, With Improvement Program Completed, Vast Fleets Ply From Pittsburgh to the Mexican Gulf". Despite the fact that most river industries now used river transport, rails, and roads to their advantage, opponents still made accusations of "Pork" and rivalries between the railroads and river interests continued. The paper urged that the river system would only be viable in cooperation with the railroads and road system and the benefit to the country would come from cooperation of these three distribution systems "freely and in the friendly spirit of co-operation". Still combating accusations of "Pork", the newspaper argued that "The practice of political powers passing out contracts to favored contractors is nowhere evident." (*Pittsburgh Post* February 11, 1923).

The Post noted that in 1921, the Jones and Laughlin Steel Corporation made an experimental shipment of 1,000 tons of steel and shipped it down the Ohio and Mississippi and thence inland by rail at a savings of $10,000 in freight, and had been using the system ever since. Although many doubted the efficacy of using the rivers, some foresaw the potential in using barges on the river. When, in 1921, the company made the experimental journey, the *Pittsburgh Sun* hailed Jones and Laughlin as a "pioneer in this revival of the rivers" (*Sun* December 10, 1921).

The Pittsburgh *Chronicle Telegraph* noted that the City of Pittsburgh was still not interested in river transportation judging by the neglect of river terminals in that city. Secretary of War Weeks noted in the Sixty-sixth Congress that Pittsburgh had 130 acres of undeveloped water front, and that while private businesses were constructing terminals on the river, the city had no terminals. Weeks stated that the "most crying need is water terminals equipped with modern machinery for quick and economical handling of freight in order that the large number of small shippers in

Pittsburgh may avail themselves of the cheaper river rates (*Chronicle-Telegraph* March 1, 1922)."

Indeed, the U.S. Steel Company used the river extensively and the Pittsburgh Steel Company had two steamers and 40 barges on the river. Wheeling Steel, Pittsburgh Steel, the American Bridge Company, National Tube Company, the American Steel and Wire Company, McClintic Marshall Company, the Tennessee Coal and Iron Company, Illinois Steel Company, the Inland Steel Company, and Crucible Steel began using the river system around this time as well (*Pittsburgh Post* February 11, 1923).

In 1923, the Jones and Laughlin Company had eight steamboats, 300 steel barges and 20 more under construction. The *Sun* noted that companies both large and small were erecting terminal facilities. The *Sun* reported: "One such terminal, being built by the Carnegie Steel Company on the Monongahela, will cost $500,000 while two others for the Jones & Laughlin Corporation at Pittsburgh and Woodlawn will cost $300,000. The terminal of the Wheeling Steel Corporation at Wheeling is to cost $200,000. The river craft has a freight displacement in the Pittsburgh District equivalent to 20,000 railroad cars" (*Sun* February 19, 1923)

The Jones and Laughlin Steel Corporation hosted dinners and supplied accommodations for delegates of OVIA during many of their meetings during the push to complete the canalization project. In 1928, they urged a timely completion of the project by 1929. Other local companies, including Carnegie Steel and Rogers Sand Company also hosted events for the delegates (*Post-Gazette* October 4 1928).

Some of the most active members of OVIA were community leaders of Evansville and Paducah who, because they understood the importance of river improvements, positioned themselves to most benefit from the work. They worked hard and methodically for these improvements. When the canalization was completed in 1929, few cities and towns realized the potential that it created.

Growth of Ohio River Industries and Towns After World War I

Some cities began to plan for the use of the new navigation system, but realization of its potential was slow. In 1930, the City of Pittsburgh planned the construction of one river-rail terminal on the Ohio in the Manchester District. The city had other terminals on the Monongahela, but most of the terminals continued to be privately owned facilities. In 1931, Ethel C. Leahy published *Who's Who on the Ohio River and its Tributaries*, which gave a snapshot of the towns and industries along the Ohio immediately after the slackwater navigation system was completed. Woodlawn, later consolidated with Alquippa, was home to the Jones and Laughlin Steel Corporation. Midland, in Beaver County, had as its principle industries the Midland Steel Co., Wheeling Steel Corp., and the Yellow Poplar Company. Portsmouth, Ohio had as its principal industries iron, steel and shoe manufacturing. Industries in Aberdeen, Ohio included D. A. Ellis Coal, Miami Coal, and Suiter Material Company. Higginsport, Ohio was a boat building center.

In Newport, Kentucky, there were the Hatfield-Campbell Creek Coal Company, the Ohio River Sand and Gravel Company, and Andrews Steel Mills. Cincinnati had "over 300 diversified industries" including the Cincinnati Sheet Metal and Roofing Company, the American Barge Line, many sand and gravel companies, a city owned railroad (Cincinnati Southern). The city boasted its position as the origin of the Ohio Valley Improvement Association in 1895, and host of the recent National Rivers and Harbors Congress.

The town of Madison, Indiana had diverse industries including saw mills and Howard's Marine Ways. Jeffersonville, Indiana boasted the American Car and Foundry and Howard's Shipyards and Marine Repair Plant. Louisville, Kentucky had iron, steel, hardware, printing, pipe, casket, wagon, baseball bat, and other factories. It also had a new terminal operated by the American Barge Line. New Albany, Indiana became a boat building and manufacturing center. Evansville housed many industries, including sand and gravel companies, the Mead Johnson River and Rail Terminal, newly opened in 1931, and others. Paducah had among its interests the Ayer and Lord Tie Company shipbuilding operations, Arrow Transportation Company, and the West Kentucky Coal Company.

Mound City had marine ways of the Mound City Ship Yard and Dock Company, which boasted having built gunboats during the Civil War. Wellsville, Ohio had the American Sheet and Tin Plate Company, Mingo Junction, Ohio had Mingo Steel Works (Carnegie), Wheeling was home to Wheeling Steel, Mail Pouch Tobacco, Ohio River Sand and Gravel, Standard Oil, Pure Oil Company, and others. Benwood, West Virginia also had works of the Wheeling Steel Corporation. Sisterville, West Virginia, was a principal producer of oil and gasoline, and Clarington, Ohio had two boat-building industries. Marietta, Ohio boasted Remington-Rand, Inc., Marietta Chair Company, National Refining Co., U.S. Tool and Supply Company, and a number of smaller businesses. Point Pleasant, West Virginia had a B & O Railroad Yard, Enterprise Dock Company, and the Point Pleasant Machine Works. At Huntington, West Virginia stood several sand and gravel companies and coal companies, Ashland, Kentucky and Ironton, Ohio both had rolling mills, blast furnaces, foundries, machine shops, and other steel production industries. (Leahy 1931:517-540).

River tonnage, which had almost been non-existent in 1919, had increased to over 14,000,000 tons by 1932. By 1934, tonnage in the Cincinnati district had increased 23-percent over that of 1929. Before the U.S. entered World War II, tonnage had increased to a remarkable 29,600,000 tons in 1940. Most of this freight was in the form of coal, coke, iron and steel, with petroleum and cement products increasing as well. (*Waterways Journal* September 5, 1936; December 27, 1941). The number of major shipyards and barge builders on the Ohio continued to grow in response to the increased tonnage on the river, and the aftermath of World War I. Table 2-1 lists those active in 1931.

Table 2-1: Active Shipyards on the Ohio in 1931

American Bridge Company	Pittsburgh, Pennsylvania
American Steel Dredge Company	Fort Wayne, Indiana
Ayer and Lord Tie Company	Paducah, Kentucky
Cook Brothers and Thomas	Clarington, Ohio
Dravo Contracting Company	Nevile Island, Pittsburgh, Pennsylvania
Chas. Hegewald Company	New Albany, Indiana
Howard Shipyard & Dock Company	Jeffersonville, Indiana
Independent Bridge Company	Pittsburgh, Pennsylvania
Peter Jensen and Company	New Albany, Indiana
Jones & Laughlin Steel Company	Pittsburgh, Pennsylvania
Kanawha Dock Company	Point Pleasant, West Virginia
Marietta Manufacturing Company	Point Pleasant, West Virginia
Midland Barge Company	Midland, Pennsylvania
McClintic-Marshall Company	Pittsburgh, Pennsylvania
Madison Ways (Howards)	Madison, Indiana
Nashville, Bridge Company	Nashville, Tennessee
Mound City Shipyards & Ways	Mound City, Illinois
Riter-Conley Company	Pittsburgh, Pennsylvania
Riverside Mill Company	Antiquity, Ohio
Tennessee River Boatyards	Knoxville, Tennessee
Treadwell Construction Company	Midland, Pennsylvania
Ward Engineering Works	Charleston, West Virginia
Zier Boiler & Sheet Iron Company	New Albany, Indiana

Source: Leahy 1931

The *Waterways Journal*, politically active as well, urged subscribers to contact their Congressmen on bills such as the 1936 Short Haul Bill introduced by Representative Samuel B. Pettengill (D) of South Bend, Indiana. The bill allowed railroads to charge different rates for long and short haul freight, calling it a "complete turnover in public sentiment toward the railroad industry" (*Waterways Journal* March 28, 1936).

"308 REPORTS"

In 1925, Congress authorized the Corps and the Federal Power Commission to submit cost estimates for combined flood control, navigation, hydroelectric power generation and irrigation improvements for every major river in the Unites States. These reports, known as the "308 Reports" since they were printed in House Document No. 308 of the 68th Congress, 1st Session, were collectively the first public proposal for the concept of multiple-purpose water resource development by the Corps of Engineers (Johnson 1975:199).

The "308 Reports" recommended levees and reservoirs for flood control, but Congress still expected that local and state governments would have to finance and construct flood control projects. The Great Depression of the 1930s made this all but impossible (Johnson 1975:201).

DEPRESSION, FLOODS, AND RELIEF

Although the Corps completed the Ohio River slackwater navigation system before the market crash of 1929, the first decade after completion was one of dire hardship for many in the Ohio Valley as elsewhere. Thus the system had to prove its worth in a particularly difficult time.

The response to the Great Depression - FDR's New Deal - made the depression a fortuitous event for the Ohio River during the late 1930s. FDR's relief programs, specifically the Public Works Administration (PWA) and the Works Progress Administration (WPA), would not have existed but for the depression. These agencies completed scores of projects in some way related to river navigation.

During the disastrous floods of 1937, Governor Chandler of Kentucky had no trouble convincing WPA Chief Harry Hopkins to begin WPA emergency evacuation work along the Ohio River. George Goodman sent over twelve thousand WPA workers to flooded areas in forty counties, many of whom went to work constructing levees on the Ohio. In addition, CCC workers and NYA students helped with relief work along the river (Blakey 1986:193). Federal relief, however came with a price. It showed that the national government could better combat such natural emergencies and it promoted the shift from self-reliance and state autonomy to greater dependence on the Federal Government. Those who adapted to the new political realities reaped the rewards of this new era (Blakey 1986:194).

The Louisville District recommended that the best method of protection from floods would be to construct a series of reservoirs in the valley, but the state of Kentucky and local communities lacked any financial resources to effect such improvements. The "308 Report" for the Ohio River recommended a series of fourteen reservoirs for immediate construction. Impediments included lack of monies, but the reasons were deeper than mere lack of funds. Different local and state governments were reluctant, especially in such lean times, to finance projects that would benefit other regions, and most felt that since the benefits crossed jurisdictional lines, the federal government should construct these improvements with tax money from all those who would benefit (Johnson 1975:203).

As in the past, it took a disaster to weaken the political opposition to river improvements. The disastrous flood of 1936, which claimed about 200 lives and hundreds of millions of dollars of property, and the so called "Superflood" of 1937 removed all opposition to federal aid for flood control in the Ohio River Basin. Conditions were so bad that the City of Louisville declared martial law. Damage was estimated at over four hundred million dollars, and the War Department spent over ten million dollars for flood relief and emergency work to prevent further damage. The American Red Cross spent over seven million dollars (Johnson 1975:205).

Some argued that the slackwater system on the Ohio caused silting of the river and had been the cause of increased flooding. This became a serious threat to navigation interests as a grand jury in Louisville had, on February 26, called upon the federal government to make outright grants and not loans to the flood victims based upon its finding that the navigation dams on the Ohio river, and not the heavy winter rains, had been the cause of the flood. Therefore, the grand jury saddled the United States with responsibility for the flood. The U.S. Army engineers vigorously denied that the flooding was caused by their improvements. Cincinnati meteorologist and flood expert W.C. Devereaux termed the idea a "silly theory". And Captain Lucious D. Clay of the Army engineers officially declared that the dams had "no appreciable effect" on the flood (*Waterways Journal* March 6, 1937). The *Waterways Journal* responded unequivocally with

measurements taken by the Army that proved that the depth of the river at the location of the dams had not changed since their construction, and significant silting had not occurred (*Waterways Journal*, September 16 1939). President Franklin Roosevelt, Congressmen, local residents, civic groups, and even railroads urged that improvements for flood protection become integrated into Ohio River improvements (Johnson 1975:207).

Within 60 days of direction from the House Committee of Flood Control, the Corps completed their recommendations for the construction of levees, floodwalls, and channel improvements for the protection of 155 communities in the Ohio Basin, including the construction of 45 reservoirs on tributary streams. Under the pressure to take quick action, Congress approved the study with the appropriation for almost twenty-five million dollars for the commencement of the recommended projects with the Flood Control Act of August 28, 1937. With this, flood control became a major mission of the Corps of Engineers (Johnson 1975:208).

Passage of the Flood Control Act of 1937 did not automatically create a favorable atmosphere for flood control reservoirs. Local and state politics still put up road blocks. When the Louisville District made plans for a flood control reservoir and hydroelectric power system in the White River near Shoals, Indiana in 1945, the district encountered strong opposition from local residents. The Governors of Illinois and Indiana also opposed the project due to its enormous size since it would inundate areas that generated large tax revenues for the state and county governments (Johnson 1975:259).

The Board of Engineers for Rivers and Harbors and the Chief of Engineers agreed with the Governors to abandon plans for three reservoirs including the projects at Shoals, Spencer, and Wolf Creek, and to instead construct a single project known as the Cagles Mill Reservoir. The Corps completed the dam and lake on Mill Creek, a tributary of the Eel River in 1958. Serious opposition to the Wabash Basin projects evaporated when the recreational value became apparent, and in 1958, 1965, and 1968, Congress authorized additional projects for the Wabash Basin (Johnson 1975:262).

In other areas local opposition made Congressional approval difficult since local Congressmen were not likely to vote against their constituent's wishes. The Louisville District recommended seven reservoir projects for flood control in the Green River Basin, and an additional large reservoir above lock No. 3 on the Green River following the 1937 flood. Known as the Mining City Reservoir, many feared that it would inundate Mammoth Cave. Not surprisingly, residents who lived in the areas to be flooded strongly opposed the project.

WORLD WAR II

With the advent of the defense emergency in 1939, ton-mile traffic on the Ohio rose 14.6-percent during 1940, and in 1941 it rose over 37-percent. Commodities consisted of coal, iron and steel, petroleum, scrap metal, and sulfur (*Waterways Journal* December 13, 1941). The *Waterways Journal* reported that by December 1941, the Ohio river shipyards cooperated by accepting contracts for Army and Navy vessels for ocean service. The Marietta Manufacturing Company in Point Pleasant West Virginia delivered the first units: four U.S. Navy net tenders. These were the Gum Tree, Larch, Holly and Elder, each 1,100 horsepower diesels. This company then began work on an order of 12 steam mine planters for the Army. The Dravo Corporation at Neville Island Ways began work on 15 sub chasers. The Nashville Bridge Company began construction of two mine sweepers, and the Jeffersonville Boat and Machine Company began construction of four sub chasers (*Waterways Journal* December 27, 1941). This company began construction 16 mine planters (*Waterways Journal* November 1, 1941). Barges were also under construction by these companies for war purposes. The Nashville Bridge Company built five cargo barges for the Inland Waterways Corporation, and the Dravo Corporation had begun construction of five deck barges 41 cargo barges, and 21 oil barges. The Weirton Steel Company began an order for ten coal barges. The Marietta Manufacturing Company also constructed two oil barges and five hopper barges. The Nashville Bridge Company had started three acid barges for the Carbide and Carbon Chemicals Corporation and nine oil barges. The Jeffersonville Boat and Machine Company of Jeffersonville Indiana was building two oil barges and one towboat for the American Barge Line Company (*Waterways Journal* December 6, 1941).

After the attack on Pearl Harbor the Corps of Engineers took responsibility for rapid mobilization of national resources, and diverted efforts away from improvements to navigation and flood control. Projects included airfield construction, quarters and training facilities for troops, utilities, roads, fencing, and the erection of office buildings to name but a few. Civil works on the Ohio were virtually suspended between 1942 and 1945 with unfortunate consequences, as several floods, most notably the March 1945 flood produced severe damage, killed 24 people and shut down 188 war production plants while impeding progress on another 93 plants (Johnson 1975:255).

In 1940, Congress proposed a radical decrease in funds for rivers and harbors by nearly 50-percent in order to make way for increased defense funding. Congressman Dewey Short (Repub.) of Missouri, president of the National Rivers and Harbors Congress led the fight to restore the appropriations, and Major General Julian L. Schley, Chief of Army engineers also warned that these funds were necessary for the defense of the nation (National Rivers and Harbors News, January 1940).

In 1941, *Railway Age* noted that a resolution introduced by Senator Vandenberg of Michigan (R) to require the formal recommendation to the Congress by the Board of Engineers for Rivers and Harbors of any bill before it could be authorized would curb the distribution of "pork" (*Railway Age* January 18, 1941). The journal criticized the tactic of introducing river and harbor items as vital to "national defense" just to get them passed, as FDR had promised to veto anything that was not vital to national defense. The journal was even more critical of the Inland Waterways Corporation, which it called the "socialist transport venture" because it had reported a net loss of $273,725 in 1940. It mocked the assertions made by the government that despite the loss, the actual direct savings to the public was in the range of two million dollars (*Railway Age* January 18, 1941). Wartime construction contracts caused a shortage of experienced rivermen, and OVIA

and the Waterways Journal began to advertise the need for new pilots, engineers, and other personnel to operate these new vessels (*Waterways Journal* November 1, 1941).

An example of the impact of the war on the growth of industry on the Ohio can be seen in the full page advertisement taken by the Ashland Oil & Refining Company in the December 27 1941 issue of the *Waterways Journal.* It boasted that the company aided in the war effort by shipping over 1,000,000 tons of crude oil in 1941, and was expanding its fleet with an additional five towboats and 37 steel barges that would increase their capacity by 50,000 tons (*Waterways Journal* December 27, 1941).

In light of the impending defense needs, OVIA drew up a set of resolutions urging the federal government to renew its support for flood protection and transportation facilities in order that the Ohio Valley might do its utmost to support the war effort (*Waterways Journal* May 3, 1941). By 1942, the *Waterways Journal* announced that every shipyard from Pittsburgh to Cairo was working at capacity to launch river craft, and the fleet was still unable to handle the war tonnage being turned out (*Waterways Journal* February 14, 1942).

In early 1942, the Navy Department announced that it planned to construct a shipyard at Evansville for the assembly of large boats. It was located just west of the Mead Johnson river terminal and operated by the Missouri Valley Bridge and Iron Company based in Leavenworth Kansas. It became a major producer of tugs and specialized landing craft for military equipment for the war effort (*Waterways Journal* February 21, 1942). Transportation of oil on the Mississippi and Ohio by barge was considered much safer than by tanker during the war, as tankers were open to attack on the ocean. General Eugene Reybold, Chief of Engineers in 1942, pointed out that the nation had a great advantage of having a completed navigation system on the Ohio that was not available during the last great war (*New Orleans Times Picayune*, May 18, 1942). River authorities and public officials spoke at length at the 36th annual meeting of the National Rivers and Harbors Congress in 1942 on the topic of increased use of inland waterways to aid the war effort. The officials found "bottlenecks" obstructing the full use of waterways for the war effort. These included the lack of sufficient oil barges and towboats and the opposition of the railroads.

Just before the attack on Pearl Harbor, the Corps began a major expansion program at Fort Knox, and the number of structures at the post grew from 864 in 1939 to over 3,000 by 1942. During World War II, the fort held large numbers of troops.

The Ohio River became the conduit for transportation of great stores of munitions from newly constructed ordnance and munitions plants. In the Louisville District alone, these included the Ohio River Ordnance Works at Henderson, Kentucky, the Hoosier Ordnance and Indiana Ordnance plants at Charlestown, Indiana, the Evansville Ordnance Plant at Evansville Indiana, the Blue Grass Ordnance Depot at Richmond, Kentucky, the Fall Creek Ordnance Plant at Indianapolis, and the Vigo and Terre Haute Ordnance Plants (Johnson 1975:220-221). The Evansville plant was operated by the Chrysler Corporation. The Remington Corporation converted its Kings Mills plant in Cincinnati to a .45 caliber ammunition plant. Other private companies involved in arms production included the Sunbeam Electric Company, which produced cartridge cases in Evansville (Thomson & Mayo 1960: 202).

The Corps expanded river facilities at the Warner Gear Division of the Borg-Warner Corporation at Muncie, Indiana and the ordnance-testing facilities at Jefferson Proving Ground, Madison Indiana (Johnson 1975:221). Private corporations benefiting from these developments included the E.I. du Pont de Nemours Company which operated the Indiana and Hoosier Ordnance plants

at Charlestown Indiana for the production of smokeless powder and the Chrysler Corporation which owned the renovated Evansville Ordnance plant, a producer of .45 caliber ammunition.

The Ohio River canalization proved to be invaluable to the war effort. As during World War I, river navigation greatly reduced the pressure on the railroads which were nearly paralyzed by the volume of transportation needed. Barges on the river transported petroleum equivalent to seven million rail tanker carloads during the war, and permitted widespread geographic distribution of military products. During the war inland river shipyards produced 4,031 landing craft and small ships. The Ohio Valley shipyards produced about a thousand vessels, including 585 LSTs, (Landing Ship Tanks), a naval ship specially designed to transport and deploy troops, vehicles, and supplies onto foreign shores. In addition, the shipyards produced 74 LCTs (Landing Craft Tanks) used to get heavy tanks and vehicles ashore in a hurry, 47 tugs, 36 patrol cruisers, and 16 mine-layers. Most of these ships came from Evansville, Indiana shipyards and the American Bridge Company shipyards at Ambridge, Pennsylvania (Plate 2-13). These shipyards were crucial for the war effort, and without the navigation system, they would not have been a reality. Through Lend-Lease the United States provided 113 LSTs to Britain. The Ohio River Canalization project greatly aided the war efforts by providing industries with low-cost, dependable transportation. "In the 1930s, the cost of moving non-metallic minerals on the Ohio was less than a third and steel products less than a quarter of the comparable rail rates" (Johnson 1975:232).

"The improvement of the river channel at the turn of the century, had a synergistic effect. Evansville and Paducah became major shipbuilding centers during World War II." Fort Knox's expansion accelerated West Point's inclusion in metropolitan Louisville, and Camp Breckinridge, the training grounds for thousands of troops, both owed their location to a navigable river. The lock and dam system promoted acceleration in the abundant coal areas near Paducah, which in turn led to the construction of large aluminum-processing facilities near Hawesville, Henderson, and Newburgh. This growth, in turn created sufficient demand for river commerce to justify enlargement and modernization of the lock and dam system in the 1970s (Bigham 1998:251).

MID 20TH CENTURY

In 1950, engineers from Electric Energy Incorporated began inspecting sites in the Ohio Valley for construction of a multi-million dollar steam operated electric plant. The company's engineers rejected one of the potential sites in the Green River Valley due to the risk of floods and lack of adequate navigation facilities. This galvanized local leaders to organize the Green River Valley Citizens League, whose purpose was to promote economic development in the region. The League's first action was to endorse the construction of four flood control reservoirs in the valley. The members of this group represented the interests of the people living downstream of the proposed reservoirs and would benefit from the flood protection that the projects would afford. Opposition to the group was strongest among those whose homes would be flooded, or the "upstream" interests. This "upstream versus downstream" controversy was typical of nearly all the proposed flood control reservoir projects (Johnson 1975:262-263).

Disastrous floods continued to settle controversies over reservoir projects. A typical example of this was the Howardstown Lake project on the Salt River. Similarly, in the Kentucky River Basin, the "upstream-downstream" conflict was strong. Additionally, the project at Jessamine Creek attracted great opposition since it would inundate a large number of historic sites. Residents of Owsley County opposed the Boonville Lake project, being satisfied with the status quo, but others fought for the project because they expected that the reservoir would bring economic opportunity to a very poor area (Johnson 1975:264). Many of the reservoir projects would probably never have been approved if it had not been for flood disasters that swayed public and political support in favor of flood control programs. The shift from mere flood control to the concept of reservoir projects with a multipurpose program having numerous benefits also proved a major catalyst in changing public and political opinion. Public and political opposition decreased to reservoir projects as people recognized the advantages in terms of economic growth, recreation, flood control, and power generation.

The publication of Arthur Maass' book: *Muddy Waters: The Army Engineers and the Nation's Rivers* introduced a new era of criticism against the Army engineers. This work was especially significant because an early draft of his work was made available to the staff of the Hoover Commission Task Force on Natural Resources in 1948 and the President's Water Resources Policy Commission of 1950. It had a significant impact on the findings of these commissions. Maass contended that the Corps of Engineers wielded a dangerous level of control because direct relations between Congress and the Corps enable the Engineers to bypass the President. He explained that since members of Congress could not get approval for any particular project without a favorable report from the Corps, that the members tend to pressure the Corps for a favorable report, and the Engineers become directly responsible to individual members of Congress. All of this was accomplished in committee hearings, and thus, Maass argued, Congress and the Corps bypassed the President through legislation by committee resolution. He concurred with the notion that the individual project nature of the omnibus rivers and harbors bills constituted "pork barrel" legislation. He noted that this was not a rational national water policy, and that the waste came from the lack of a clear plan. Maass asserted that when the Hoover Commission, in 1949, set out to consolidate the functions of the Corps of Engineers and the Bureau of Reclamation into a Water Development and Use Service within the Department of Interior, the supporters of the Corps fought the bill, and Congress defeated it (Maass 1950).

Harold L. Ickes wrote the introduction to the *Muddy Waters*. In accepting the invitation from Maass to do so, Ickes wrote: The Corps of Army Eingineers [sic] has developed, in my judgement, into a positive administrative evil. It is a veritable old man of the sea, clinging to the

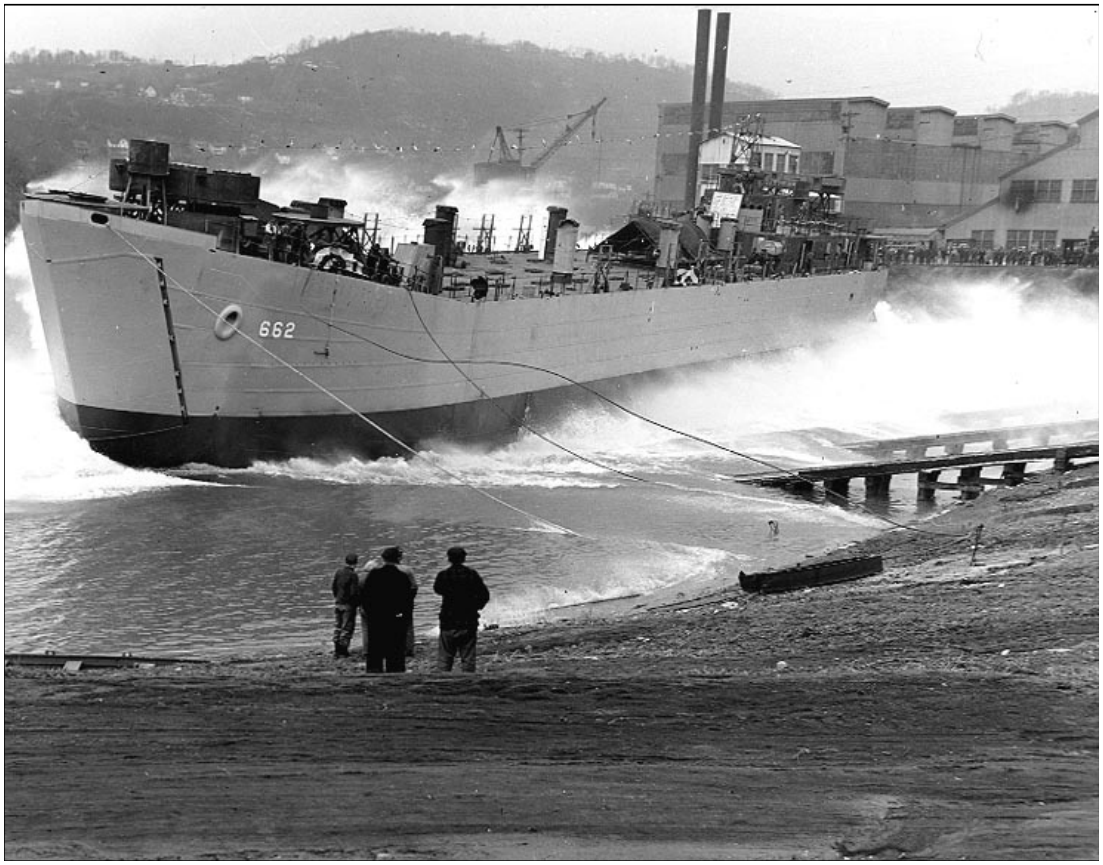

Plate 2-13. Launching of LST 662 at Ambridge in 1944

shoulders of the taxpayers. Congress has continued to do its bidding in return for improper favors, and even strong Presidents have been unable to prevail against it in the public interest" (Harold L. Ickes, March 26, 1951 Maass Papers, Folder 467). The fact that Ickes had served as U.S. Secretary of the Interior from 1933-1946 may have colored his views on the Corps of Engineers, as the Interior Department has historically been at odds with the Army Corps of Engineers and the Department of Agriculture. Although he had helped to form the Progressive Party, in 1932 he led liberal Republican support for the Democratic candidate, Franklin D. Roosevelt, who subsequently appointed him Secretary of the Interior. Ickes ardently supported social reform and conservation of natural resources.

Between 1940 and 1970, the Louisville District contributed greatly to the success of the American armies overseas. Although many of the Corps districts resumed predominantly civil works after 1945, the Louisville District continued to have a military mission during the Cold War, with major involvement during the Korean War (Johnson 1975:209). The Indiana and Hoosier Ordnance plants were re-fitted, and proving grounds and warehouses were constructed. Additional barracks were constructed at Fort Knox and Fort Campbell as well (Johnson 1975:225). The war efforts altered the nature of river commerce. Prior to 1941, the bulk of the river trade consisted of coal and steel, and flowed mostly downstream. During the war, there was a shift in commodity to petroleum products. By the 1950s, diversification and volume on the river had vastly increased, and tonnage upstream and downstream had become equal. River traffic, nearly extinct by 1917, had become so large by the end of the Korean War that modernization of the navigation system began - this time without the great struggles of the past (Johnson 1975:227).

Originally, the canalization project on the Ohio planned for 54 lock and dam structures. The elimination of 40, 42, and 54 reduced this number to 51. In 1953, a modernization project began in order to meet the increased volume of traffic and size of tows. Fifty-one dams and single locks were to be replaced by 19 dams and dual locks. This modernization project will be accomplished upon the completion of the Olmstead structure is completed. By the 1950s, the success of the Ohio River System was the pride of the Ohio Valley. Articles of its success appeared in most major newspapers and magazines, including the National Geographic and the New York Times. The November 20, 1955 issue of the *New York Times* ran a large story entitled "The Ohio Becomes Industrial Aorta". It proudly listed the achievements of the "roster of companies that . . reads like and expanded "'Whos Who' of American industry," calling the Ohio Valley the "World's Mightiest Industrial Area" (*New York Times*, November 20, 1955).

In the mid-20th century, civic and business groups, and the industries they represented, constituted a powerful political force. In 1961 they produced a large advertisement insert in the New York Times in an effort to attract industry and labor to the Ohio Valley (New York Times October 29, 1961 Section 11). Accusations of "pork" spending still surrounded the issue of Ohio River improvement, even in the 1960s. The April 28, 1964 issue of the OVIA News Letter addressed these accusation head on. This issue came after the devastating Ohio Valley flood in March of 1964. As a preemptive strike against opponents to the Public Works Appropriations Bill for Fiscal Year 1965, this issue claimed that one and a quarter billion dollars worth of damage had been prevented for expenditures of $657 million (OVIA April 28, 1964).

LATE-20TH CENTURY

The Conservation Movement of the early-20th century generally saw the Corps in a good light, as conserving water, preventing floods, erosion, forests, and finding multiple uses for natural resources while ensuring adequate protection. The Environmental Movement of the 1960s and 1970s, in contrast with the earlier Conservation Movement, criticized the Army engineers. In many eyes, the development of natural resources for economic benefits no longer justified a project. Long term environmental quality became an important issue. The Army engineers, who had generally been viewed as proponents of the conservation of natural resources now found themselves on the defensive. Environmentalist accused the Corps of destroying the natural environment with water resource development programs, and devising "make work" projects. The Corps found themselves embroiled in public protests and legal actions to stop various projects. This led to increased commitment on the Corps part to give consideration to all environmental features of navigation and flood control projects.

During this period, OVIA continued its uncompromising promotion of navigation improvements, lobbying Congress, and expending considerable resources on educating the public on Ohio River navigation issues. Pamphlets, such as one produced in 1964, presented the history and future goals of the organization to the public. It emphasized that OVIA promoted the interests of public-minded citizens, community organizations, river operators, agricultural interests, and leading industries including coal, oil, steel chemicals, electric power, and aluminum. The pamphlet emphasized the benefits that navigation improvements had yielded, including a doubling of tonnage of commodities shipped on the river in the previous 15 years, recreational developments, flood control, cleaner water, and job creation. This particular pamphlet was aimed at making the public aware of recent proposals to impose a toll on waterways, stating that it was a "breach of faith" of the government, and such a toll would "have a retardant effect on the Ohio Valley expansion, and remake the existing complex social, economic and industrial map which has been drawn in 175 years of toll-free waterways in the Nation." These tolls would "remove the corner-stone of the Valley's future, the orderly development and economic progress of the Ohio Valley." OVIA considered itself the guardian of the Ohio River navigation system, and the leader and catalyst for the modernization project for nineteen locks and dams begun in 1954. Leading members of the group included the presidents of the Mississippi Valley Barge Line, the Ashland Oil and Refining Company, Olin Mathieson Chemical, Armco Steel, National Steel, Island Creek Fuel & Coal, Consolidation Coal, American Electric Power Service, Wheeling Steel, Johnson & Higgins, Cincinnati Gas & Electric, Canal Barge Co., Standard Oil, and the Kanawha Sand & Gravel (OVIA 1964).

Criticism against the Corps of Engineers never ceased despite the apparent success of slackwater navigation on the Ohio and other systems. Excesses of waterways lobbies only exacerbated the image of "pork". In 1968 a major source of ridicule and disgust for the waterways lobby surfaced with the plans of the National Rivers and Harbors Congress to "erect a 'monumental building' on the public mall between the Jefferson Memorial and the Washington Monument." The article, although supposedly written against the lobby group, directed most of its heat against the Corps of Engineers, quoting from Arthur Maass' book for ammunition. Whether or not the Corps of Engineers had anything to do with the plans is not discussed, rather, it is assumed to be the case (*Free Press* April 10, 1964).

According to Johnson (1975), the comprehensive program for the development of water and related land resources between 1936 and 1973, had a revolutionary effect on "living standards and life quality in the Ohio River Basin" (Johnson 1975:3). Although it is difficult to measure the

social and economic impact that dependable, low-cost navigation on the Ohio River Basin had on riverside communities, it is clear that the impact has been enormous. The inland waterways system attracted steel plants, chemical factories, petroleum refineries, coal and coke industries, power generators, and scores of other industries. These industries in turn attracted people in search of employment, and these people often comprised a specific ethnic group. Secondary industries and commercial establishments grew around these communities to serve the growing population. This chain reaction of growth became especially strong after World War II. Johnson reports that from 1950 to 1960 alone, the population of Louisville increased 24-percent, retail sales increased 54-percent, and tonnage moving to and from the port increased about 80-percent (Johnson 1975:250).

ESSAY ON SOURCES

Research into the politics of the Ohio River Navigation System began by preparing a bibliography of relevant sources. Pittsburgh repositories included the Hillman Library at the University of Pittsburgh, the Carnegie Public Library of Pittsburgh, the Carnegie Public Library storage warehouse, and the library and archives of the Historical Society of Western Pennsylvania at the Senator John Heinz Pittsburgh Regional History Center. Additional repositories consulted included the Library of Congress, the Libraries of the University of Maryland, and the archives and library of the U.S. Army Corps of Engineers, Office of History at Fort Belvoir, Virginia. During the course of this project, many internet resources also provided valuable information. In particular, the *Biographical Directory of the United States Congress* at http://bioguide.congress.gov proved invaluable for biographical and legislative information on members of Congress.

Leland R. Johnson's historical studies of the U.S. Army Corps of Engineers provided general information on the development of the Ohio River Navigation System. These included *The Ohio River Division, The Davis Island Lock and Dam, 1870-1922,* and *The Falls City Engineers.* Other useful books covering general background of the navigation system included the works of Charles Ambler, Darrel Bigham, and Carter Goodrich.

Publications of the Ohio Valley Improvement Association, and the works of Harold Moulton (*Waterways Versus Railways),* and Herbert Quick (*American Inland Waterways)* in particular, gave insight into contemporary thought and literature on politics, technologies, and public opinion.

Essential technical reports included Albert Gallatin's *Report on Roads and Canals,* the *Annual Reports of the Chief of Engineers, U.S. Army,* and the *Preliminary Report of the Inland Waterways Commission.* Contemporary newspapers and periodicals, in particular, the *Military Engineer,* the *Waterways Journal,* the *National River and Harbors News,* also proved invaluable.

The papers of Arthur A. Maass, at the Office of History archives for the U.S. Army Corps of Engineers, Samuel P. Hays' *Conservation and the Gospel of Efficiency, The Progressive Era,* by Lewis Gould, and *Structures in the Stream,* by Todd Shallat, all provided valuable historical analyses of the operations, public relations, political climate, as well as a broader historical context for the events surrounding the development of Ohio River navigation. While a fascinating source of information, the *Roads and Canals* series available at the Corps' library in Fort Belvoir, ends in 1890, and does not include the period of intensive work, both physically and politically, on the Ohio River Navigation System. The *Rivers and Harbors* series at the library proved more useful, as it contains the vast majority of pertinent official documents, and legislation on navigation development during the period of intense interest in Ohio River navigation development. Although the documents found within this compilation are generally available within other legislative collections, its usefulness lies in the fact that it focuses on documents relating to river and harbor development.

Perhaps the most useful primary source, the *Congressional Record* was essential for its exhaustive coverage of Congressional debates, committee reports, bills, speeches, and Congressional commentary, and statistics. Finally, the help and guidance or Corps historian Dr. Martin Reuss, has been greatly appreciated throughout the duration of this project.

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CHAPTER III

COMMUNITY GROWTH, ECONOMIC DEVELOPMENT, AND THE EFFECTS OF THE OHIO RIVER NAVIGATION SYSTEM

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THE CONTEST FOR THE MIDDLE AND UPPER OHIO RIVER VALLEY AND THE ORIGINS OF URBAN SETTLEMENT

The Ohio River as an Eighteenth-Century Cultural Divide

Many of the first towns in the Ohio River Valley developed out of or around military fortifications during the second half of the eighteenth century. The course of urbanization therefore reflected much larger, indeed international, political developments, first between England and France, then between England and her American colonies. A third geo-political dimension involved continuing land disputes with Native Americans. The Ohio River Valley, especially that section between Pittsburgh and Cincinnati, became a dividing line between the protagonists and one of the most important scenes in which these dramas were played out between 1754 and 1795. A basic understanding of these larger events is therefore necessary to understand the course of urban development in the river valley.

When Euro-American settlers began to filter over the mountains from the East and arrive in the Ohio country in the eighteenth century, they found few Native Americans who were long-time residents of the area. Although the land abounded with game, only small Indian hunting camps and a few villages were found. Most Native Americans in the Upper Ohio River Valley at that time had been displaced from homelands farther to the east by encroaching European settlement. Hunting and raiding parties of Shawnee, Delaware (originally from eastern Pennsylvania, southern New York and New Jersey), Wyandot (an amalgam of Hurons, remnant Petun, and Neutral), Mingos (Ohio River Iroquois), some Cherokee, Miamis (also known as the Twightwees, who were resident in northern Ohio), and perhaps a few Tuscarora (an Iroquoian-speaking group native to North Carolina who journeyed north to live with the Iroquois in New York after the Tuscarora War from 1711 to 1713) roamed throughout the area. However, few villages or permanent settlements of these displaced native peoples were found.

There were some signs in the landscape, however, of an earlier human occupation of the river valley. Early European maps sometimes recorded the locations of abandoned Indian agricultural fields (usually called “old fields”), and what some early visitors interpreted to be abandoned towns or villages marked by large earth mounds or mound complexes. The cartographers sometimes attributed these sites to the Shawnee, the most numerous and often the most hostile of the Indians that the settlers encountered. When Europeans first saw them, these old clearings were overgrown with weeds, thistles, and prickly locust (see Briceland 1991: 34). But there seemed to be little possible relationship between the size of these former clearings and the small numbers of Native Peoples the settlers encountered. These abandoned patches, however, could be re-cleared much more easily than the surrounding virgin forest and therefore became desirable sites for early European homes, settlements and agricultural fields.

In addition to these "old fields", there were other signs of an earlier, more widespread, and more populous human occupation. Stone implements, pottery, and human burials were soon unearthed as Europeans began to cultivate the soil. Visible, too, were the well-worn routes of trails that crisscrossed the ridges and river valleys, where they also provided the first land routes for the first European settlers.

In the Kanawha, Potomac, and Ohio River Valleys, especially, many large earthen mounds and mound groups, obviously man-made, were evident (Figure 3-1). These mounds frequently occurred at or near the mouths of tributaries of the Ohio River, so it was impossible for the early settlers to

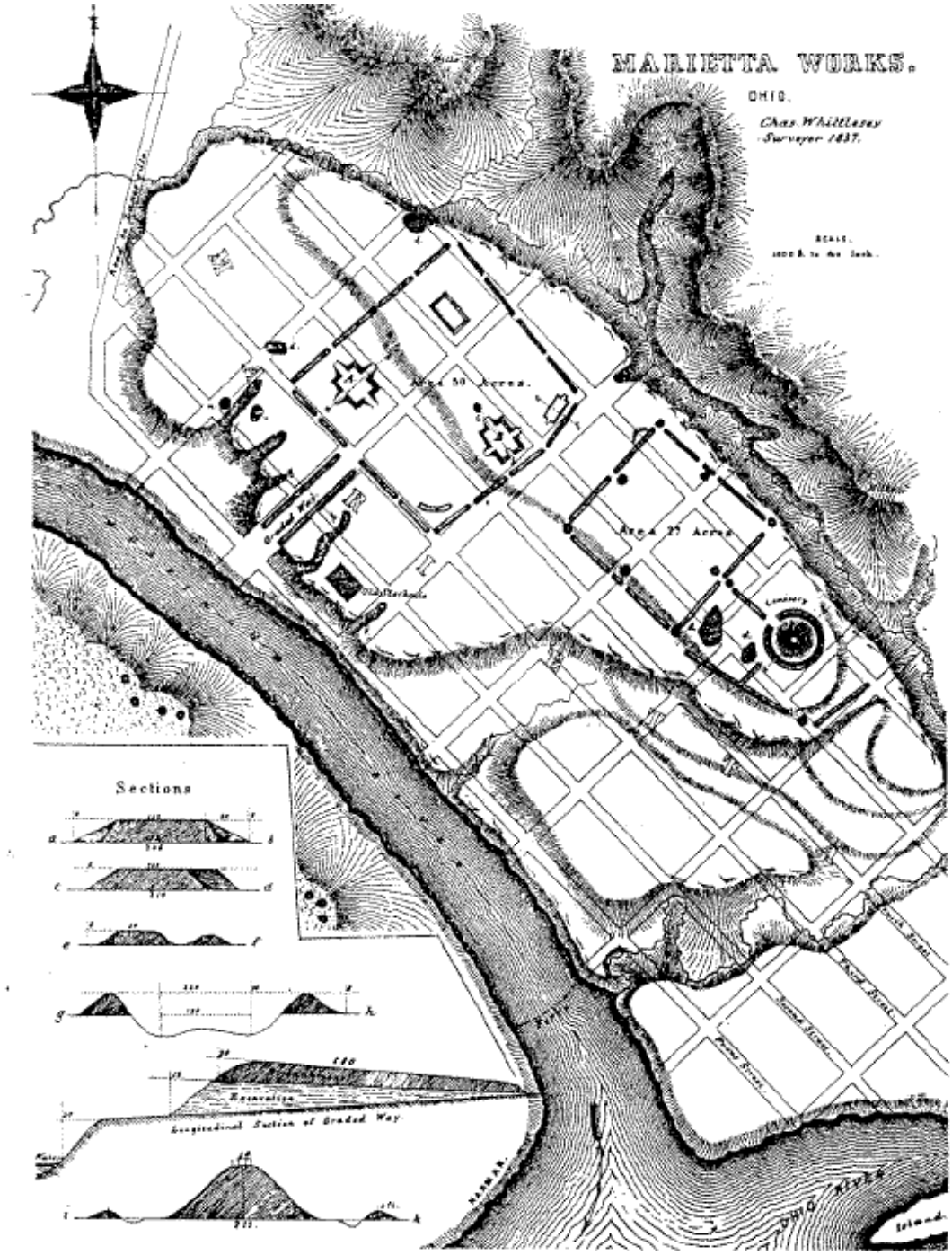

Figure 3-1: The prehistoric earthworks and mound at the confluence of the Muskingum and Ohio rivers, Marietta, Ohio, as drawn by Squier and Davis in 1848. From Silverberg (1968: 31).

ignore them. The large mounds at the mouth of the Muskingum River, the future site of Marietta, Ohio, for example, were first noted by General Samuel H. Parsons while on military duty in the river valley in the 1780s, and knowledge of them was communicated to Ezra Stiles, then president of Yale College (Silverburg 1968: 26). The Marietta mounds were incorporated within the new town's plan, and a map of them was prepared when Massachusetts and Connecticut men from the second Ohio Company arrived to begin the construction of Marietta in the winter of 1787-1788. Prehistoric mounds and mound complexes also once stood at many other Ohio cities including Circleville, Chillicothe, and Cincinnati, though most were ploughed away in the early days of settlement (Jakle 1977: 71).

Europeans developed various explanations to account for these artifacts, trails, and earthen mounds that were debated for the following century. It was obvious, however, even to the most casual observers, that the number, distribution, and size of the abandoned agricultural fields, village sites, mounds, and aboriginal artifacts far exceeded the number and, some whites thought, the intellectual and technological capacity of the sporadic Native American groups scattered throughout the area. The architectural complexity and sophistication of the mounds and the numerous abandoned sites evident across the landscape provided a sharp contrast that the European mind interpreted to be the result of a cultural disjunction. Europeans rationalized the construction of the impressive mounds, which obviously had required the coordination and expenditure of considerable human labor, by appeals to Biblical or classical "explanations." Carthaginians, lost Israelite tribes, Assyrians, and other Old World cultures known to have built similar structures were also proposed as the architects of the North American mounds. Another long-held view attributed the mounds to an extinct race of "moundbuilders."

These early European explorers and settlers were unaware that the comparatively simple bands of migratory native hunters and horticulturists of their own day were the products of more than a century of cultural upheaval, dissolution, and widespread geographical relocation. This cultural turmoil had been precipitated beyond the curtain of the Appalachian Mountains by the development of sustained European settlement on the eastern seaboard beginning in 1607 and by related socio-political changes within other Native American cultures.

Archaeologists have only recently begun to reconstruct the cultural and historical threads that knit together the native cultures of the Late Prehistoric and Protohistoric periods in the Ohio River Valley with the more familiar named tribes of the Historic period. The Late Prehistoric peoples of the Fort Ancient Tradition, for example, were once numerous in the Ohio River Valley; however, the rare historical and even more limited archaeological data for the immediately succeeding Protohistoric period, just prior to the time of the first contacts between Native Americans and Europeans, indicate that by A.D. 1650-1700 few Native Americans permanently resided in the Upper Ohio River Valley.

The Upper and Middle Ohio River Valley in the Military Contests of the Eighteenth Century

The pattern of settlement in the Upper and Middle Ohio River Valley during the second half of the eighteenth century was greatly affected by larger European political struggles, by nearly constant hostility between settlers and Native Americans, and by the American colonists' own struggles for independence from Great Britain. In contrast to the relative peace that prevailed along Virginia's northwestern frontier in the first half of this pivotal century, every decade in the second half was influenced, often extensively, by some form of military activity. One result of this military turmoil was that permanent settlements and the establishment of urban centers in the Upper Ohio River Valley were delayed until later in the century.

French claims to dominion in the Ohio drainage were based on the precedents set by their early explorations. Joliet's discovery of the western end of Lake Erie in 1669 brought within the French sphere the last of the Great Lakes to be discovered by Europeans. French exploration south of Lake Erie began well into the eighteenth century. The southern expedition of the Baron de Longueil to subdue the Chickasaw Indians in 1739 traversed Lake Ontario and Lake Erie to Niagara Falls. From there, he proceeded down the Allegheny and Ohio Rivers (which the French considered to be one river, *La Belle Rivi—re*), and from the modern day site of Pittsburgh down the Ohio into the American interior via the Mississippi River. Ten years later, another French expedition, under the command of Celeron de Blainville reasserted French claims to the Ohio River in the face of the increasing encroachment of English traders.

Britain's claims to the Ohio Valley rested on their rejection of LaSalle's boast that he had seen the Ohio River in 1669 as well as on the Batts and Fallam expedition in the seventeenth century and the penetration that English fur traders and settlers were making by the time that hostilities commenced in 1754. British traders and settlers also began to move into the Shenandoah Valley, the South Branch and Patterson Creek Valleys, the Greenbrier Valley and to the headwaters of the Monongahela River (a major tributary of the Ohio River) during the 1730s and 1740s.

English claims were further strengthened by the formation of the Ohio Company in 1747 for the express purpose of developing and settling lands in the Ohio River drainage for England. Many of Virginia's most prominent and wealthy men were partners in the Ohio Company and saw it not only as a way to acquire personal wealth through control over vast amounts of land but as a way of substantiating their own and England's claims against France.

The Ohio Company erected a trading post on the Potomac River at Will's Creek, Maryland, (now Cumberland, Maryland) before 1752, and it was to that place that the scout and compatriot of George Washington, Christopher Gist, moved his family from the Yadkin River of North Carolina in 1750. Gist's mission for the Ohio Company was to explore the lands of the Ohio River Valley, one of the first men to do so. He first traveled through what is now western Pennsylvania and into Ohio in 1750. This trip also strengthened Britain's claims to the area.

Gist was sent out again from Will's Creek in November 1752 in the company of the Delaware Indian Nemacolin and Thomas Cresap to scout out suitable lands for settlement south of the Ohio River. The objective was to define the most convenient route for a road between Will's Creek and the Monongahela River, where the Ohio Company wanted to erect one of its forts/trading houses. The trio carved out a rough wagon road from Will's Creek to the Youghiogheny River, a tributary of the Monongahela River in Pennsylvania (Buck and Buck 1967: 66). Between 1752 and 1754, this trail was expanded and was followed in 1755 by troops under the command of Major-General Edward Braddock, after whom it was called the Braddock Road. Later, it was known as the Cumberland Road. This route later became the basis for the National Road, today's U.S. Route 40. Together with the later Forbes Road (U.S. Route 30) across Pennsylvania, the Braddock Road became a primary overland route for settlers traveling to the Ohio River Valley in the late eighteenth and nineteenth centuries.

In June, 1752 Gist and three representatives of Virginia met with the Indians at Logstown, the major historic-period Indian town on the Upper Ohio River. The site of this important Indian settlement is near present-day Ambridge, Pennsylvania. In an attempt to secure better access to trade goods, the Indians at the Treaty of Logstown made two important concessions. They permitted the English to erect two forts on the Ohio River and to allow English settlement in the land south of that river.

The French were alarmed at the English and Ohio Company overtures in the Ohio river Valley, and in response they erected three fortifications in northwestern Pennsylvania in 1753 and 1754. They also sent a force down the Allegheny River to the present-day site of Pittsburgh where they removed a band of Ohio Company men who were constructing Fort Prince George at the headwaters of the Ohio River. In place of the Ohio company post, the French erected fort Duquesne.

The spring and summer of 1754 saw further military action culminating in July with the defeat of Virginian forces under a young George Washington at Fort Necessity. After this time, all of southwestern Pennsylvania/northwestern Virginia remained under the military thumb of the French and their Indian allies. An English military expedition under Major-General Edward Braddock was dispatched the following year to oust the French from control of the headwaters of the Ohio, but the column was attacked within the boundaries of the present-day town of Braddock on the Monongahela River on July 9, 1755 and suffered great losses.

Braddock's defeat encouraged the Indian allies of the French to attack all the English settlements in the western country. The entire curtain of English settlement was pushed back east, and Winchester, Virginia, at the mouth of the Shenandoah Valley again became the western outpost of English settlement in Virginia. The thinly scattered English settlements that did remain west of Winchester were poorly defended by frontier forts and ill-supplied militia. As a result, they remained in constant danger of attack.

In 1756, Virginia attempted to mount an expedition against the Shawnee Indians in Ohio under the command of Major Andrew Lewis, a prominent military, political, and social leader of colonial Virginia. The expedition, known as the Sandy Creek expedition, failed utterly and only reinforced the lessons learned earlier during Braddock's campaign about the difficulties of supplying an offensive military force in a frontier setting where roads were primitive or non-existent and where there were no towns or commercial centers to supply food, equipment, and other essentials.

Another British military expedition under General John Forbes succeeded in driving the French from Fort Duquesne in November 1758. Over the next several years, the British constructed Fort Pitt at the confluence of the Monongahela and Allegheny rivers that marks the origin of the Ohio River. After the fall of Fort Duquesne, the prosecution of the war shifted to other theaters, and after the fall of Quebec in 1759 and Montreal in 1760 the fighting ceased. A treaty however, was not signed for three additional years.

Settlers in northwestern Virginia and southwestern Pennsylvania were anxious to return to their abandoned settlements and to push even farther westward into the new lands of the Ohio River Valley. The war had sealed France's fate in North America, but the renewed encroachments of English settlers on their lands promoted continued conflict and warfare the Ohio Valley Indians. In May 1763, Fort Detroit was attacked by a force under the leadership of the Ottawa chief, Pontiac. Later in the month Shawnees and Delaware's also attacked Fort Pitt, and during the summer other British posts fell. Forts Detroit, Pitt, and Niagara remained in British hands, and British forces put down the rebellion (which has come to be known as Pontiac's Rebellion) during 1764. These events further delayed but did not halt the re-population of the western frontier. By the summer of 1763, for example, more than 50 people had already re-established themselves as far west as the Greenbrier Valley (Rice 1970; Rice and Brown 1993: 26).

The British response to the continued Indian threats to settlers was to issue the Proclamation Line of 1763. This forbade further white settlement west of the Allegheny Front, a dictate from the

offices in Whitehall that did nothing to please either individual settlers or the land speculators of such companies as the Ohio Company. Line or no line, settlers began to move back to the frontier almost as soon as the most recent fighting had stopped.

Between the formal cessation of hostilities in 1764 and the outbreak of Dunmore's War in 1774, there was a decade of relative peace if not calm during which additional Euro-American settlements in the Trans-Allegheny region were made, either illegally or legally after the negotiation of several important treaties. The Treaty of Fort Stanwix (at Rome, New York) in November 1768 as well as the Treaty of Hard Labor and the Treaty of Lochaber (October 1770) with the Indians effectively moved the dividing line between white and red lands farther west. In the Treaty of Fort Stanwix, for example, the Iroquois agreed to a dividing line set at the Ohio River. The few Shawnee and Delaware present at the treaty did not participate, however, and did not sign the treaty. The agreement only added to their resentment and set the stage for continued hostilities with white settlers (Buck and Buck 1939: 114). To the English, the agreement secured all of the land west of the Allegheny Front to the south bank of the Ohio River for settlement. Between 1764 and 1774, thousands of new settlers flocked to the area to set up farms, villages, mills, and towns.

The general conditions of peace that prevailed between 1764 and 1774 began to unravel in 1773 as it appeared to the Indians that settlers were waiting restlessly to cross over to the north side of the Ohio River. Britain had maintained troops at Fort Pitt to keep the lines of communication down the Ohio River and into the Illinois country open, but British troops were withdrawn from this seminal post in 1772 leaving no professional military force in the Upper Ohio to mediate or resolve problems with the Indians.

Several isolated incidents soon exacerbated the tensions along the western frontier in 1773, and in February 1774 Indians killed a number of whites on the Virginia border. The following April, several Indians were killed in a canoe near Wheeling and the father, brother, and sister of the Mingo chief Logan also were killed near Wheeling. Aroused by these incidents, Virginia Governor Lord Dunmore raised a force for the protection of the frontier settlers that was stationed at Wheeling. Dunmore also raised several other armies to take the war into the Indian lands on the north side of the Ohio. This move was opposed by the followers of Chief Cornstalk at the Battle of Point Pleasant, fought on October 10, 1774, where the Kanawha River joins the Ohio. Although nominally a victory for Dunmore, the Virginians lost some 46 dead. After some additional military action, a temporary treaty was concluded at Camp Charlotte by which the Indians promised not to hunt or travel south of the Ohio River. Dunmore strengthened his detachment at Fort Dunmore (as he had renamed Fort Pitt) and at other garrisons along the Ohio River (Hughes 1932: 37-42; Rice and Brown 1993: 31-36).

While Lord Dunmore pursued military adventures in Ohio and set the stage for renewed hostilities with the Indians that characterized the American Revolution in the West, most citizens in the western Virginia counties concerned themselves with building homes and small communities and laying out farms. Larger political events soon overtook these mundane concerns as relations between England and her American colonies worsened and then exploded into open war in April 1775.

Like other colonies, Virginia raised line regiments to fight in the major battles in the eastern theater of the Revolution, but the primary threat to her frontier settlements such as those on the South Branch of the Potomac and the scattered settlements arrayed southeast of the Ohio River came from the “Ohio Indians” on the north side of the river who allied themselves with the British. By the time of the Revolution, the leading edge of American settlement on the frontier

extended west of the South Branch and Patterson Creek areas into the Tygart, Cheat and Monongahela drainages. Most of the Indian raids on these outlying Virginian settlements and individual farms during the American Revolution took place in what today are the West Virginia counties bordering the Ohio River. These scattered and small settlements, established or re-established between 1763 and 1774 or 1775, served as buffers against raids on the more heavily populated South Branch and Patterson Creek Valleys.

The British presence at Fort Mackinac and Fort Detroit, however, provided ample opportunity for dissembling amongst their Indian allies against the Americans. The Indians were held firmly in the economic clutch of the British fur trade and were antagonized by years of illegal American settlement on their lands. The 1763 proclamation line that divided English from Indian claims had been routinely ignored by settlers, and British machinations to play off the western Indians against the Iroquois Confederacy contributed to the smoldering hostility among the Ohio tribes (Downes 1968: 140-151).

Throughout the American Revolution, the Ohio River continued to define an important cultural divide between American settlements to the east and south and the Indian lands on the north and west sides of the river. Many of the first settlements in the Ohio River Valley therefore were military fortifications and camps erected to protect the western door of the 13 colonies. A number of these fortifications eventually were built, often at sites that later developed into the earliest towns in the Upper and Middle Ohio River Valley. The presence of these posts and smaller "frontier forts" conveyed a measure of protection to settlements and farms that clustered near them, but almost always the posts were poorly supplied and inadequately garrisoned by militia units (e.g., Carlisle 1978). For example, in September 1775 Virginia sent John Neville of Winchester, Virginia, a veteran of Dunmore's War, and 100 militiamen to occupy Fort Pitt (Pittsburgh). Neville remained in command there until April 1777 and participated in several treaty negotiations with the Indians. Neville's—and therefore Virginia's—titular military authority also extended down the Ohio River to include command of the small frontier fortifications erected at the site of Wheeling (originally Fort Fincastle, later replaced by Fort Henry) and Point Pleasant (Fort Blair, burned by the Indians in 1775 and replaced by Fort Randolph). Neville maintained communication with the subordinate commanders of these posts, and periodic attempts were made to provision them from Pittsburgh via the river (Carlisle 1998: 12-13). Thus, even at this early time, Pittsburgh exerted a regional influence in the Upper Ohio River Valley that extended down the river at least as far as Point Pleasant and the Kanawha River.

Neville, like many other prominent military men of his day also combined land acquisition and speculation in the fertile Ohio River Valley with his military duties. As early as 1774, in fact, he had purchased some 14,000 acres of land on the Ohio frontier. Thousands of acres of this property were located a short distance above the confluence of the Great Kanawha and Ohio rivers. Although Neville's plans for this property are unknown, the large amount of land buying and selling he conducted elsewhere in the valley suggest that he hoped eventually to make a profit by selling off lots to individuals or to land companies, or by establishing one or more towns (Carlisle 1998: 8-9). Neville was in good company. Lord Dunmore had made many large grants of land in the Kanawha River Valley to other Virginia land speculators. George Washington himself eventually acquired some 35,000 acres of land in the Ohio and Kanawha valleys and even dispatched men to build houses, barns, and other structures on his Kanawha River parcel in 1775. Here he hoped to settle immigrants from Europe, but the onset of the Revolution and the resumed Indian hostility on the western frontier forced him to abandon this work (Rice and Brown 1993: 31).

Based on George Rogers Clark's successful campaigns against Vincennes and Kaskaskia, the Americans assembled several other expeditions to carry the war to the British and their Indian allies across the Ohio. The Western Department of the Continental Army, headquartered first at Fort Pitt and then at Fort McIntosh (constructed in 1778 on the north side of the Ohio at present-day Beaver, Pennsylvania), attempted but failed to sustain military expeditions against the British at Fort Detroit under General Edward Hand and, in 1778, under General Lachlan McIntosh (Carver 1975; Carlisle 1979). The inability of McIntosh's expedition, to penetrate the Ohio country presaged the failure of two later expeditions mounted by General Josiah Harmar (1790) and General Arthur St. Clair (1791). Military ineptitude, poor planning, lack of familiarity with Indian battle tactics, and, perhaps especially, poor military training and the lack of towns and settlements large enough to supply these expeditions severely hampered the American military in the Ohio River country from the French and Indian War into the Indian Wars of the 1790s. The inability of the American military to guarantee protection for settlers in turn must have retarded but did not prevent settlement in the river valley and the establishment of new communities.

Indian rights to lands north and west of the Ohio River defined at the second treaty at Fort Stanwix in 1784 were reaffirmed by treaties concluded at Fort McIntosh (1785) and at Fort Finney in January, 1786. Fort Finney was another of the military posts of the Ohio River Valley. It was first located at the junction of the Miami and Ohio rivers, but the garrison and name were moved in the summer of 1786 to the falls of the Ohio River opposite present-day Louisville, Kentucky. The legal restrictions imposed by these treaties had little effect, however, on the movement of squatters into Indian territory.

The number of whites living north of the Ohio River ca. 1785-1790 is difficult to estimate. In accordance with the Treaty of Fort McIntosh in 1785, Ensign John Armstrong was ordered by General Josiah Harmar to remove the white families who had settled there between Pittsburgh and Wheeling. Armstrong reported that 600 families already had settled on the Hocking and Muskingum rivers, and that 1,500 people then occupied the banks of the Miami and Scioto rivers (Roseboom and Weisenburger 1986: 51). Kohn (1975: 92, note) has estimated that perhaps 4,200 whites could be found in the entire Northwest Territory in 1790 at a time when the Indian population ranged from perhaps 2,000 to 2,500.

By 1786, construction of American settlements and forts had followed the twists and turns of the Ohio River as far west as the present-day border of Ohio and Indiana. Fort Harmar, for example, was established by 1785 at the mouth of the Muskingum River (Figure 3-2). The town of Marietta, Ohio—the first legitimately authorized community in the Northwest Territory—subsequently was laid out here by the Second Ohio Company in 1788. Fort Harmar joined other Ohio River fortified settlements at Fort Henry (Wheeling, West Virginia) and Fort Randolph (Point Pleasant, West Virginia). Fort Steuben, at present-day Steubenville, Ohio, was set up in August, 1786 and was soon joined by Fort Knox, built at Vincennes on the Wabash River in 1787. Another post, Fort Washington, was built at present-day Cincinnati in the autumn of 1789. The last remained the most important of the American posts on the Ohio throughout the period of the Harmar, St. Clair, and Wayne expeditions. It was to Fort Washington that General Anthony Wayne and his "Legion of the United States" marched in April 1793 after leaving their encampment at Legionville on the Upper Ohio River near the site of Logstown, the old Indian town not far below Pittsburgh (Prucha 1969: 34; Carlisle 1991). It was only after Wayne's victory at the Battle of Fallen Timbers in northwestern Ohio in 1794 and the conclusion of the Treaty of Greeneville in 1795 that the threat of Indian attacks on Upper Ohio River settlements was eliminated and the development of towns and communities in the river valley could proceed unimpeded.

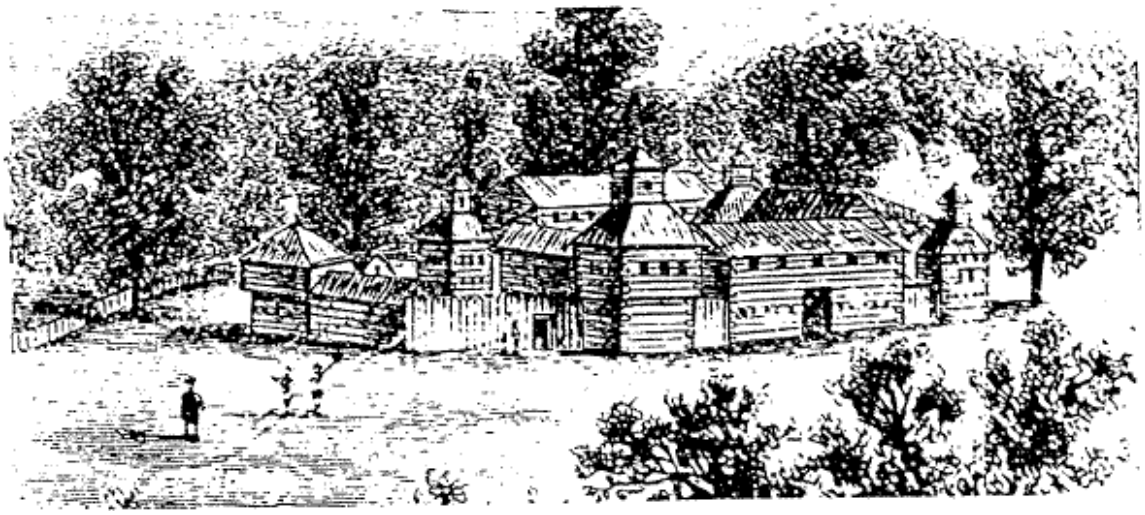

Figure 3-2: Fort Washington, constructed at the present site of Cincinnati, Ohio. From Prucha (1969: between pages 206 and 207).

Political Subdivision of the Land as a Prelude to Settlement

Throughout much of the eighteenth century both Virginia and Pennsylvania laid political claim to what today is southwestern Pennsylvania. Prior to the American Revolution, several land schemes were advanced to erect an entirely separate government in a large tract of land that included most of present West Virginia as well as part of Kentucky. "Vandalia" was the most famous of these proposed schemes. Plans called for a capital to be located at the junction of the Great Kanawha River and the Ohio River, where Point Pleasant, West Virginia is found today. The proposal foundered at the commencement of the Revolution with Indian attacks on western settlements (Hughes 1932: 36). In 1775, petitions were circulated to admit nearly this same large block of land as the fourteenth colony under the name "Westsylvania," but this attempt also failed.

At the same time, Virginia's interpretation of its colonial charter placed the colony's western boundary at the Ohio River (Figure 3-3). Only two of the Virginia counties that later became part of West Virginia existed at the start of the Revolution: Hampshire (1754) and Berkeley (1772). The rest of today's West Virginia was subsumed within Fincastle County, south of the New and Kanawha rivers, Botetourt and Augusta counties, which extended across the north-central portion of the state to the Ohio River, and the District of West Augusta, set up in 1773. In 1776, Fincastle County was divided into Kentucky, Washington, and Montgomery counties. Kentucky County subsequently developed into the state of Kentucky, fueled by a 600 percent population increase between 1783 and 1790. In November 1776, Dunmore called for a separate court to be convened at Fort Dunmore (Fort Pitt/Pittsburgh) for the District of West Augusta. This was an attempt to separate this large and poorly defined territory administratively from Augusta County and to stimulate settlement by Virginian colonists. Three Virginia counties were erected within the District of West Augusta in 1776: Ohio, Yohogania, and Monongalia. Both Yohogania and Ohio counties directly bordered the Upper Ohio River and represent the first attempts to establish

political and administrative boundaries in this portion of the Ohio River valley (Figure 3-4). In 1778, the portion of Botetourt County on the west side of the Alleghenies became Greenbrier County (Rice and Brown 1993: 47-48).

Virginia's western population grew considerably after the Revolution. In 1790, it is estimated that some 125,000 lived on the west side of the Appalachians, and about 70,000 of these had taken up residence in the fertile lands of Kentucky. The 1790 population of that portion of Virginia now included in West Virginia stood at about 55,873, but only about 20,000 of these lived west of the Appalachians. By 1800 the population, particularly in the Monongahela, Kanawha, and Upper Ohio River Valleys had grown sufficiently that eight additional counties in current West Virginia had been formed, and the General Assembly also had authorized the creation of 19 new towns. Among these were Wellsburg, on the Ohio River between Steubenville and Wheeling, and West Liberty, just east of the Ohio River and north of Wheeling. Between 1790 and 1830, western Virginia's population grew 317 percent, somewhat below the nation's average of 354 percent (Rice and Brown 1993: 47-48).

The boundary dispute between Pennsylvania and Virginia over land in what is now the southwest portion of Pennsylvania remained until after the American Revolution, even though a preliminary agreement to extend the Mason & Dixon Line (which defined the southern boundary of Pennsylvania) west was reached in 1781. The dispute was not completely resolved until the survey of the line was finished in August 1786.

Not unlike its rival colony Virginia, Pennsylvania also engaged in political development of its western lands in the Ohio country, sometimes overlapping Virginia's claims. In 1773,

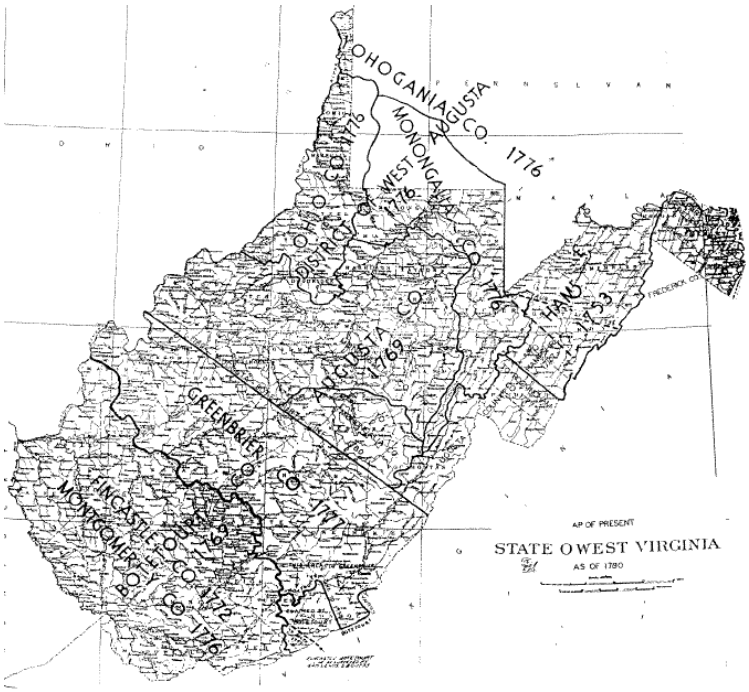

Figure 3-3: The development of Virginia counties by 1780. From Sims (1956).

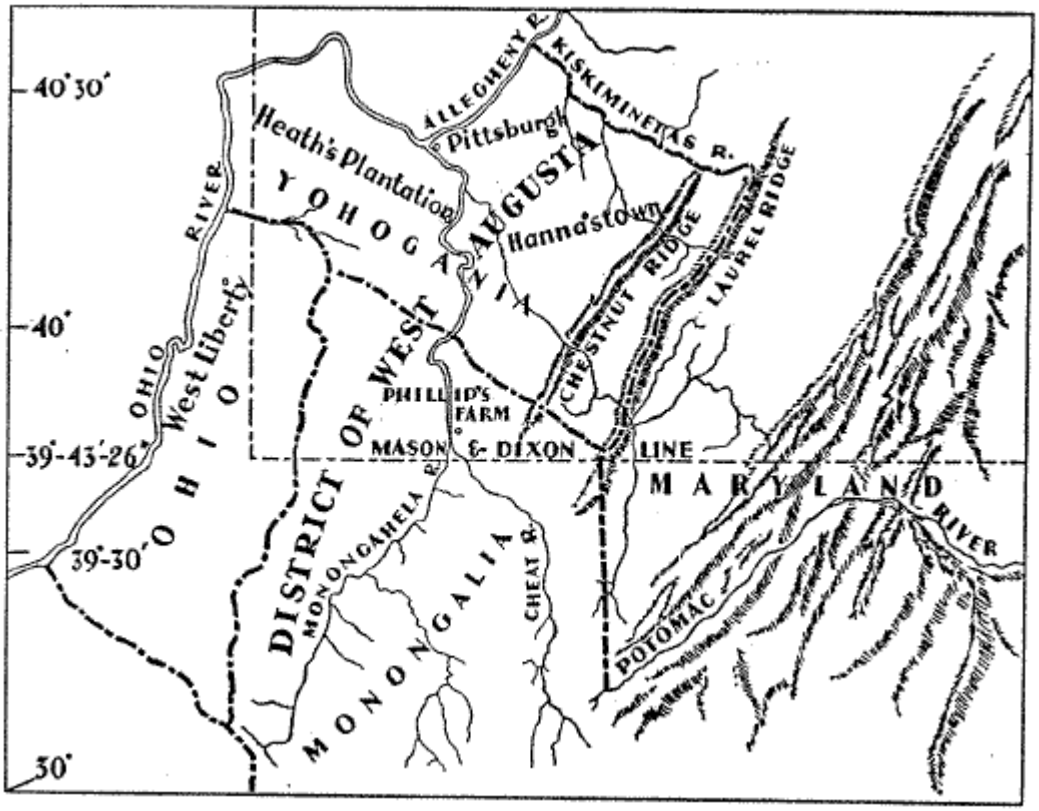

Figure 3-4: Division of the District of West Augusta in Virginia into Ohio, Yohogania, and Monongalia counties encompassing the lands of the Upper Ohio and Monongahela River drainages. From Buck and Buck (1939: 165).

Westmoreland County was set up in southwestern Pennsylvania. It became the parent county for all of the counties in this part of the Commonwealth south of the Ohio River. The formation of other Pennsylvania counties followed the conclusion of the Revolution: Washington (1781), Fayette (1783), Allegheny (including Pittsburgh at the head of the Ohio River, 1788), and Greene (1796). Beaver County, with its southern border on the Ohio River, was not formed until 1800.

Although the American army failed to subdue the hostile Indians on the north side of the Ohio River until the mid-1790s, land speculation, land claims and surveys, and political subdivision of the Ohio land bordering the river was well underway by that time. Thomas Jefferson authored the Ordinance of 1784, which, although it was never enacted, provided for the future division of the Northwest Territory into 16 to 18 prospective states. Rectangular survey of the land was specified by the Land Ordinance of 1785. Two years later, the Ordinance of 1787 established three successive stages of governance for the Northwest Territory based upon increases in population. Government in the first stage consisted of a governor, a secretary, and three judges appointed by Congress (Roseboom and Weisenburger 1986: 47, 49).

Land squatting, legislation to survey and carve up the Northwest Territory, and the lucrative potential of land speculation proved irresistible forces that all contributed to the pattern of settlement north of the Ohio (Figure 3-5). Virginia provided land grants to its veterans in the

6,570 square miles of the Virginia Military Reserve, located between the Scioto and the Great Miami rivers, for military service during the Revolution thereby guaranteeing that men with a military background would be resident in the area. Land grants here were liberal. John Neville, for example, eventually received 7,777 2/3 acres based on his rank of colonel. His son, also a Revolutionary War veteran received 7,000 acres in the Virginia Military Reserve as a lieutenant colonel. As early as November 1787 John Neville had arranged for the survey of 1,400 acres of this property, the first survey carried out in what became Washington Township of Clermont County, Ohio. John Neville died in Pittsburgh in1803 and never lived on his Ohio land. In 1808, Presley Neville laid out the small Clermont County town of Neville within his father's land on the Ohio River about 30 miles southeast of Cincinnati. Through an agent, Presley sold off town lots in Neville, which originally contained 120 quarter-acre lots. About 1816, Presley and his family moved from Pittsburgh to Neville, where Presley died in 1818 (Carlisle 1998: 39-42).

A second Ohio Company (based in New England, not Virginia) and the Scioto Company were both formed as land speculation ventures for the Northwest Territory. The Ohio Company, under Rufus Putnam and Manassah Cutler, was responsible for the establishment of Marietta at the confluence of the Ohio and Muskingam rivers in 1788. The Scioto Company, headed by William Duer (then Secretary of the Treasury Board of the United States) and Manassah Cutler arranged with Congress to purchase nearly five million acres between the Ohio Company's property and the Virginia Military Reserve. Not coincidentally, General Arthur St. Clair, then President of Congress, concurred with this land speculation plan and was, in turn supported by both companies in his bid to become the first Governor of the Northwest Territory (Roseboom and Weisenburger 1986: 52-53).

Another land speculator, John Cleaves Symmes, petitioned for and was granted the sale of a large tract of land around present-day Cincinnati as early as 1788. The Symmes Purchase fronted on the Ohio River and extended between the Big Miami and Little Miami rivers. It was largely to protect settlers in the Symmes Purchase that Fort Washington was erected at the site of present Cincinnati in 1789. This post was soon garrisoned by troops from Fort Harmer, and Governor St. Clair moved his headquarters there, proclaiming it the capital of the Northwest Territory, a move that enhanced Cincinnati's later reputation as the major city of the Middle Ohio River.

A final tract of land in the Northwest Territory (though not on the Ohio River), Connecticut's Western Reserve, was not ceded to the United States in 1786 but remained as an important and large land claim, originally set aside to compensate Connecticut citizens who had lost their property to Tory raids during the Revolution. Parts of this important chunk of northeast Ohio, which included the present site of Cleveland on the Cuyahoga River, were distributed among some 1,870 Connecticut claimants. The rest of the property was sold after 1795.

The rapid creation of new counties and towns in both the Northwest Territory and in trans-Appalachian Virginia after the Revolution was both an important reflection of population increases and settlement in those areas and a stimulus for it. Once created, the county as a legal entity helped to attract new residents by offering a place where land patents could be recorded, the services of a surveyor, and the protection of a county seat where deeds, wills, taxes, and other legal documents were settled or filed and courts where disputes were resolved. New towns therefore contested hotly for the role of county seat because they attracted both new and long-term residents from all parts of the county on a recurring basis. Lawyers and judges were also drawn to reside in and near the county seats and added to the sophistication and educational level of these frontier towns To accommodate visitors transacting legal business, the county seat also needed hotels and taverns and one or more general merchandise stores.

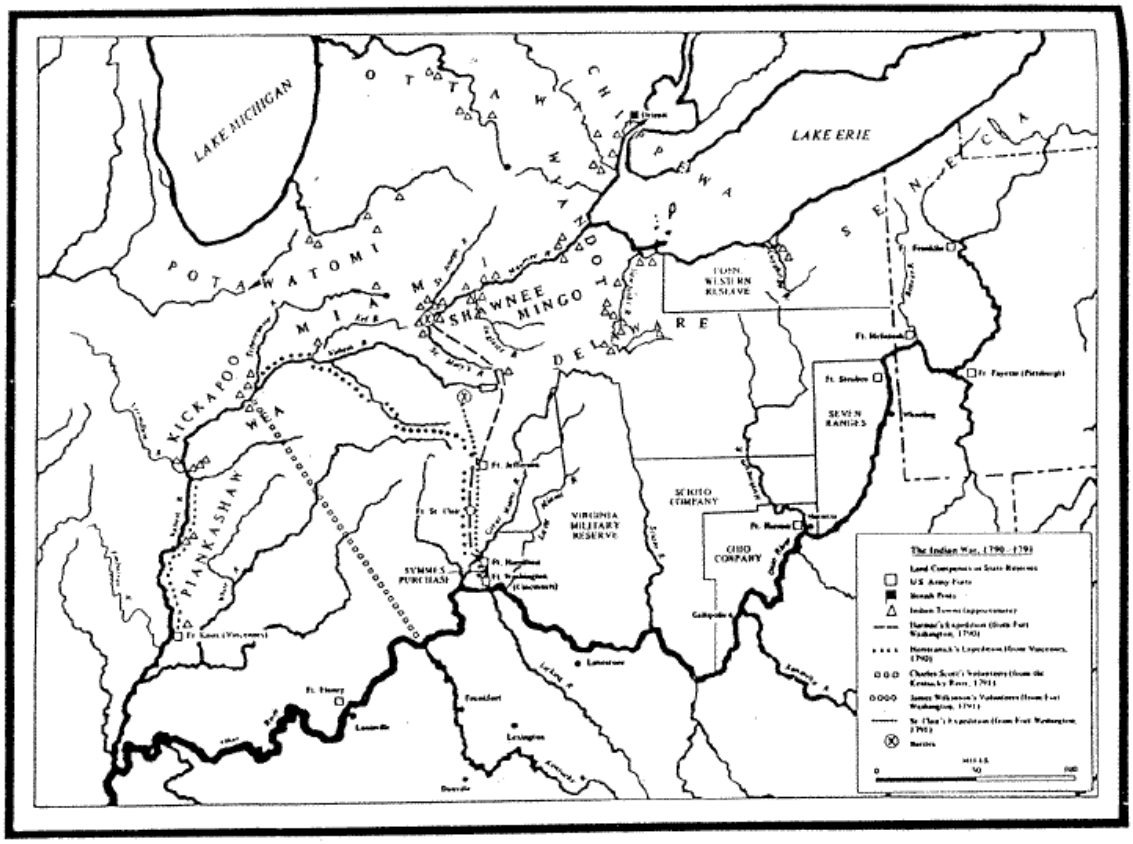

Figure 3-5: Distribution of land speculation and state reserve tracts in present-day Ohio. From Kohn (1975: 105).

URBAN ORIGINS AND THE DEVELOPMENT OF THE MAJOR TOWNS AND CITIES OF THE MIDDLE AND UPPER OHIO RIVER VALLEY

Trends in Town Formation and Development in the Middle and Upper Ohio River Valley

Permanent settlement and established urban life in the main stem of the Middle and Upper Ohio River Valley depended upon the resolution of international and local political and military conflicts. Some small towns, such as Marietta, had been planted on the banks of the Ohio in the late 1780s, and both Pittsburgh and Cincinnati had begun their long course of evolution that transformed them into the major cities. In all three cases, military fortifications at or near the new settlements were precautions against attack from Indians in northwest Ohio. The forts afforded a measure of protection for the residents of incipient towns. The need to provision and supply the troops stationed at these posts also generated some commercial and market opportunities that supported the blossoming urban and local agrarian economies. The military setbacks suffered by the Harmar and St. Clair expeditions against the "Ohio Indians" in 1790 and 1791, respectively, retarded both rural and urban settlement in the Mid- and Upper Ohio River Valley, but after Anthony Wayne's victory at Fallen Timbers in northwest Ohio (1794) and the conclusion of the Treaty of Greene Ville (1795), the Indian threat to rapid American settlement here was over.

Settlers and elected officials of early inland towns were quick to realize the commercial importance of establishing good transportation ties to larger urban centers and to the Ohio River. As early as October 1781, for example, officials of the recently laid-out settlement at Washington, Pennsylvania, the county seat of Washington County, presented petitions to build roads to streams and rivers. The 1781 petition proposed a road from "Catfish Camp" to the "Presbyterian meeting-house in the forks of Chartiers Creek", which joins the Ohio River just a few miles below Pittsburgh. Washington residents also wanted a road to the developing Ohio River commercial center at Pittsburgh, as well as a road to connect their town with Redstone Ferry (Brownsville), an important early commercial center on the Monongahela River above Pittsburgh.. Many similar road-building petitions were filed between 1781 and 1794. Looking to the west, Washington residents and merchants also established overland transportation connections to the evolving Ohio River town of Wheeling, and a mail coach was operating between the two towns by 1811.

The formation of speculative towns by individuals, such as that at Neville, Ohio, after 1808 was one of the means by which urban centers were carved out of the Old Northwest wilderness. The small, compact, and regular town lots were often easier to sell to new arrivals who had little cash, and the presence of blacksmiths, millers, and other artisans in these towns could also make the speculator's larger tracts of nearby rural property more valuable as the town provided services, amenities, and a market for the sale and redistribution of agricultural products. Agricultural and manufactured goods also could be traded up and down the Ohio River, so locating a town like Neville on the river improved access to both nearby and more distant markets and directly benefited both the town and its residents. The centrality and importance of such a town was further enhanced if a land office was located in it, or if it became the county seat. Competition among the new towns of the Northwest Territory for political prominence was therefore keen.

The Effects of Some Early Transportation Improvements on Towns and Cities

The National Road and Virginia Turnpikes to the Ohio River

The first major transportation project that benefited the population growth and economic development of both inland and Ohio River towns, especially Wheeling (West) Virginia, was the National Road. The route of this road is followed today by U.S. Route 40. The road began in Cumberland, Maryland. It proceeded west and crossed the Ohio at Wheeling, then passed through Columbus, Ohio, and Indianapolis, Indiana, before terminating at Vandalia, Illinois. The National Road is historically significant as the federal government's first attempt to improve the nation's systems of internal transportation and communication. The Pennsylvania Society for Promoting the Improvement of Roads and Inland Navigation had developed and submitted to the state legislature the first transportation plan developed in the country as early as 1791; however, few individual states then had the finances needed to build and maintain roads. Private turnpike companies attempted to plug the gap, but road building at the beginning of the nineteenth century was insufficient to accommodate the nation's rapidly increasing population.

In 1808, Secretary of the Treasury, Albert Gallatin, presented his *Report on the Subject of Public Roads and Canals* and became a strong proponent for the federal government's involvement in the construction of internal improvements. Gallatin believed that the construction of roads and canals would spur the nation's economic growth, especially in the rapidly growing Midwest. An east-west road into and through Ohio was especially desired, and Congress passed an act allowing a "2 percent fund" to be collected for that purpose.

Two years before Gallatin's report, an "Act to Regulate the Laying Out and Making a Road from Cumberland, in the State of Maryland, to the State of Ohio" was passed. The survey for the road began at Cumberland, Maryland, in early September 1806 and had progressed 131 miles to the Ohio River by the end of August 1808. The surveyors proposed that the road should be covered with stone to prevent rutting and estimated the construction costs at $6,000 per mile, excluding bridges. The roadbed was to be 66 feet in width and constructed of layers of crushed stone, sand, and earth.

Towns in southwestern Pennsylvania were quick to appreciate the potential economic advantages of steering the new road through their town, and political wrangling over the road's exact course was intense. Selection of the route between the Monongahela River west to the Ohio River was especially contentious. Two routes through Washington County, Pennsylvania, were surveyed in 1815 and 1816. One led through the county seat of Washington while the other – and initially preferred -- route led through the southern part of the county. Political forces in the town of Washington, Pennsylvania, prevailed on President Madison, however, and it was he who determined that the National Road would pass through that town. This was a major coup for the small borough of Washington and a good example of how quickly such small communities could threaten larger, more economically significant urban centers by capturing transportation routes. As built, the National Road passed through Brownsville on the Monongahela River across country to Washington, Pennsylvania, and from there westward to Wheeling and the critical juncture with the Ohio River. Merchants and political leaders in Pittsburgh were both furious and frightened that the selected route of the National Road completely cut off their town while it promoted Washington's and Wheeling's direct trade and passenger traffic with the rapidly developing commercial metropolis of Baltimore.

Navigation conditions on the Ohio River upstream from Wheeling played a significant role in Wheeling's selection as the point where the National Road crossed the Ohio River. Obstructions

in the river between Wheeling and Steubenville were notorious and created hazardous travel conditions for river craft, especially during periods of low water during the summer and autumn. As a result, by the time the route of the National Road was being finalized, Wheeling already had emerged as a dry-season "point of departure" for downstream river traffic. Providing it with a connection to the new road therefore made a great deal of sense as did the fact that Wheeling lay in a line from Brownsville, Pennsylvania (formerly, Redstone Old Fort, the road's crossing point of the Monongahela River) and the center of the state of Ohio. The road's exact crossing point at Wheeling was selected to allow travelers to traverse the river on a ferry at high water and by a "good ford" during low-water. Thus, river navigation conditions, commercial considerations, and the convenience of travelers all played important roles in Wheeling's selection as the Ohio River crossing point for the National Road (Hulbert 1901: 503-504).

Construction of the National Road was slowed by a lack of funding and by the outbreak of the War of 1812. By 1813, perhaps only 24 miles of road had been built west from Cumberland. The next 18 miles were not finished until 1817, but progress improved considerably after 1816. With the exception of the road segment from Brownsville to Washington, Pennsylvania, contracts for construction of the roadbed in that state west to Wheeling had been awarded by the spring of 1817. Colonel Eli Williams, who was in charge of road construction from Brownsville west to the Ohio River, advertised the construction contracts in mid-November 1816. The following March, Thomas McGiffin, Thomas H. Baird, and Parker Campbell of Washington were awarded the construction of the road from 2 miles east of Washington to the (West) Virginia line. In 1819, the same men were awarded the contract to construct the road eastward from Washington to a point 2 miles west of Brownsville (Peyton 1996: 133, 135).

By the summer of 1818, construction of the National Road had reached the Youghiogheny River, a tributary of the Monongahela River. McGiffin, Baird, and Campbell received another contract for road construction westward from Uniontown "to the vicinity of Washington" in May 1819. Road construction had a rapid influence on the development of passenger transportation services and quickly improved the speed and occurrence of inter-city communications and travel. In August 1819, for example, a thrice-weekly stage line began operations between Washington, Pennsylvania, and Pittsburgh. From Pittsburgh, a traveler could continue by stage to either Washington, D. C. or to Baltimore, a trip that required about four days. By the fall of 1820, the National Road was complete along its length to Wheeling even though it remained unpaved from a point 5 miles east of Washington, Pennsylvania, to Wheeling until 1835. In 1821, a stage journey from the inland town of Washington, Pennsylvania, to Wheeling on the Ohio River required 11 hours. By 1837, one Washington-based stage line was running two daily departures between Wheeling and Baltimore that passed through Washington, and stage service connecting Wheeling and Philadelphia also was in operation (Forrest 1926: 842).

Travel on the National Road was at first free of charge, and large herds of cattle, sheep, and horses, plus stagecoaches, travelers on horseback, settlers moving west in Conestoga wagons, and freight wagons often clogged the route. This traffic prompted construction of numerous hotels and taverns in towns and at intervals along the road.

Construction of the road, originally heralded as a national triumph, was not matched by a continuing federal commitment to its maintenance. The often poor condition of the road only enhanced the attractiveness of river travel. Writer Charles Fenno Hoffman, commenting on the condition of the road between Washington and Wheeling recorded that "the ruts are worn so broad and deep by heavy travel, that an army of pygmies might march into the bosom of the country under the cover they would afford" (quoted in Peyton 1996: 149).

Federal allocations for road repairs between 1823 and 1827 averaged just $88 per mile. Finally, in 1829, a $100,000 appropriation was obtained for repairs to the road east of Wheeling, and between 1829 and 1835, over $1,000,000 was allocated for repairs from the Ohio River eastward (Peyton 1996: 150). As each section was repaired, jurisdiction was turned over to the states. Toll houses were then erected, and the road was operated as a turnpike. The toll gates on the road in Washington were erected in 1835. The imposition of tolls actually helped to clear the road of the earlier large flocks of live animals that were driven along it. Very large freight wagons, some with wheel rims 9 inches in width and drawn by six to eight draft horses, now appeared. Such wagons could carry five to six tons of merchandise. In the fortunate towns through which the National Road passed, it was not unusual to see these wagons filling the streets from one end of town to the other. Such wagons carried previously hard-to-get manufactured goods for sale in the general merchandise stores of towns. The road also provided access to new, more distant markets where agricultural produce from farms outside the towns was sold. Hotels and taverns in National Road towns also grew in number to feed and house the itinerant wagon drivers and stage-coach travelers.

Completion of the National Road west to the Ohio River also facilitated the delivery of the mail. This was an important consideration for the thousands of new migrants to the West and for western businessmen who sought to establish or improve their trade and other business connections with major eastern population centers. Mail service between Wheeling and Washington D.C. was initiated in 1818, even before the road itself was completed. In 1837, mail delivery from Wheeling through Washington to Uniontown in Fayette County, Pennsylvania, took just 6.5 hours, the fastest overland mail route operating anywhere in the country. This service was replaced by the “Monkey Box Line” in 1838, a series of mail coaches that also carried passengers.

Continuing problems with expensive repairs and a lack of commitment from the federal and state governments to maintain it meant that the National Road was never a paying proposition. By the 1850s, railroads, and later the development of interurban rail lines had largely usurped the road’s purpose and provided better transportation for freight and passengers alike. Although the National Road continued to provide important local transportation connections and was eventually integrated into the nation’s interstate highway system as U.S. Route 40, its period of true national prominence came and went in a remarkably short time between approximately 1818 and 1860.

In addition to the National Road, a number of other east-west turnpikes were constructed in the nineteenth century that connected the more settled towns of the East to the western frontier. Such roads were rare at first, but Virginia built three state and privately funded turnpikes that connected eastern Virginian towns with towns on the Ohio River (Figure 3-6). From north to south, there was the Northwestern Turnpike (today’s U.S. Route 50) between Winchester, Virginia, and Parkersburg on the Ohio. Parkersburg was also the river terminus for the Staunton-Parkersburg Turnpike from Staunton, Virginia, located at the head of the Shenandoah Valley. Similarly, Lynchburg, Virginia, was the eastern terminus for the James River and Kanawha Turnpike (today’s U.S. Route 60) that ran through Charleston, West Virginia, to Huntington on the Ohio River.

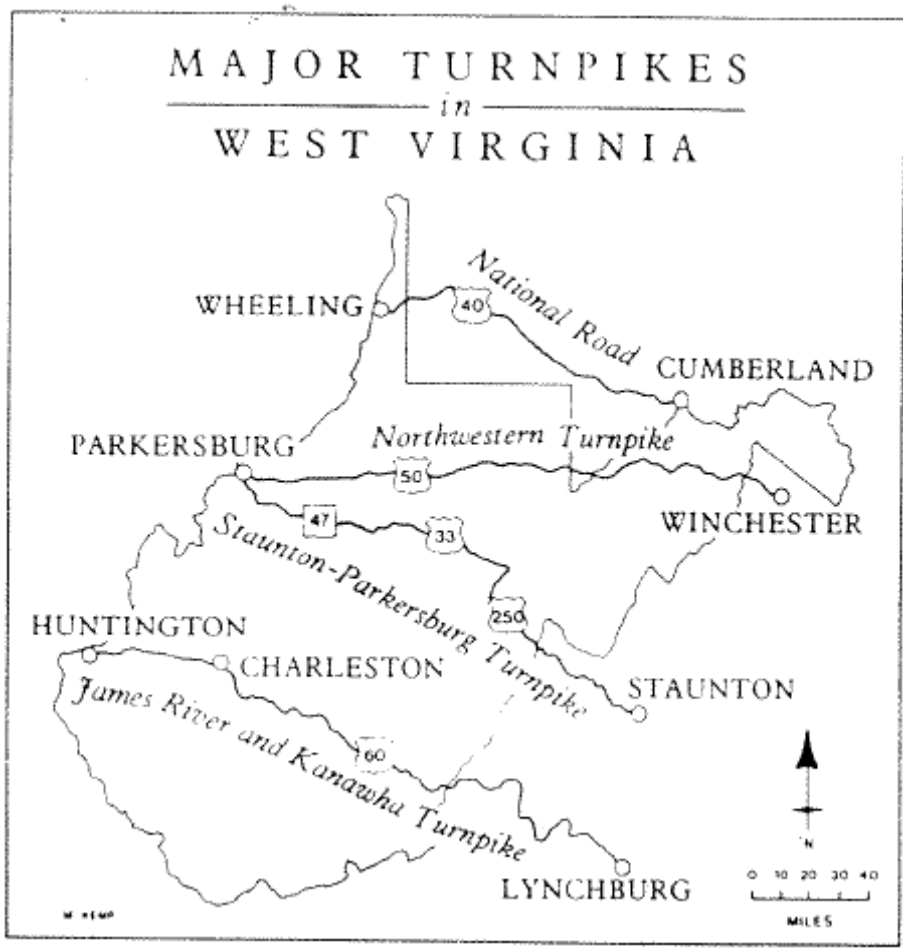

Figure 3-6: Construction of new roads in the nineteenth century linked older, more established eastern towns with newer towns on the Ohio River and improved the freight and passenger trade of both in the days before canals and railroads. From Cohen (1992: 6).

Canals

The construction of a system of canals as a stimulus to population growth and economic development in the trans-Appalachian interior was proposed in the late eighteenth century, but the dreams of George Washington and like-minded men to connect the nation's interior river valleys required the passage of several additional generations to achieve fruition. The great era of American canal construction between roughly 1825 and 1850 was frenetic but remarkably short-lived. It contributed significantly, however, to the explosive growth of the American economy between 1800 and 1860. The focus of American business during this period shifted from overseas trade to internal markets, principally on the rapidly expanding western frontier. This period witnessed multiple revolutions in agriculture, technology, transportation, energy production and consumption, industrial capitalism and production (the "Industrial Revolution"),

and a modern system of capital investments, to say nothing of the great increase in the nation's population achieved by immigration and by natural increase. The population of the country increased from about 2.5 million in 1776 to 8.5 million by 1815, and to 31 million in 1860 (Blackford and Kerr 1990: 81). In the first half of the nineteenth century, both state and federal governments also began to participate with private companies and individual investors in the creation of business opportunities and large-scale projects that were perceived as benefiting the nation as a whole and as safeguards to republicanism (Shaw 1990: 18). The canal-building era focused as never before the debate over public and private roles in the promotion of internal improvements (Carlisle 1994: 5).

The American era of canal construction began with the opening of the Erie Canal connecting Lake Erie with New York on October 26, 1825. Even before the canal had been completed, thousands of barrels of flour, grain, millions of board feet of lumber, and thousands of gallons of whiskey began flowing to New York City from the agrarian hinterlands of the state. This revolution in transportation promoted the construction of new gristmills, saw mills, and distilleries in towns along the canal route and increased the business opportunities for commercial agriculture (Blackford and Kerr 1990: 86).

The initial success that the Erie Canal enjoyed served as both an incentive and a warning to businessmen and politicians in neighboring states. Pennsylvania business interests, especially those in Pittsburgh, feared the loss of their Ohio River trade to the Erie Canal, especially when Ohio initiated two canal-building projects in the 1820s to join Lake Erie to the Ohio River at the Ohio town of Portsmouth via the Ohio & Erie Canal. In response, Pennsylvania soon entered the canal-building fray by constructing an east-west canal in three segments across much of the state. The Pennsylvania Mainline Canal, built between 1825 and 1830, required some ingenious technology. On the east, the canal terminated some 20 miles outside Philadelphia, where an early railroad connection continued into the city. The mountainous section in the center of the state between Hollidaysburg and Johnstown was crossed by winching the canal boats up the mountain side on flat cars, then lowering them down the other side to resume their canal trip.

When the canal was completed to Pittsburgh (with a separate terminus in Allegheny City, the present North Side neighborhood of Pittsburgh, but a separate municipality before 1907), Pittsburgh business interests breathed a sigh of relief. The new canal permitted more effective and economical commerce between Philadelphia and Pittsburgh but also, via a short passage on the Ohio River, allowed the Pennsylvania and Ohio Canal systems to operate in greater harmony with each other. Instead of simply diverting the New York trade from Pittsburgh to Ohio, completion of the Pennsylvania Canal system and the Pennsylvania and Ohio Canal (also called the Mahoning or "Cross Cut" Canal) through the Mahoning River Valley opened up Ohio markets to greater penetration by Pennsylvania, especially Pittsburgh, products. The production and transportation of cheese and other dairy products, wool, and agricultural produce in the valley were stimulated, and these products were soon being shipped by canal to Pittsburgh, Cleveland, and New York, and down the Ohio River to Cincinnati. Large amounts of Pittsburgh ironwares—for which Pittsburgh already had become a major center--also were transported to Ohio via canal, some 4 million pounds in 1840 and 12 million pounds by 1845. This canal also played a significant role in the industrial development of the Mahoning Valley, especially Youngstown, Ohio. It linked Youngstown with the important Brier Hill coal mines, which in 1840 were producing about 700,000 bushels of coal per year. Due to the increasing demand for coal by the growing town of Cleveland, Ohio, on Lake Erie and to the transportation possibilities afforded by the Pennsylvania and Ohio Canal, output at the Brier Hill mines increased to about 2 million bushels annually by 1848 (Scheiber 1969: 215-216; Carlisle and Dalesandry 1988: 2.15-

2.16; Carlisle et al. 1994: 33). By 1830, more than 3,000 miles of canals crisscrossed the United States (Blackford and Kerr 1990: 86).

The widespread construction of canals from the 1820s into the 1850s had significant consequences for urban life. As canals were constructed, prices for imported and native manufactured goods declined and became more affordable to a greater proportion of town residents. Canal warehouse and dock areas became busy loci of urban commercial life. Furthermore, extracted mineral wealth such as coal and iron ore could be shipped or trans-shipped more economically to the rapidly growing population of urban consumers and to a growing number of businesses (Carlisle 1994: 6). At first, canals were not necessarily the cheapest form of transportation (though rates on the canals generally were better than overland rates), but canal transportation often was faster. For example, in 1833 New York goods could be shipped to Nashville, Tennessee, more cheaply by coastal sailing from New York to New Orleans and then by transporting the goods up the Mississippi, Ohio, and Cumberland river on steamboats. The same goods, however, arrived more quickly by sending them on the Erie Canal, across Lake Erie to the Ohio & Erie Canal at Cleveland, Ohio, down that canal to the Ohio River at Portsmouth, then down the Ohio River and up the Cumberland. After 1833, the canal route became even more desirable as rates fell further in comparison to the earlier coastal route. In 1852, businessmen in Cincinnati found it more economical to ship tobacco to New York markets via the Ohio River, the Ohio & Erie Canal, Lake Erie, and Erie Canal route than to send it down the Ohio and Mississippi rivers to New Orleans and up the coast by ship. The tobacco also arrived at its destination in much better condition (Blackford and Kerr 1990: 86).

Railroads

As great an improvement over land transportation as canals proved to be, they were still hampered by ice in winter and by periods of low water in the summer and autumn months. Upkeep on the canal prisms, towpaths, conduits, bridges, and other features was expensive and never-ending. The railroad, in contrast was, for the most part, unhampered by winter weather, was mechanically reliable, faster, and new lines could be laid down relatively quickly to connect any two points. Railroads were developed in England during the early 1800s, and the first American Railroad, the Baltimore & Ohio, was chartered in 1828 to connect, as the name reflects, the growing Maryland metropolis with the Ohio River and the growing markets of the American West. Almost from the beginning of the canal era, then, a new and better form of transportation was on the march and would soon make most of the canals obsolete.

The use of rail to connect a city with a major interior waterway was typical of the early railroad period in this country and acknowledged the importance of the rivers as the dominant avenues of travel and trade. Soon, however, railroad tracks were being laid between inland towns away from the major rivers. At even greater fever pitch than it had been with canals the generation before, boosters in every town now competed with those in every other town for the railroad's patronage and the feeling of importance and "centraility" that being on the rail line conveyed.

The effects of the construction of the first railroad lines were felt far beyond the physical limits of their rails. For example, the Baltimore & Ohio Railroad line was extended to Cumberland, Maryland, from Baltimore in 1844. From that time until the arrival of the railroads in western Pennsylvania in 1852, it was not unusual for perhaps 25 stagecoaches a day, each with nine or more passengers, to leave Wheeling and to pass through Washington, Pennsylvania, en route to Cumberland. Similarly, a like number of passengers would leave Cumberland for Wheeling, traveling through Washington on the National Road.

In addition to the railroads, early river navigation improvements also played an important role in facilitating travel and commerce and had a profound effect on the relative economic fortunes of urban centers. Pittsburgh's boosters and merchants had been deeply worried by the construction of the National Road well south of their town and by the competitive advantage that choice had given to Brownsville and to Wheeling. When the Monongahela Navigation Company completed its slackwater improvements on the Monongahela River as far upstream as Brownsville in the 1850s, however, National Road travelers could leave their stages at that town and travel to Pittsburgh by steamboat. Rail connections at Pittsburgh were available after 1852 and provided additional travel and shipping options for National Road patrons.

The implementation of private navigation improvement measures on the Monongahela River during the 1840s and 1850s and the arrival of the railroad in Pittsburgh in 1852 therefore had a detrimental effect on the National Road traffic west of Brownsville. Long before any major navigation measures were built on the Ohio River itself, much of the mid-nineteenth-century National Road traffic now found it advantageous to complete the Wheeling to Brownsville portion of their trip by water, moving up the Ohio to Pittsburgh and then through the four locks and dams completed on the Monongahela River in 1844 (Gannett Fleming Corddry, and Carpenter, Inc. 1980: 3-4). In 1850, for example, although National Road stages still carried more than 18,000 passengers directly between Wheeling and Brownsville each year, the numbers had been larger in each of the three preceding years. Construction of the first navigation improvements on the lower Monongahela River aided Pittsburgh merchants by allowing them to secure a greater portion of the road's trade.

The railroads were quick to extend their lines into the Middle Ohio River Valley. The early rail lines in Ohio during the 1840s generally ran north to south, connecting the established Great Lakes (and Erie Canal) trade corridor with the older port cities on the Ohio River (Muller 1972: 336, 339). These early railroad lines effectively served the role of connectors to the dominant lake and river transportation system.

This pattern started to change in the early 1850s. Rail lines were extended rapidly to newer interior towns. This trend had a differential effect on the economy and success of towns. In some cases, the rail lines improved the standing of new towns while reinforcing the status of more established towns. In other cases, the lack of a rail line could place even an established town at a serious competitive disadvantage. In 1851, for example, the Columbus and Xenia Railroad connected the river port city of Cincinnati with the interior state capitol at Columbus (located on the National Road). Rail connections could be made at Columbus to reach Cleveland. Cincinnati's established prominence as a river port town was thereby quickly increased by gaining rail access to Lake Erie ports and to the state capitol. By the mid-1850s, Cincinnati had established additional rail connections eastward to Cleveland, Pittsburgh, and Wheeling, and rails also connected the growing city to Lawrenceburg, Madison, Indianapolis, and other western terminals (Muller 1972: 339).

The great period of rail expansion in the Middle Ohio River Valley came between 1850 and 1855 (Figure 3-7). In fact, if anything, the system was overbuilt during this period and established much of the rail pattern seen to the present day. There were 242 miles of rail lines in operation there in 1850. By 1855, more than 12 companies completed an additional 1005 miles of tracks. This represented fully 94 percent of the 1,327 miles of railroad that existed in 1860. Only 80 miles of track were laid down between 1856 and 1860.

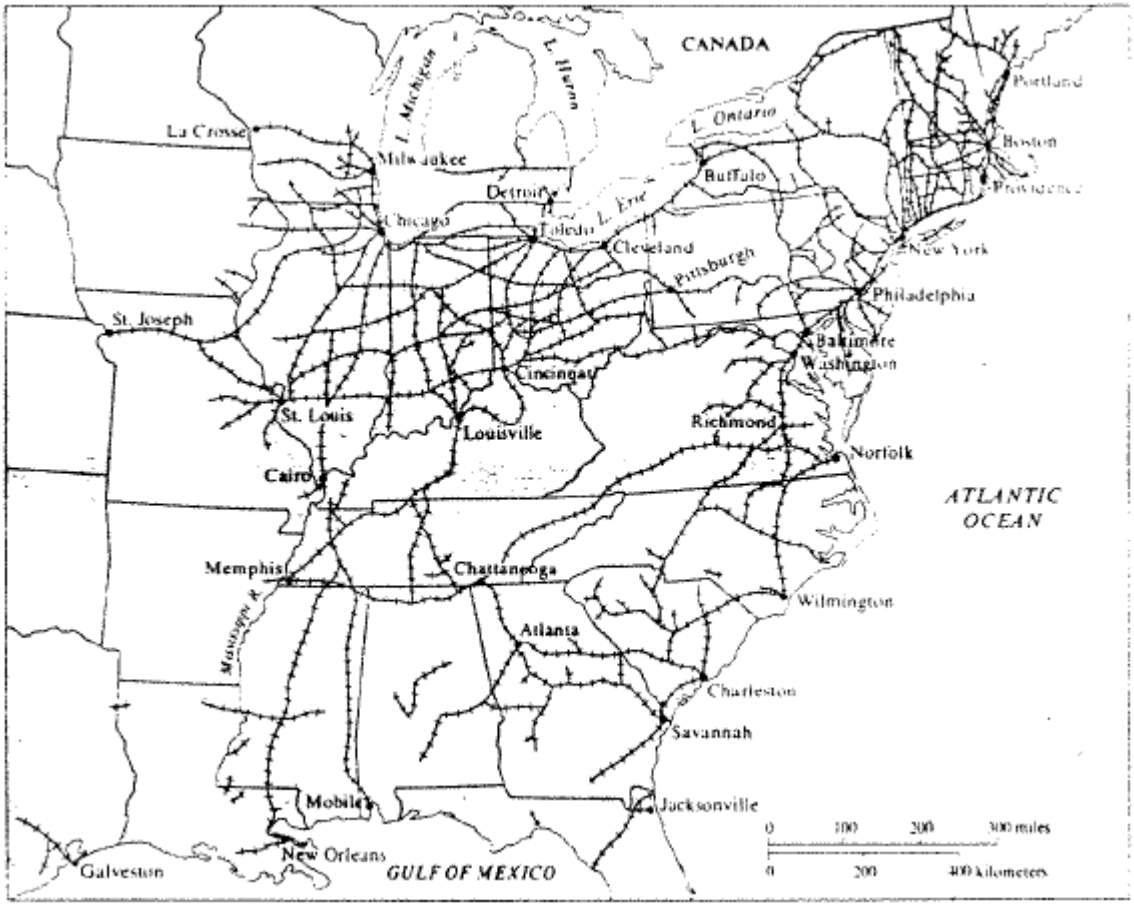

Figure 3-7: The distribution of major railroad lines in the United States in 1860. From Blackford and Kerr (1990: 89).

The rapid expansion of the rail lines in the Middle Ohio River Valley, together with the national economic downturn in the middle 1850s increased competition, caused a sharp drop in freight rates, and reduced the earnings of most rail companies. The drop in rates increased the attractiveness of rail over water transport. The capacity of the railroads to operate year-round also helped to attract a growing trade that traditionally had moved only on the Ohio River. This was especially important during several years in the 1850s when river water levels (either too high or too low) interrupted water-borne commerce. As a result of these and other factors, rail lines increasingly came to dominate the transportation of Upper and Middle Ohio Valley agricultural produce to national markets and the movement in merchandise and manufactured goods moving the other way (Muller 1972: 343). This was a more gradual process than the rapid construction of the railroads in the 1850s might suggest. Steamboat construction in Cincinnati, for example, declined only slightly during the 1850s, and the cheaper cost of water transportation combined with the opening of other markets farther west where the railroad had yet to penetrate meant that the long-term effects of the railroads on river commerce took a while to be fully realized (Muller 1972: 346).

The lack of much additional rail expansion in Ohio by 1860 also meant that cities were largely "stuck" with the network that had evolved quickly during the 1850s. This benefited some Ohio

River cities. Marietta and Belleaire, for example, had three rail connections with the Baltimore & Ohio Railroad on the Ohio River. Wheeling and Parkersburg also enjoyed connections with the B&O. A good deal of the agricultural produce of Ohio now moved east on these lines rather then down the Ohio River to traditional southern markets (Muller 1972: 345-346). Cincinnati, too, was well supplied with rail lines though it now had to compete with inland towns for its share of trade (Muller 1972: 349). However, there was a long stretch of Ohio River between Cincinnati and Portsmouth where there were no rail connections on the eve of the Civil War (see Muller 1972: 341-342). Smaller towns in this stretch had little chance to grow beyond dependence on local commerce and whatever could be brought in or shipped out in the slowly diminishing river trade. Overall, the effect of the railroads on Ohio River towns was beneficial if the town was selected as a railroad through-way or terminal. Even so, the railroads gave increased economic importance to newer inland towns located well away from the river and re-directed the movement of trade. River towns were no longer the only "players" on the urban scene.

Overview of the Development of Major Urban Centers in the Middle and Upper Ohio River Valley

Pittsburgh

Like many other Ohio River towns, Pittsburgh had both a commercial and military component to its origins. The Ohio Company of Virginia began construction of a fortified headquarters at the confluence of the Monongahela and Allegheny rivers in 1754. The purpose was to establish a beachhead in the headwaters of the Ohio River to serve the company's commercial interests in the Ohio River Valley and to provide for its defense. The French and Indian War witnessed the temporary expulsion of the English and Virginians from the area and the construction of Fort Duquesne. Over the next several years after the defeat of the French and Indians in 1758, the English constructed Fort Pitt on the burned-out remains of this earlier fort. Fort Pitt (renamed Fort Dunmore for a time in 1774) remained the most important fortification in the Upper Ohio River Valley throughout the American Revolution. Its military significance declined after the Revolution with the westward movement of the American frontier and the construction of other forts farther down the Ohio River.

Travelers, passengers, and freight were moving actively on the Upper Ohio River long before the improvement of navigation on the river became a reality. In 1787, for example, 120 flatboats passed Pittsburgh on their way down the Ohio, and on one day alone in 1796, 70 flatboats arrived in Pittsburgh from points downstream **(**Kussart 1937: 16). The trade on the Monongahela River upstream from Pittsburgh also developed in the late eighteenth and nineteenth centuries, and a number of important towns sprang up on that river. One of these, Brownsville, began as another early supply depot for the Ohio Company. Selected in 1818 as the point where the new National Road would cross the Monongahela, Brownsville posed a challenge to Pittsburgh for a time as the center of emerging industry and commerce in the region (see Baldwin 1933, 1938; Carlisle 2000a, 2000b).

In 1803, Pittsburgh business was dominated by iron working and textile production followed by boat-building. Iron products and textiles produced in the town were often marketed via the area's rivers (Reiser 1951: 13, 14). Shortly, glass making became another major industry in early Pittsburgh. The town's first glass factory began as early as 1798. Glasswares also were often marketed by flatboat, keelboat, and later by steamboat to other river towns.

The Monongahela River towns of Brownsville, Elizabeth, and West Elizabeth together with Pittsburgh became the heart of the steamboat-building industry in the Upper Ohio River Valley in

the nineteenth century. In the 1830s some 20,000 people and 4,000 freight wagons annually arrived at Brownsville from the East where they transferred to river craft for the trip downstream to Pittsburgh and beyond. As these and other upstream Monongahela River communities continued to grow during the nineteenth century in population and in the number and diversity of their manufactures and agricultural produce, their residents became avid supporters of river navigation improvements that would enable them to get their products to the evolving downstream population center at Pittsburgh and farther down the Ohio and Mississippi rivers.

The completion of the Pennsylvania Canal to Pittsburgh in November 1829 (with through connections available to Philadelphia by 1834) greatly increased the economic prospects of its merchants and early industrialists. It also increased Pittsburgh's significance as a trans-shipment point for Monongahela River Valley farmers and early industrial producers. Pittsburgh also now could receive many new products from eastern and central Pennsylvania. Iron produced at the furnaces in the central part of the state could be shipped more cost-effectively to Pittsburgh's industrial workshops.

The Pittsburgh wharf master drew up a document in 1840 as a type of survey of potential river traffic that might pass through the locks and dams then being proposed by the Monongahela River Navigation Company. The document showed that in 1839, 686 keelboats loaded with produce and 1,084 flatboats loaded variously with iron, coal, and bricks had used the Monongahela wharf at Pittsburgh. This enumeration did not include the steamboats that were using the river in increasingly large numbers. (Kussart 1937: 15).

In 1841, the Pittsburgh-based Monongahela Navigation Company opened the first of a series of locks and dams on the Monongahela River that greatly facilitated commerce on that river as well as increased trade to towns down the Ohio River. Between 1841 and 1856, the Monongahela River had been slackwatered as far upstream as the towns of Greensboro and New Geneva, both of which soon thereafter developed important stoneware pottery businesses that marketed their wares by river in Pittsburgh and as far south as New Orleans. Soon thereafter, Pittsburgh also became a transportation nexus for rail lines, the Pennsylvania Railroad being only the first to arrive in 1852.

Coal was among the earliest commodities shipped on the Monongahela River, and the coal trade came to dominate the river's commercial traffic, especially from the 1880s through World War I. The Street's Run Creek area along that river was being mined intensively by 1828 to meet Pittsburgh's own demands. The town's population stood at about 30,000 people in 1833 and required some 140,000 tons of coal annually for domestic consumption and perhaps 40,000 additional tons for stores and public buildings. Its 90 steam engines consumed approximately 90,000 tons of coal annually (Binder 1974: 22, 43). Through-shipments of coal down the Ohio River also were important to Pittsburgh's economy even before navigation improvements were introduced on the Monongahela River beginning in 1841. Southwestern Pennsylvania sent bituminous coal to the East Coast via river shipments to New Orleans and then by sailing ship up the coast as early as 1803. Cincinnati, Louisville, Mayville (Kentucky), St. Louis, and New Orleans all were early recipients of bituminous coal from western Pennsylvania, regular shipments of which began about 1817 (DiCiccio 1996: 17). About 5,000 southwestern Pennsylvania men were engaged in bituminous coal mining by 1860 (DiCiccio 1996: 31).

Between 1860 and 1900, the population of Allegheny County, Pennsylvania, which includes Pittsburgh, increased from 179,000 to 775,000 (Couvares 1984: 32, Table 3; 81, Table 4). A large percentage of this growth took place in the city, but the populations of adjacent Monongahela River Valley industrial towns also increased greatly during this period due to the

construction of huge steel plants in Braddock, Duquesne, McKeesport, Monongahela City, Monessen, and other river towns. The Monongahela and its excellent system of locks and dams, the availability of rail connections, and an increasing supply of immigrant urban labor all contributed significantly to the selection of these towns as sites for new plants. The railroads, the rivers, and later in the century, industrial boat fleets on the Great Lakes connected the steel making process together and allowed all of the essential materials to come together at one place. These transportation venues then allowed the finished products to be shipped out at competitive prices.

Between 1841 and 1904, the Monongahela Navigation Company and, after 1897, the U.S. Army Corps of Engineers extended the Monongahela River navigation improvements upriver through the heart of the river valley's rich coal fields to the vicinity of Fairmont, West Virginia. The Monongahela River Valley was transformed by industrial growth along its banks and by access to cheap river transportation into one of the most important and productive industrial river valleys in the world. By 1935, more tonnage was being shipped on Monongahela River than through the Panama Canal, and in 1937, the Monongahela was carrying slightly more tonnage annually than the Ohio River. The great majority of this freight consisted of coal.

Iron and steel started to be shipped on the Monongahela River in World War I as an auxiliary to the rail lines. Increased rail freight rates after the war and a shortage of rail cars led several mills to look to the rivers as a less expensive mode of transportation for some steel products to distant customers. They also began to ship scrap, pig iron, and molds from blast furnace to the mills by river (Tomer 1939: 47).

In 1922, the Carnegie River Service expanded its services and began to tow finished steel products down the Ohio and Mississippi River systems as far as New Orleans and opened its major river terminal near Pittsburgh's major steel plants in 1924. Following the U.S. Army Corps of Engineers' completion of the 9-foot canalization of the Ohio River in 1929, it was possible to ship finished steel products from Pittsburgh down the Ohio and Mississippi to the Carnegie-Illinois Steel Company's warehouse in Texas via the Intercoastal Canal (Tomer 1939: 49). Under a series of ownerships, this river transportation service continued throughout the critical days of World War II ceasing operation in 1985 in the face of the widespread collapse of Pittsburgh's heavy industry (Kudlik 1998: 90-91; Carlisle 2000a, 2000b).

Beaver, East Liverpool, Weirton, Steubenville, and Wheeling

The small town of Beaver, Pennsylvania, is located high on a bluff overlooking the confluence of the Beaver River to the east of the town and the Ohio River on the south. In the eighteenth century, this was about one day's river trip below the Forks of the Ohio. The area was a favored location for settlement well before the permanent arrival of white settlers and the laying out of the town. At least two earlier Indian towns are thought to have been located in this stretch of the Ohio River. The first was located at the present site of Rochester Borough (est. 1849) on the Ohio and the east side of the Beaver River. The names "Logan's Town", "Sawcunk", and "King Beaver's Town" may all refer to the same or successive Indian towns at that location. The Delaware may have been living here by 1725. Conrad Weiser reported visiting the town, which he described as being eight miles below Logstown, in 1748. The second Indian town in the area, "Shingas' Old Town", is thought to have been three-quarters to one mile downstream from the confluence of the Beaver and Ohio rivers. The site was probably settled first by the Shawnee in the 1730s. The French are believed to have constructed some 38 log houses for the Indians at this town, and it became an important early trading center. George Croghan established one of his

trading posts here in 1748. The Indians apparently abandoned the town after the English took the Forks of the Ohio in 1758 (Richardson and Carlisle 1977: 108-109).

Fort McIntosh was built within the present limits of the town of Beaver in 1778. The post was used as a staging ground for an abortive American campaign against British-held Fort Detroit during the Revolution. For a time, it replaced Fort Pitt as the headquarters of the Continental Army's Western Department. An overland road from Pittsburgh led to Fort McIntosh, but troops and supplies often shuttled to and from the post on the Ohio River. The fort was maintained until 1788, when it was torn down and its function replaced with a blockhouse on the Beaver River (Carlisle 1979). Its major importance in the post-Revolutionary period was as the site of the Treaty of Fort McIntosh in 1785.

The town of Beaver is a pleasant and comfortable residential community with a small main street commercial district. Its selection as the county seat of Beaver County (formed in 1800) steered most of the county's law and court activity to the town.

East Liverpool, Ohio, just about mid-way between Pittsburgh and Wheeling on the Ohio River, lies near the center of the Upper Ohio River Valley's historic manufacturing district. Pittsburgh soldier and businessman Isaac Craig purchased the first land that later included the town site of East Liverpool from the federal government in 1797. Craig subsequently sold part of this tract to Thomas Fawcett, an Irishman who then lived on Chartiers Creek south of Pittsburgh. Fawcett's plot, which he called St. Clair Town (but which other early inhabitants usually called Fawcettstown) marked the first settlement at the site of East Liverpool in 1802 (Gates 1984: 5, 8, 10). The town became part of the new state of Ohio, formed in 1803.

Despite a seemingly advantageous initial location on the Ohio River, the town grew slowly at first. It contained only five or six houses in 1807. Between 1802 and 1816, Fawcett managed to sell only 16 of the 117 lots in his town plan even though another of the Fawcetts had erected a tavern and gristmill, and the town had attracted a post office before 1810. Early East Liverpool developed few roads leading inland from the river to connect the fledgling settlement with its agrarian hinterland. It seems likely that early East Liverpool's relatively slow growth also may have been due to a lack of entrepreneurship on Fawcett's part and competition from nearby areas and other early towns on Little Beaver and Little Yellow creeks, both of which were better situated to support water-powered mills. In contrast to East Liverpool the community of Georgetown, on the Ohio River opposite the mouth of Little Yellow Creek, for example, had three mercantile stores, 30 houses, and a post office by 1807 and was recognized as an important stopover for river travelers. East Liverpool also received competition from the town of West Union (Calcutta), established three miles to the north and Wellsville, set up in 1823. In contrast to Fawcett, Wellsville's founder, William Wells, was an aggressive promoter and actively sought the construction of new roads to his town. Consequently, Wellsville rather than East Liverpool attracted new stage and mail routes and became a transfer point for steamboats headed to and from Pittsburgh in the late 1820s (Gates 1984: 10-15). In such ways could one town gain ascendancy over its competitors.

A name change from Fawcettstown to Liverpool in 1816 marked the transfer of ownership of unsold lots in the town from Thomas Fawcett to a consortium of buyers that included his son, John. The new owners promoted the town more actively, sold lots at public auction, built a warehouse near the Ohio, a school, and increased the width of the town's streets from 50 to 60 feet. The group sold the remaining lots in the town to Claiborne Simms in 1825. In only seven years, Simms had sold off 101 lots in the town and had added an addition. The town was incorporated as East Liverpool in 1834.

The town's growth in the 1830s was tied directly to the development of roads connecting it with the hinterland and to the development of river shipping for agricultural produce and industrial goods produced in the rest of Columbiana County. The prospects for construction of nearby canals and a railroad (the Ashtabula, Warren, and Liverpool) also boosted enthusiasm for the town as did the creation of Liverpool Township in 1834, of which East Liverpool was the only sizable urban center. East Liverpool's population rose from a mere 136 in 1830 to 503 in 1840. The population was relatively young, too. Forty-nine percent of its residents were in the prime working years between 15 and 50 years of age. The economy also had diversified and matured. Only 12 East Liverpool citizens were engaged in agriculture in 1840; 80 were employed in manufacturing; 12 others in commerce; 14 in river, canal or lake navigation; and three in "learned professions" (Gates 1984: 18-27).

East Liverpool's claim to fame as one of the country's premier producers of ceramics began in 1839 (Figure 3-8). It was predicated on the growing domestic market for locally produced household wares and storage vessels, the availability of high-quality clays, and the presence of the Ohio River used to transport the ceramics to both local and more distant markets. English potter James Bennett fired his first earthenware in East Liverpool in 1840. His three brothers joined him from England in 1841, and the Bennett Brothers Pottery produced both yellow earthenware ceramics and a manganese-mottled form of the pottery, known as "Rockingham." The Bennett Brothers' commercially produced wares were being advertised in Pittsburgh newspapers in 1841 and also were sold through Cleveland, Cincinnati, Louisville, and St. Louis

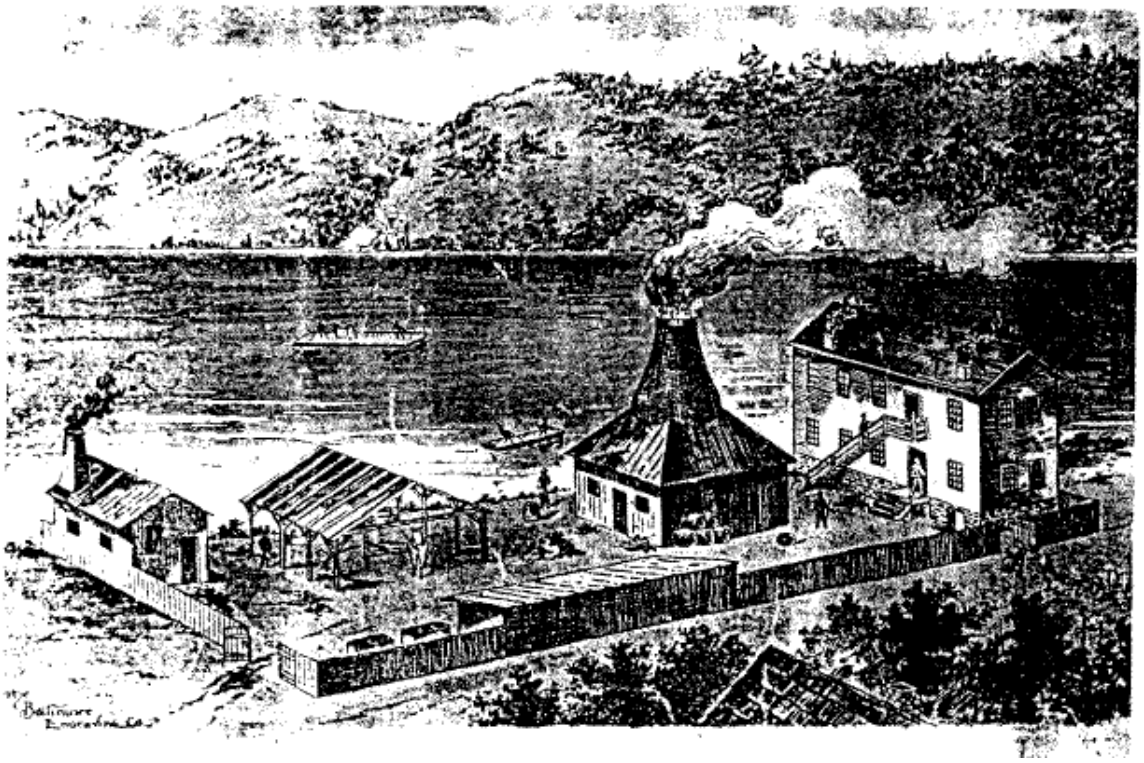

Figure 3-8: An artist's rendering of what an early pottery in East Liverpool, Ohio, might have looked like ca. 1840. From Gates (1984: 30).

merchants. Although the Bennetts were successful in East Liverpool, they moved their pottery operation up the Ohio River to Pittsburgh in 1844, to take advantage of better access to fuel (Gates 1984: 32) and, presumably, to the enhanced transportation facilities that came with the opening of the Monongahela Navigation Company's locks and dams on the Monongahela River.

The Bennetts' success in East Liverpool attracted many other potters, and the increased business made the once lackluster town "…very agreeable and prosperous…" by 1850 (Gates and Ormerod 1982: 3-4). In 1853, 11 potteries were operating in the town that employed 387 people and turned out $175,000 worth of ceramics annually. The largest producer in the town at that time was the Phoenix Pottery. The pottery complex consisted of five buildings and three kilns and employed 40 people (Gates and Ormerod 1982: 4). Before 1852, East Liverpool pottery was marketed almost exclusively via river transportation. Completion of the Cleveland and Pittsburgh Railroad to nearby Wellsville in 1852 and extension of the line to East Liverpool itself in 1856 significantly boosted the town's commercial pottery industry by offering new trade routes directly to the new inland towns that were growing up along the tracks. East Liverpool ceramics were being sold in Chicago, for example, by 1857, as well as in the New Orleans market.

In 1877, there were 23 potteries in East Liverpool, and the ceramic industry dominated employment in the town. Prosperity peaked between 1880 and 1930 when the traditional yellow ware and Rockingham wares were supplemented by newer white earthenwares. Production of this additional ceramic line required the importation of new and different clay types from Missouri, Texas, Georgia, and as far away as England. This was made economically feasible primarily by the excellent rail connections that the town enjoyed. The period also witnessed the adoption of more modern ceramic-making technology, mechanization, and mass production. Growth of the ceramic industry also led to specialization of production and the rise of support businesses within the town. Clay preparation, ceramic decorating, and ceramic design could be "farmed out" to smaller companies. By 1877 the firm of Knowles, Taylor and Knowles was using natural gas to heat its kilns. East Liverpool supplanted Trenton, New Jersey, as the country's leading producer of dinner wares and ceramic toilets by 1895. Town population swelled with the success of the ceramic industry: 2,105 people in 1870 to more than 20,000 by 1910. Seven thousand people were employed in the town's ceramics industry in 1930 (Gates and Ormerod 1982: 3-6).

The twentieth century also witnessed changes in the ways in which ceramics were marketed. Mail order catalogs and wholesale ceramic merchants were used. Department stores now offered the wares through their own outlets. Plates, cups, saucers, and other wares were also given away to housewives as "free" premiums with the purchase of everything from movie tickets to newspaper subscriptions. Annual ceramic production in East Liverpool was valued at $25,000,000 in 1923 (Gates and Ormerod 1982: 5-7).

Although the growth of the ceramic industry contributed greatly to East Liverpool's fame and success as a town, the requirements of the growing industry had begun to outstrip the available space as early as 1900. Hemmed in by the Ohio River and other geographic barriers, the growing potteries began to look for space outside the town. This contributed to the establishment and growth of nearby towns even as it began to sap East Liverpool's vitality Chester, West Virginia, opposite East Liverpool on the Ohio, became the site of the Taylor, Lee, and Smith pottery and later of the Edwin M. Knowles China Company, and the Harker Pottery Company. Other potteries were started in Newell, West Virginia, Wellsville, and Salineville, Salem, East Palestine, and Sebring, Ohio. By 1940, only six dinnerware potteries and a few other manufacturers of ceramic products remained in the East Liverpool area. Mismanagement, foreign competition, and the Great Depression of the 1930s also contributed to the downturn in East Liverpool's ceramic

industry and with it, the economic fortunes of the town. Still, a few East Liverpool potteries held on, modernized, and introduced new lines of products into the 1960s (Gates and Ormerod 1982: 6-7). From the 1950s onward, however, trends in both the local and national pottery industry have continued to decline (Gates 1984: 313-407). The condition of homes, the business climate, and the civic infrastructure of East Liverpool have tended to mirror all of these larger and mostly negative trends.

Steubenville, Ohio, is 20 miles below East Liverpool on the Ohio River and was established in 1798. The flood tide of immigrants pouring into the Northwest Territory at this time soon swelled its population, which had a large German component. The establishment of a federal land office in the town in 1800 also helped to attract new residents, visitors, and those purchasing lands in other parts of Ohio. The needs of this rapidly expanding western population contributed to Steubenville's early industrial and commercial development. The young town soon boasted a woolen mill, iron foundry, several potteries, brewery, paper mill, steam-powered flour and cloth mills, and a tobacco/cigar factory. Town artisans also turned out a host of consumer goods suitable for sale to local residents and to settlers moving down the Ohio into the Ohio and Kentucky frontiers. These goods included such necessities as shoes, clocks, guns, wagons, and hats. Most of these products and the people who purchased them traveled down the river on flatboats, keelboats and, later, steamboats. The down-river traffic included mainly agrarian produce and manufactured items, but cotton, fur, tobacco, and hemp also moved upriver from Kentucky. Steubenville's population grew rapidly in these exuberant times. It stood over 2,000 in 1818 and 3,000 in 1830. Among contemporary Ohio towns, only the populations of Cincinnati and Zanesville were larger (Gates 1984: 7; Roseboom and Weisenburger 1986: 64, 112). Steubenville (as well as Gallipolis, Portsmouth, Ironton, and Ripley) also developed a small industry in the construction of steamboats. The production was not as large as that in Wheeling or Marietta. The latter had developed substantial boat construction businesses, though much smaller than the major steamboat-building centers that evolved near Pittsburgh and up the Monongahela River at towns such as Elizabeth, West Elizabeth, Brownsville, and California, Pennsylvania (Hunter 1949: 107).

Late in the nineteenth century, historian Reuben Gold Thwaites found that Steubenville's population had grown to about 16,000, and like many river towns, presented a wide, impressive stone-paved wharf to visitors arriving by boat. Some of the town's residents were disturbed by the fall-off in steamboat traffic, but just three miles down the Ohio a large iron and steel plant at Mingo Junction created many new industrial laboring jobs filled by Eastern European immigrants, a situation that Thwaites feared was "…fast degrading legitimate American labor" (Thwaites 1999: 45). In addition to steel, the Steubenville area's traditional industrial base also has included coal, as well as glass and tin manufacturing (Klein 1968: 37).

Next to Pittsburgh, Wheeling became the most important town on the Upper Ohio River at an early date. Numerous pioneers pushed into the Ohio River Valley between 1772 and 1777 coming either down the Ohio River via Pittsburgh or up the Shenandoah Valley of Virginia, across the Blue Ridge and down the Kanawha, Big Sandy and Kentucky River drainages. The earliest settlement at Wheeling is usually attributed to Ebenezer, Silas and Jonathan Zane about 1769; however, George Washington made no mention of any settlement there on his 1770 tour through the Ohio River Valley in search of good lands. Ebenezer Zane, David Shepherd, John Wetzel, and Samuel McCulloch, all early settlers in the Wheeling area, later maintained that their initial settlement there began in 1772.

Two years later, Major William Crawford erected Fort Fincastle at the future site of Wheeling, where Colonel Angus McDonald raised a force of about 400 men for an expedition against the

Shawnee during Dunmore's War of 1774 (Rice and Brown 1993: 29, 33). This was one of a number of frontier fortifications designed to protect the early settlers of the Ohio Valley. It was an important rallying center for George Rogers Clark's planned expedition against the British at Fort Detroit in 1781, and the post was attacked by the Indians in September of the following year (Rice 1970: 67, 82, 110, 116). In 1785 or before, Isaac Zane and George Green developed a cattle trade between Wheeling and Detroit. Cattle were exchanged for skins and furs. Indians killed both men, however, on a later trip (Rice 1970: 158).

In the early nineteenth century, Wheeling developed as a place where settlers moving down the Ohio could acquire provisions. The river between Pittsburgh and Wheeling hosted many floating stores and vendors of all sorts. Small but useful manufactured goods could be exchanged or bartered for agricultural produce. Together with Point Pleasant and Cedar Grove (on the Kanawha River) boat building became an economic focus in Wheeling at an early date (Rice 1972: 112). In 1816, the 403-ton steamboat *Washington* was built at Wheeling and made a round-trip to New Orleans from Wheeling and back up to Louisville in just 41 days (Rice 1972: 117). The boat managed to chug up the Mississippi and Ohio system from New Orleans to Louisville in 25 days (Rice 1970: 320). This was one of the first indications of the utility of steam-powered navigation on inland waters. Before long, the trip from New Orleans to Louisville was cut to five days (Rice 1972: 117).

Wheeling's evolution in the nineteenth century was marked by economic growth and diversification, the emergence of industry, and by attendant progress in health care and education. Several early physicians took up residence in Wheeling, including one in 1808 who came with a medical degree from the University of Pennsylvania. Another graduate of this institution arrived in 1819 (Rice 1970: 201, 202).

The first newspaper was published in Wheeling in 1807, 21 years after the first newspaper had been published in Pittsburgh (Rice 1970: 262). The Wheeling Lancastrian Academy was established in 1814 (Rice 1970: 237), and in the 1820s the town was an important site for early textbook publishing as well (Rice 1970: 265). In 1849, the Wheeling area became the first independent school district in Virginia (Rice 1970: 232). An attempt to start a university at Wheeling occurred in the spring of 1831, but the initiative failed to win the support of the state legislature. Before 1840, Wheeling (and Wellsburg) were among other Virginia towns that had developed literary or library associations to promote education (Rice 1970: 259).

These educational endeavors grew out of the town's increasingly important status as a center of trade and commerce poised at the crossing of the National Road over the Ohio River. In 1810, Wheeling was a village of only 120 houses and 11 stores. By 1820, two years after the National Road had reached the town from Cumberland, Maryland, Wheeling was Virginia's second most populous town after Richmond. In 1830, it was the most populous town in northwestern Virginia (Rice 1970: 255, 334). It was estimated that 4,681 wagons, each averaging about 3,500 pounds, were unloaded in Wheeling in 1822 as a result of the presence of the National Road. The cost of transporting this merchandise to Wheeling from Baltimore was calculated at $390,000. These figures did not include wagons that merely passed through Wheeling, perhaps another 468 wagons or 10 percent of the larger figure (Rice 1970: 334).

Wheeling became an industrial center before the Civil War even though the development of its banking institutions lagged significantly behind the development of that crucial business in Pittsburgh and Washington, Pennsylvania, and Marietta, Zanesville, and Steubenville, Ohio. Since the early nineteenth century there had been a branch of the Bank of Pennsylvania in Pittsburgh. In contrast, there were still no state-chartered banks in Wheeling in 1815 (though a

private bank had organized there the year before). Businessmen in western Virginia complained that banks in the eastern part of the state would not make them loans due to the great distance and the poor transportation facilities connecting eastern and western Virginia (Rice 1970: 317, 318, 320, 322; 325-327). Thus, despite the fact that Wheeling and Pittsburgh were industrial competitors, many businessmen in Wheeling had to look to the capital available in Pittsburgh to fund their ventures (Rice 1970: 326-327). Even in the early nineteenth century, one perhaps can see the beginnings of the metropolitanism that allowed Pittsburgh to exert its influence as the major city of the Upper Ohio River Valley, an influence that has remained to the present time (see Muller 1989). The pleas of western Virginia businesses were answered in 1817 with the establishment of the Northwestern Bank of Virginia at Wheeling. The bank was authorized to establish branches at Clarksburg, Morgantown, and Wellsburg and was capitalized at not less than $400,000.

The Wheeling Iron Works was turning out about 1,000 tons of iron annually in 1835. Most of this output was nails (leading Wheeling to be called the "Nail City"), about 300 tons, but bar, sheet, hoop iron, and boiler iron also were produced. Four foundries and four steam engine factories in the town employed about 140 workmen. The Wheeling Manufacturing Company produced steam engines and other iron products. Coal from the West Virginia Northern Panhandle often fueled the Wheeling industries. In the 1830s, the town had foundries, steam engine factories, flour mills, glass houses, distilleries, cotton and wool factories, paper mills, and sawmills that used up perhaps 1,000,000 bushels of coal each year (Rice 1970: 315, 316). Good sources of clay, coal and wood for fuel, and access to the river for the transportation of the finished products made the Wheeling-Wellsburg area an ideal location for early pottery and glass production. Wellsburg was the earlier glass-making center, but Wheeling's location on the National Road attracted the attention of that industry in the 1820s. In 1820 or 1821, an eight-pot glass factory was in operation in Wheeling, begun by George Carothers who came from Brownsville, Pennsylvania, on the Monongahela River. The business was short-lived, however. John and Craig Ritchie opened a more successful flint glass plant in Wheeling in 1829 and put sevral other plants into operation a few years later. By 1835, there were five glasshouses and two glass cutting businesses in operation in Wheeling that employed 193 men (Rice 1970: 317). Potteries were working at Wellsburg by 1805, and Wheeling had two major potteries in operation by 1814. The large number of landless working men attracted to the town's industries also made Wheeling the focus of the first important labor movement in what is now West Virginia in 1829 (Rice 1970: 325). Wheeling also has been a center of pottery-making in more recent years together with Ravenswood, Huntington, and Parkersburg, all on the Ohio River (Rice 1972: 268).

Both Wheeling and Wellsburg were important milling centers on the Upper Ohio River. Wellsburg shipped 30,000 to 40,000 barrels of flour down the Ohio and Mississippi rivers to New Orleans each year, and Wheeling then had three steam-powered gristmills in operation. Fulling and carding mills were significant in Wellsburg, which also had rug and cotton factories (Rice 1970: 322). Wheeling eventually became known as a center for the manufacture of calicoes (Rice 1972: 268).

All of the products of the Wheeling industries and businesses discussed above had to be shipped either overland via the National Road (after 1818) or were marketed by loading them onto flatboats, keelboats, or, later, steamboats for distribution via the Ohio River.

Several new transportation improvements at Wheeling about the middle of the nineteenth century gave that town a shot in the arm in its economic competition with Pittsburgh. An engineering marvel of its day, and the first of its kind in the country, was the construction of the Wheeling Suspension Bridge over the Ohio River, which opened in 1849 (Rice 1972: 138). This was

followed by the arrival of the first railroad to reach western Virginia, the Baltimore & Ohio (B&O). This railroad reached Wheeling on New Year's Day in 1853 and provided a direct link to Cumberland and Baltimore.

When West Virginia became the thirty-fifth state in 1863, the first capital was located at Wheeling to place it safely within Union lines during the Civil War. In 1870, however, Charleston, an inland town on the C&O Railroad line then under construction was selected as the capital. However, Wheeling constructed a large building that it offered to the state as a capitol, and the seat of government therefore was moved back to Wheeling in 1875. A state referendum in 1877 selected Charleston, however, and in 1885 the capital of the state was again moved to Charleston. On the occasion of each move, all the state records were moved by steamboat (Rice 1972: 206, 215-216).

In the industrial era of the later nineteenth and most of the twentieth centuries Wheeling and Weirton were part of the national heavy industry heartland in the Upper Ohio River Valley. The center of this heartland was at Pittsburgh until the collapse of that industry between roughly 1960 and 1980. By the late nineteenth century, electricity was becoming indispensable for industrial production. The first electric light plant in West Virginia was opened at Wheeling in 1882 (Rice 1972: 265). Weirton Steel Company, however, opened a "Steel Mill of the Future" in the early 1970s, and Wheeling-Pittsburgh Steel Company, although beset with recurrent financial problems, has become a leader in the field of tin plate products. The steel industries in both Weirton and Wheeling utilized shipping on the Ohio River and developed significant markets in the lower South (Rice 1972: 263). In 1968, four Ohio River metals plants—Weirton Steel, Wheeling Steel (now Wheeling-Pittsburgh), International Nickel Company at Huntington, and the Kaiser Aluminum plant at Ravenswood employed over 2,000 workers each (Rice 1972: 263).

Marietta

Fort Harmar, located at the confluence of the Ohio and Muskingum rivers, originally was established to interdict boatloads of squatters heading downstream into the Ohio country. The community of Marietta, Ohio, first called Adelphia or Adelphi, the first legal settlement on the Ohio side of the river, was started by the Ohio Company of Associates (often called the "second" Ohio Company) in the spring of 1788. Most early settlers at Marietta were New Englanders. The residential architecture of the town to this day reflects this origin. A number had been educated at Harvard or Yale and formed a contrast with most frontiersmen. A good number of the early men of Marietta also had served in the Revolution, and they supported law, order, and the operation of fraternal organizations in their town, such as the Society of the Cincinnati and the Masons. The arrival of Arthur St. Clair, the first governor of the Northwest Territory in July 1788 also increased Marietta's prominence as a recognized seat of political and military power (Roseboom and Weisenburger 1986: 54, 62). The active promotion of new settlement by the Ohio Company of Associates soon resulted in the establishment of additional communities, including Belpre (a contraction for *belle-prairie*), 12 miles down the Ohio from Marietta, in April 1789 as well as other settlements up the Muskingum River at Waterford, Plainfield, and Big Bottom (Bond 1941: 287; Carlisle and Michael 1981: 26-27). The Big Bottom settlement was attacked by the Wyandots and Delawares on January 2, 1791, and 12 settlers were killed.

Washington County, containing Marietta, was the first Ohio County to be set up (in 1788) in the tumultuous days after the establishment of the Northwest Territory. Belpre Township came into being on December 20, 1790. The town of Belpre was separated into an "upper" and "middle" settlement by a large soil bank, known historically as "the Bluff." The rich agricultural soil naturally resulted in farming as the mainstay of Belpre's economy in the nineteenth century

(Andrews 1902: 296-297). Most of the early improvements in this area consisted of grist and saw mills, orchards, vinegar mills, and other agriculturally related endeavors (Washington County Historical Society 1980).

The constant threat of Indian attack led many early homes in Belpre to do double duty as residences and as blockhouses. Colonel Battelle's and Colonel Cushing's residences formed two such structures within a tightly knit cluster of 13 log buildings at the Belpre settlement that was known as "Farmer's Castle." This was on the north shore of the Ohio River approximately opposite the middle of Blennerhassett Island. In addition to Fort Harmar (at Marietta) and Campus Martius, the fortified settlement erected by the Ohio Company of Associates at that town, Farmer's Castle presented one of the most secure and imposing appearances on the American frontier in 1790 (H. Z. Williams and Brother 1881: 509-510).

Another frontier fortification, Nye's Fort, was built in 1792 on the Ohio side of the Ohio River opposite the southern end of Washington Bottom and Newbury Island or Newbury Bar. This fort protected settlers in the "Lower Settlement," also called the Newbury Settlement, southwest of Belpre and south of the Little Hocking River, who were too far from the protection of Farmer's Castle. Newbury Island in the Ohio River is a linguistic reminder of this early Ohio River settlement. The name "Newbury" also reflects the New England origins of many of the early settlers who came to the Parkersburg/Belpre area by way of Marietta, Ohio. Newbury is derived from Newburyport, Massachusetts, the home of Nathaniel Sawyer. Sawyer arrived in Marietta in 1789 and built the first home near the mouth of the Little Hocking River in 1796 (Preston 1909: 4).

In 1800, William Henry Harrison and Albert Gallatin succeeded in getting new federal legislation passed that dropped the minimum amount of land a person could purchase in Ohio from 640 to 320 acres and extended credit for four years. Reinforcing the importance of early towns in Ohio, the act also opened land offices at Marietta, Cincinnati, Chillicothe, and Steubenville. The resulting inflow of new settlers soon paved the way for a movement to admit Ohio to the Union (Roseboom and Weisenburger 1986: 64).

Marietta, Pittsburgh, and Wheeling all became major ship-building centers on the Ohio River early in the nineteenth century. Sailing schooners were constructed for the down-river trade to New Orleans, but most of these ships then took to coastal sailing rather than hazarding the return up the Mississippi and Ohio River system. In 1807, some 1,800 boats went down the river to New Orleans, but only 11 came back up. British interruption of the Atlantic sailing trade during the War of 1812 caused American merchants to turn to the interior river systems, and numbers of southern keelboats were arriving in Pittsburgh and other Ohio River towns by 1815. Together with Pittsburgh, Brownsville (on the Monongahela River), and Cincinnati, Marietta became a leading manufacturer of flatboats and keelboats in the era before steamboats controlled the river trade (Wade 1959: 40).

By 1810, newspapers were being published in Marietta, which joined Cincinnati, Chillicothe, Steubenville, and other Ohio towns.. Sixty newspapers were being published in Ohio’s towns by 1826. Building on the respect for education that Marietta’s first settlers brought with them. the decade between 1830 and 1840 saw the establishment of the school that grew into Marietta College. In subsequent years, Marietta developed an economy based on varied manufacturing, and both wholesale and retail trade. Its population had grown to about 17,000 by the late 1940s (Banta 1949: 537). Today, it is a rather sleepy but beautiful Ohio River town that gives the casual visitor little sense of its earlier importance in the history of the Ohio River Valley.

Parkersburg

One of the most important towns on the Ohio River between Pittsburgh and Cincinnati is Parkersburg, West Virginia, located on the south bank of the river at its confluence with the Little Kanawha River. The first tentative settlements at Parkersburg occurred in 1773 when Robert Thornton, Vallentine Cooper, Benjamin Harding, and James Neal arrived at the mouth of the Little Kanawha. A number of other settlers spread out along the nearby tributaries of the Little Kanawha but were soon driven out by Indian raids that began in 1774.

Thornton sold his original land holdings to Captain Alexander Parker of Pennsylvania in 1783 for $50.00 (Inslee and Kaltenecker 1949: 5). Although the later town was named for him Parker never lived there. He died in Pennsylvania in 1791 at the age of 38 (Dawson and Null 1969: 2; West Augusta Genealogical and Historical Society 1980: 5).

John Stokely was the next to settle on the Parkersburg side of the Little Kanawha. The area about the mouth of the Little Kanawha became known as "the Point," not to be confused with ground of the same name at Marietta, Ohio, at the junction of the Muskingum and Ohio rivers. Stokely laid out a small community containing 6-8 small houses, a church, school, and store on both sides of that river that he called Newport or Stokelyville (Bartlett 1903: 3; Dawson and Null 1969: 2; West Augusta Genealogical and Historical Society 1980: 5).

The name of Parkersburg was adopted after 1810, when Parker's daughter, Mary Parker Robinson, obtained title to the land. Her husband, William Robinson, was from Pittsburgh, where his family was among the earliest settlers on the north side of the Allegheny River. Robinson laid out the town of Parkersburg in 1811 into a series of lots with streets running both parallel and perpendicular to the Ohio River (Inslee and Kaltenecker 1949: 13).

On the north or Parkersburg side of the Little Kanawha, Captain James O'Neal (later Neal) became the first surveyor and permanent settler. Neal was originally from Springhill Township in Fayette County, Pennsylvania, and was a Revolutionary War veteran. Neal first explored the area about the Little Kanawha in 1772, and he returned in 1783 to survey property Parker had acquired. In 1785, Neal established Neal's Station (or Fort Neal) and acquired title to several thousands of acres on the south side of the river. The settlement was threatened several times and attacked in 1791 (Withers 1895: 400; West Augusta Genealogical and Historical Society 1980: 5-6).

Before the discovery of oil at the Burning Springs field on the Little Kanawha River about 40 miles up the Little Kanawha River, Parkersburg and the community of Belpre across the Ohio River developed population slowly as the local market towns and redistribution points for regional agricultural produce and livestock. Parkersburg's population in 1820 stood at only 400 and by 1850 had increased to only 1,218.

The economic orientation of this commercial town began to change with the extension of connections with the Baltimore & Ohio Railroad to Parkersburg in 1857 and the discovery of oil at Burning Springs in 1859-60. Parkersburg soon became a major storage and refinery center for oil, which was either carted or floated down the Little Kanawha River to the Ohio River from Burning Springs. Parkersburg's significance as an oil storage, refining, and shipping point and as a railroad center also made it an important area of Union defense during the Civil War.

After the Civil War, Parkersburg's once independent refineries and oil companies eventually were acquired by John D. Rockefeller's Standard Oil Company conglomerate, largely through the efforts of Parkersburg's most famous oil man, J. N. Camden.

The local oil industry required a great deal of lumber for barrels, derricks, and boats; thus, Parkersburg also became a prominent site of sawmills and lumber mills. The mills, as well as tanneries, usually were found along both banks of the lower Little Kanawha River, where both water and water transportation were close at hand.

Parkersburg's population was increased by the influx of oil speculators and workmen. The city's boundaries soon expanded outward and its economic basis became grounded in the increasing industrialization of the nation as a whole. Oil, and later natural gas, remained major economic pursuits in Parkersburg until the city's last refinery closed in 1937, but other industries, specifically wood products, iron and steel, brick making, and to a smaller extent pottery, silk making, and castings continued to contribute substantially to the economic life of the town.

On the opposite side of the Ohio River, Belpre also participated in the economic growth that Parkersburg enjoyed during the nineteenth and early twentieth centuries, though to a more limited extent. Many Parkersburg businessmen originally came from families on the north side of the Ohio, but Belpre retained a more rural and agricultural orientation, and its population remained well below that of Parkersburg. The links between the two towns were first improved by the operation of river ferries across the Ohio River and by the completion of the B & O Railroad Bridge across the Ohio in 1871.

The wealth generated by the oil, timber, and metal industries and the resulting population growth led Parkersburg to expand outward from its original epicenter at the confluence of the Little Kanawha and Ohio rivers. Some architecturally impressive homes and blocks of worker housing were built in the Beechwood, North Parkersburg, and Riverside neighborhoods north of the older city. City parks, rural cemeteries, and some recreational areas such as Terrapin Park, were also erected. Inter-urban trolley lines developed to serve these new suburbs and to tie them to Parkersburg. By the beginning of the twentieth century inter-urban lines also provided transportation connections between Parkersburg and towns such as Vienna and Marietta.

The Little Kanawha River separated Parkersburg from its neighborhoods of Tavennerville, South Parkersburg, and Lauckport south of the river. A bridge over the Little Kanawha joined these areas in 1858 but was destroyed by floods. River ferries therefore continued to provide transportation for many years. Physical separation reinforced political separation; South Parkersburg did not officially become part of Parkersburg until 1950.

Parkersburg was fully integrated with American urban industrialization in the second half of the nineteenth century, but a short distance outside the city one re-entered the earlier agrarian world of subsistence and commercial farming. Family farms continued to dominate Washington Bottom until after the Second World War, for example, and provided many Parkersburg markets with produce and dairy products year-round. Few of the amenities and innovations of Parkersburg's industrial expansion extended even as far as Washington Bottom. Parkersburg received electrical service in 1896, for example, but the farmers of Washington Bottom were still without any regular electrical service as late as 1935. Similarly, the major road across the bottom remained unpaved until industrial growth there by the Dupont, Borg-Warner, Carborundum, and other companies after the Second World War demanded it. These companies, and the development of the petrochemical and synthetics industries provided thousands of new jobs for area residents during the boom years of the 1950s and later.

Parkersburg's population began to decline with the advent of inter-urban transportation about the beginning of the twentieth century and with the spread of the automobile in the 1920s and 1930s, both of which allowed daily long-distance commuting to work and fostered the development of suburban living. Today, Parkersburg is part of the Parkersburg-Marietta Metropolitan Area, and as of 1989 it ranked 221st among 320 MPOs in the nation based on population (West Virginia University, Center for Economic Research 1991).

Huntington

The earliest evidence of settlement at the location of the current Ohio River city of Huntington, West Virginia, came on December 15, 1772 when John Savage and 60 other men received land grants for service in the French & Indian War. Savage's grant included the site of Huntington. A trade in bearskins soon occupied the area around the mouth of the Guyandotte River. A small village called Guyandotte served as a local trading center. By 1800, there was a ferry across the Ohio and one across the Guyandotte River at this village, which did not merged with Huntington until 1911.

Richard and Benjamin Brown laid out a town on tract 37 of the Savage grant. Originally called Brownsville, the town was equipped with an excellent river landing and land transportation route. The "Jeems" and Kanawha Turnpike connected the area with eastern Virginia. The new town was incorporated in 1831-1832. No lots were sold, however, and Brownsville remained a town in name only for four decades (Wallace 1947: 8-11).

In 1869, Collis P. Huntington, who had made money during the California gold rush, was elected president of the Chesapeake & Ohio Railroad. Huntington also had helped to finance the Central Pacific Railroad. He pictured the erection of a town on the Ohio at the junction with the Guyandotte River and the completion of a bridge over the Ohio. At the time, there was no railroad in the state south of the Little Kanawha River, so construction of the C&O was vital to the progress and development of the area. Based on Mr. Huntington's progress over the next two years, the Virginia legislature incorporated the town of Huntington in 1871. Construction of the railroad was carried out from both ends, and the track was completed at the end of January 1873 providing the new town with rail connections via Charleston to Richmond (Wallace 1947: 67-86). A freight and passenger station built at the river dock on Ninth Street in Huntington facilitated transfers of passengers and freight to and from river steamers. An incline was used to move the freight between these two modes of transportation.

Once the C&O rail line was extended to Cincinnati river passenger traffic, especially, began to decline (Wallace 1947: 111). Construction of the Ohio River locks and dams, however, had a beneficial effect on river freight traffic at Huntington. Lock and Dam No. 28 at Huntington was constructed between 1911 and 1915, and the Gallipolis Lock and Dam was built about 32 miles above Huntington; it opened in August 1937.

After the completion of the Ohio River navigation system, the port of Huntington alone contributed waterborne freight in the amount of 3,892,139 tons in 1942, 3,964,377 tons in 1943, and 4,045,102 tons in 1944 (Wallace 1947: 113). These amounts can be compared with freight totals carried on the entire Ohio River system of 18,000,000 tons in 1934, 38,000,000 tons during the early war year of 1942 and 37,000,000 tons in 1944 (Wallace 1947: 113).

Huntington became an important switching point for transfers between river and rail. In the late 1940s, there were 13 river terminals in the short distance of 1.7 river miles at Huntington. These

included no fewer than six petroleum terminals, three coal terminals, two sand and gravel terminals, a marine repair terminal, and one terminal that handled miscellaneous river freight (Wallace 1947: 113).

Huntington is an excellent example of a town where a river confluence, a major road, and excellent river wharf possibilities were insufficient to make the town "happen." The railroad and the town development and jobs associated with that were required. In time, other rail lines were completed to the town providing connections to Cincinnati and other towns and cities. Eventually, passenger service on the C&O was available through Huntington connecting Louisville and Cincinnati on the west with Washington D.C. and Richmond on the east. The Cincinnati Division of the C&O opened on New Year's day, 1889. Through acquisition of another railroad, a connection to Louisville was established in February 1892 (Wallace 1947: 89-90). By 1887-1888 the Baltimore & Ohio (B&O) line also served the Huntington Area through a connection with the C&O via Wheeling Parkersburg and Point Pleasant. Thus by the late 1880s, the Ohio River was paralleled by railroad tracks all along the distance from Steubenville to Cincinnati, Ohio and continuing on to Aurora, Indiana (Wallace 1947: 109). Huntington profited from its position at the junction of both the C&O and the B&O.

When the railroad was started, Collis P. Huntington did not even consider coal to be a potentially major source of revenue for his new line since the West Virginia industry was then in its infancy. There were coal mines in operation at present Montgomery, Loup Creek, Paint Creek, and Coalburg. The Coalburg, West Virginia, mine was in operation before the Civil War. Before the advent of the railroad, the mine shipped its coal on the Kanawha River. Collis Huntington reckoned that Virginia iron ore would be the major freight for the new line at the time. By 1900, however, West Virginia mining had developed to the extent that coal headed for the Virginia Tidewater was the major freight carried on the C&O. Between 1902 and 1945, the amount of West Virginia coal the C&O carried increased from 4,164,260 tons produced at 105 mines to 44,488,630 tons produced by 280 mines The C&O also became a partner in the C&O Steamship Company, which operated a fleet of seven trans-Atlantic steamships out of Newport News, all of which were supplied with West Virginia coal carried on the C&O line (Wallace 1947: 88, 90, 92). The C&O's Newport News terminal covered over 1,000 acres in the late 1940s and had a water frontage of 8,000 feet. There were two electrically operated coal piers, one of which was 1,200 feet in length and capable of loading four large vessels simultaneously (Wallace 1947: 104). In 1945, the railroad operated 1,708 miles on its main line, 1,736 miles on branch lines, and had sidings, second and third tracks, etc. besides, in all 6,192 miles of track. Moreover, the line had been profitable every year since 1889. Passenger service was operated and daily service each way between Cincinnati and Washington, D.C. was being planned at the end of World War II. Coal was the big money maker, however, and comprised 77 percent of the freight tonnage carried in 1945; merchandise freight contributed another 37 percent. The line hauled a little over 12 percent of all the bituminous coal in the United States in 1945 (Wallace 1947: 108).

Another market for C&O-carried West Virginia coal developed in New York, where steamships, the elevated subway, and even the New York and New Hampshire Railroad became major consumers--on the order of 2,000,000 tons of New River coal annually--in the late nineteenth century. Subsequently, however, the New York market was closed-off to West Virginia coal by competition from the Pennsylvania Railroad, which cut its coal freight costs to the New York market dramatically. For good measure, the Pennsylvania Railroad's A. J. Cassatt and the New York Central Railroad, also purchased some 40 percent of the stock of the C&O in late 1899 for $9.5 million (Martin 1992: 153-154) and raised the freight rate on West Virginia coal that the C&O carried to its deep water terminal at Newport News from $1.00 to $1.40 per ton (Wallace

1947: 92). These two steps effectively blocked West Virginia coal from entering the New York market.

Before the Interstate Commerce Commission stepped in and forced a widespread divestiture of railroad stock by 1906, the Pennsylvania Railroad had extended its substantial influence over the nation's railroad business at the beginning of the twentieth century by purchasing a 40 percent interest in the Baltimore & Ohio Railroad for $65 million and a 39 percent interest in the Norfolk & Western Railroad for $17.9 million (Martin 1992: 154). With four other railroads, the C&O in 1904 also operated rail lines between Columbus and Toledo, Ohio, and in 1910 the C&O had a one-half interest in the Kanawha and Michigan Railroad (Wallace 1947: 92, 96). Chicago was added later to the list of cities the C&O served as the Great Lakes region and the city of Chicago evolved into economic powerhouses in the late nineteenth and twentieth centuries. Thus, like other major railroads, its influence spread out widely, and its lines wove together the economies of many cities in a national transportation web.

The direction of coal shipping changed radically with population growth, competition from other rail lines, and increased industrialization in the West and Midwest in the twentieth century. By the 1940s, the coal shipments from Huntington moving west exceeded those moving east by three to one (Wallace 1947: 92).

Huntington also became the site of major train workshops, including an early engine house that could hold 42 locomotives, a smith shop, foundry, machine and car shops, a brick passenger station, and 14 homes for the shop employees. A branch of the C&O Hospital Association was set up at Huntington in 1900 an provided that town with an important medical service.

Thus, Huntington was first a railroad town, but one that also had excellent water transportation possibilities. It therefore became a product redistribution center. Since cheap supplies of coal and gas also were available nearby, manufacturing became a major economic focus as the town matured in the nation's industrial era. Beginning in 1888, electric inter-urban car lines were constructed to serve the growing town population. These were consolidated in 1899, the same year that natural gas began to be piped from Warfield, Kentucky, to Huntington for both heating and light. Six years before, the Huntington and Kenova Land Company had begun development of a neighboring town called Central City, where a broom factory and a brick kiln had operated. The company attracted three glass factories to their development that operated for a number of years (Wallace 1947: 8-18).

After 1903, Huntington experienced a considerable growth spurt when the Huntington Land Company was formed. A federal post office was built in the town in 1908. Early twentieth century industries in Huntington included brick making, ice making and brewing, packing houses (Armour & Company), lumber and box-making businesses, and a veneer-making plant. A major industrial presence headquartered in Huntington but with much wider importance was the Island Creek Coal Company (Wallace 1947: 255-281).

The importance of the railroad to early Huntington's economy was underscored by the presence of the American Car and Foundry Company, dating to 1871, which produced railroad freight cars, wheels, mine cars, forgings and pressings that were used in many countries. The Duncan Box and Lumber Company began operations in Huntington in 1895 and produced all manner of wooden shipping crates. The West Virginia Steel and Manufacturing Company occupied some 23 acres along the Ohio River frontage at Huntington after its organization in 1907. Huntington also continued its tradition in glass making. A glass plant was operated there by Charles Boldt beginning in 1913. Michael J. Owens, who learned the glass-making business in Wheeling, took

over the Boldt plant in 1918. Owens later became an internationally recognized inventor of glass making machinery that automated the glass bottle manufacturing process in the early twentieth century. In 1929, the firm merged with the Illinois Glass Company to form the Owens-Illinois Glass Company. In addition to the Huntington plant, the company also operated plants in Charleston and Fairmont, West Virginia, and in many other cities across the country. Owens-Illinois provided jobs to 1,133 people in Huntington in 1947 (Wallace 1947: 143-157). Other important industries that developed in Huntington included the Standard Ultramarine Company (a dye manufacturer), the International Nickel Company (began operations in 1922), the Armstrong Products Corporation (a maker of gas stoves, lawn sprinklers, electric heaters and ironers, etc.), a specialty metals manufacturer, and a branch operation of the Pittsburgh-based Westinghouse Electric Corporation, among others (Wallace 1947: 153-165).

Cincinnati

The earliest eighteenth-century explorations near the present site of Cincinnati date to 1754 and again in 1767, but the dangers of the region prevented any attempts at permanent settlement. Upon their return from attacks on the Indian towns at Piqua and Chillicothe in 1779, the troops of George Rogers Clark constructed a blockhouse at the intersection of what is now Front and Main Streets in Cincinnati. The purpose of the blockhouse was to protect the Licking River settlements on the Kentucky side of the Ohio from attacks originating in northwest Ohio. Thus, the first evidence of any substantial building on the subsequent site of Cincinnati was rooted in the military necessities of the time.

After the Revolution, Benjamin Stites of New Jersey visited the Cincinnati area while on a trip to Limestone, Kentucky (current Maysville), one of the few early settlements to take root on the Kentucky south side of the Ohio River. Stites was impressed with the possibilities of the region and encouraged other settlers from New York and New Jersey to emigrate. Stites' enthusiasm also attracted the attention of New Jersey politician John Cleves Symmes, who eventually bought the whole tract. From this purchase, Symmes reserved for himself one township at the mouth of the Big Miami River and its confluence with the Ohio. Recognizing the potential advantages of the location, Symmes planned to build a town to be called North Bend.

In 1788, Mathias Denman, another New Jersey resident, bought a plot of ground within Cincinnati's current boundaries. Denman divided his land into thirds, kept one-third for himself and sold the other lots to Robert Patterson and to Kentucky schoolteacher John Filson. Filson's name already was well known on the frontier through his 1784 publication, Discovery, Settlement and Present State of Kentucky. The book also had been translated into French in 1785. It was reprinted in English versions in 1792 and 1793. Filson's boosterism and that of other writers advertised the conditions and opportunities of the American West to a wide national and international audience and helped attract many new settlers to the Cincinnati area.

Like Symmes, Denman, Patterson, and Filson also planned to lay out a new town on the north side of the Ohio. They proposed to construct their town opposite the Licking River and to establish a ferry across the Ohio connecting their settlement by road with the rapidly developing town of Lexington. Both Stites and Symmes also went forward with their competing town-making schemes. Symmes enticed prospective buyers by offering land at cheaper prices to those who bought first. Each purchaser was bound by the terms of the deal to begin improvements within two years, and was offered certain inducements for staying on the land for three successive years. In this way, Symmes hoped to stem one of the major problems for most new towns in the Ohio Valley—keeping the people they initially attracted. The seemingly pervasive restlessness of western settlers and their haste to move on into ever newer western lands produced large

turnovers in Ohio River town populations. The rapid population turnover , in turn, contributed to the fast-paced, rootless, free-wheeling, highly individualistic, impermanent, and often lawless quality those early settlements took on, and threatened their economic and social prospects.

In mid-November 1788, 26 persons from Stites' group came by boat from Limestone, Kentucky, to the junction of the Little Miami and Ohio rivers, where they constructed a stockaded blockhouse. This was the beginning of a settlement that Stites called Columbia. On Christmas Eve the same year, the small community of Losantiville, which grew into Cincinnati, was started five miles down the Ohio from Columbia near General Clark's old blockhouse of 1779 (Chambrun 1939: 50-56).

In 1789, Mother Nature and the Ohio River chose among the three competing town sites of North Bend, Columbia, and Losantiville. The floods that spring left no doubt that the sites chosen for North Bend and Columbia were less than ideal. Only Losantiville was elevated far enough above the river to emerged unscathed. As a result, General Josiah Harmar selected the area east of Losantiville for the erection of Fort Washington. This was a substantial military structure, 200 feet square, and one of the fortifications the Americans were building in the Ohio River Valley to protect new settlements and as bases for military operations against the Indians in northwest Ohio. The presence of the fort offered protection for the little settlement at Losantiville but also contributed residents. The garrison numbered 140 men in 1789, and 350 additional troops came with Harmar in January 1790. General Arthur St. Clair soon came to the new fort from Marietta, established Hamilton County (not coincidentally named after Alexander Hamilton), and changed the name of Losantiville to Cincinnati to honor the Society of the Cincinnati (Chambrun 1939: 57-58). The choice of name seemed appropriate not only to honor the Revolutionary War officers' society but to embrace the symbolism of the old Roman ideal of the farmer implored to take up arms but who later returned to the land, the citizen soldier who would rather be at his plow. Thus, in a very brief time Cincinnati had built on its initial advantage of location on the Ohio River. It was relatively safe from floods, was the site of a major new fortification, and had attracted a sizable contingent of troops, "camp followers", and civilians—all of whom had to be housed, fed, and supplied. The fledgling community was, in turn, afforded a measure of military protection that harbored its early growth and had achieved recognition and local prominence as the focal point of a newly established county.

The new settlement of Cincinnati was soon tested by the stinging military defeats of both Generals Harmer and St. Clair. It persevered through the troubled years between 1790 and 1794, but only Anthony Waynes's victory at Fallen Timbers in the latter year and the resulting Treaty of Greene Ville in 1795 conveyed a peace in which growth could resume.

Other towns soon blossomed in the Northwest Territory as well. Dayton was established by promoters who originated in Cincinnati. Chillicothe, the ancient site of Indian settlement, was set up out of Massieville on the Ohio River at the confluence with the Scioto River, a town that later became Portsmouth. Zanesville and New Lancaster also were founded.

Despite the appearance of these new and competing urban centers, however, the population of Hamilton County and Cincinnati in 1798 already had outstripped other areas of Ohio. It stood at something on the order of 4,000 white male inhabitants at the time (Chambrun 1939: 76). The meteoric population growth attracted new political attention as well. As Ohio prepared to enter the union in 1803, the capital was moved down the river from Marietta to Cincinnati, but protests from rival towns got it moved to Chillicothe, though it returned to Cincinnati again before moving permanently to Columbus. In 1803, Cincinnati had a population of perhaps 1,000. Most of the early log cabins had given way to frame houses of which there were now about 110.

The streets connecting the town to the Ohio River had been graded, and trees on the first terrace below the town had been cleared away giving unimpeded access to the all-important river. The wharf area was the center of trade and commerce. Not only had the town's population grown, it had diversified as well. There were some 24 merchants in the town plus numerous artisans and professional men, primarily lawyers. Lawyers often were the most formally educated of the town's population, and their presence added to Cincinnati's youthful but evolving cultural, artistic, and literary life. Over the next 30-40 years, a socially elite nucleus of professionals, established businessmen, manufacturers, and merchants would emerge and lend Cincinnati the high degree of social coherence, business acumen, and community leadership needed to govern and guide a town whose population was doubling in every decade of the first half of the nineteenth century (Glaser 1999: 8, 14).

Important technological changes were soon to make their presence known as well. In October 1811, Cincinnati received the New Orleans, a Pittsburgh-built steamboat and the first of its kind to descend the Ohio River. Low water prevented the boat from continuing down the Mississippi until December, so in the meantime it traversed the Ohio back and forth between Cincinnati and the Falls of the Ohio at Louisville. This inaugurated the steamboat era on the Ohio and Mississippi River system.

The materiel needed to fight the War of 1812 was good for the early industrial and commercial economies of Ohio River towns, but the economic ebullience fell hard in the post-war downturn. Much like Filson's writings a generation before, publication of Daniel Drake's Picture of Cincinnati in 1815 renewed public curiosity and interests in the city and did much to encourage the arrival of new residents.

By 1819, 70 steamboats plied the river trade from Pittsburgh to New Orleans and back (Chambrun 1939: 118). Cincinnati soon became one of a number of urban centers of steamboat construction along the Ohio. The steamboats also increased the scope and diversity of the river trade to and from towns. Raw materials, agricultural produce, and livestock rolled into the town's workshops, markets, and slaughterhouses. These were transformed or processed into tools, furniture, clocks, paper, hats, books, flour, whiskey, beer, porter, linseed oil, lard, bacon, and pork. Cincinnati became so famous for its pork and pork products that the boosters of competing cities dubbed it "Porkopolis" (Chambrun 1939: 125).

A census of the town in 1818, the year it was incorporated, showed that just 30 years after its first tenuous beginnings, Cincinnati's population stood at some 8,000 whites and 367 African Americans. There were then 1,000 houses; 95 stores; 100 groceries; 11 drug stores; 5 print shops; 214 factories, mills, and mechanics shops; 17 taverns, 400 warehouses, a sugar refinery; a glass factory, churches, etc., all-in-all, some 1,900 buildings of which 200 were constructed of brick or stone (Chambrun 1939: 131). A large percentage of the city's business was oriented to river commerce, but by the 1830s and 1840s manufacturing was on the increase as well (Glaser 1999: 8). By 1828, the monetary value of the town's exports already exceeded $2,500,000 (Chambrun 1939: 125) and amounted to $6,000,000 in 1835 (Roseboom and Weisenburger 1986: 122). Population growth increased Cincinnati's numbers to 30,000 by 1830 (Chambrun 1939: 188). Ten years later, almost half of all the money invested in Ohio manufacturing had been plowed into Cincinnati firms (Roseboom and Weisenburger 1986: 123).

As in many other towns at the time, disease and medical ignorance of its causes detracted from the generally positive run of social, business, and institutional growth that Cincinnati enjoyed in the ante-bellum period. Cholera outbreaks occurred in 1832, 1834, and again in 1849. A flood in 1847 also took a toll on the town.

The comparatively high costs of transporting iron products to the West from the iron production and working center at and near Pittsburgh soon led to the establishment of iron furnaces and foundries in Ohio. Muskingum County was the site of early cast iron production of stoves and other useful products from bog ores. The opening of the Erie Canal offered this early industrial center an important new outlet for its products. In the ante-bellum period, a large charcoal iron industry also developed on both sides of the Ohio River in the so-called Hanging Rock District. In 1849, 17 hot-blast and five cold-blast iron furnaces were operating here (Roseboom and Weisenburger 1986: 122). Much like the earlier relationship that Pittsburgh had enjoyed with iron furnaces in central Pennsylvania, and in the Allegheny and Monongahela River Valleys, the Ohio furnaces supplied pig iron that was worked into finished products in Cincinnati's foundries.

By 1850, the 30,000 inhabitants of the town 20 years before had grown to 115,000. Cincinnati then stood as the fifth largest city in the country and its second largest manufacturing center (Glaser 1999: 7). It had long before become the major metropolis of the Middle Ohio River Valley. Railroad growth in Ohio between 1850 and 1855, however, favored connections to other cities such as St. Louis and Chicago. The older towns along the Ohio River were to some extent, passed by. Cincinnati fared well during the Civil War but its economy, particularly its down-river trade with the South was hurt by the disappearance of southern markets after the war.

The January 1884 a flood decimated the city's gasworks, wiped out 1,500 businesses, and made about 2,000 people homeless. Covington, Kentucky, on the opposite side of the Ohio, also was hard hit. Weakened homes collapsed, and schools closed or were washed away. A large lake was created up the Miami River by impounded waters in the Ohio that reached a flood crest of 71 feet and one inch (Chambrun 1939: 265-266).

Despite such losses, the growth of the city was spurred on by the arrival of new rail lines, eventually numbering seven trunk lines in all, and by the erection of the magnificent Union Station during the Depression years of 1929-1933. The new station consolidated the freight and passenger rail operations in the city. The seven lines that served Cincinnati in the 1930s drew on a network that amounted to 20 percent of all the rail lines functioning in the United States(Chambrun 1939: 301-302).

About this same time, the Mississippi Valley Barge Line built a freight river terminal, crane, and a freight depot that allowed the rapid transfer of freight between river barge and truck and river barge and railroad. This made good use of the greater Cincinnati area's 23 miles of river frontage. A broad road was built to give trucks access to the river terminal. The barge line also operated four large twin-screw propeller tows and 50 steel barges as part of Cincinnati's new freight-handling complex. These new constructions took advantage of the Corps of Engineers' completion of the Ohio River Navigation System in 1929 for the cost-effective river transport of freight. As a result of the synergy derived from the implementation of river navigation improvements and the construction of urban terminals, river-borne freight at Cincinnati increased from less than 2,000,000 tons annually in the 1920s to nearly 3,500,000 tons by 1935 (Chambrun 1939: 304-305, 309).

In the 1930s, industrial Cincinnati included some 1,400 manufacturers employing 40,000 workers. The effective area of industrialization extended outward from the city itself to included four counties in Ohio and across the river in Kentucky. Leading businesses and industries in the 1930s included meat packing (and the allied dairy, leather, soap and candle industries), malt liquors, bakery products, and furniture making as well as steel, iron, machine tools, petroleum products, and electrical appliances. Cincinnati was second only to Chicago in the meat packing

industry at the time. Eighty-eight manufacturers in Cincinnati specialized in the production of men's and boy's clothing, while 160 others were involved in publication of newspapers and journals. The list of early Cincinnati businesses and the trade names coined in the "Queen City" still have meaning in contemporary American commerce—Proctor & Gamble, Jergens, Kroger, Fleischmann, and Baldwin to name a few (Chambrun 1939: 309-317).

ECONOMIC BENEFITS OF THE OHIO RIVER NAVIGATION SYSTEM

From the information presented above, it is clear that urban life has been an important part of the Ohio River Valley's history from the arrival of the first Euro-Americans settlers in the late eighteenth century. For many of these newcomers, town life was an already familiar experience. Before they moved to the Ohio country, a significant number of them had lived in eastern towns, had participated in, or had benefited from the economic, social, legal, educational, and other functions that urban institutions provided. Town-building, therefore, went hand in hand with the settlement process.

In a day when rivers represented the only real highways of travel, communication, and commerce, most early towns in the Ohio River Valley were founded on the Ohio River itself, often at its confluence with tributary streams or rivers. A water-side location was a significant factor in their economic prospects. It is therefore unsurprising that many towns and cities in the Middle and Upper Ohio River Valley, including both of that region's entrepots, Pittsburgh and Cincinnati, were settled at an early date. These first towns developed when and where they did largely due to the fact that the Ohio River conveyed an "initial advantage" in trade, travel, and transportation over other locations. The relative economic standing of the valley's major urban centers has experienced comparatively little change over the last two centuries. Pittsburgh and Cincinnati were as important to the economic vitality of the Ohio River Valley at the beginning at the nineteenth century as they are at the start of the twenty-first. It is true that Huntington, West Virginia, has developed into a major river port city largely due to its oil, gas, coal, and chemical industries and to its excellent rail connections, but this more recent economic growth has not diminished the larger cultural significance of either Cincinnati or Pittsburgh.

Given the importance of urban life to the history of the Ohio River Valley, it is ironic that there have been so few formal studies of the river's contribution to the culture, economy, and population of its towns. Rarer still are studies of the impacts of the Ohio River navigation system on urban life and economy.

In general, historical geographers and historians have paid insufficient attention to the importance of the Ohio River and its navigation system on the development and growth of river cities and towns in the Middle and Upper Ohio River Valley. The rarity of comparative studies of the river's impact on urban economies poses considerable challenges to understanding the more specific effect of the Ohio River navigation system on river-side towns. Although historians of the nineteenth and the first half of the twentieth centuries acknowledged the river's significance for town life, their work focused largely on the creation of historical narratives, chronicles, and descriptive histories. This earlier generation of historians chronicled, preserved, and presented much interesting and colorful information about pioneer life on the river and in early river towns, and they painted often vivid verbal portraits of the Ohio River Valley as part of the nation's great westward migration, but little attempt was made to quantify the contribution of the river to the urbanization process.

The relatively late construction of the Ohio River Navigation System, extending from the late nineteenth century into the early decades of the twentieth century, also has acted to limit the historian's evaluation of the system's consequences for urban life. Since the completion of the first great era of railroad building between 1850 and 1860 the economic success of Upper and Middle Ohio River Valley towns has not been directly tied, as it was for all practical purposes before that time, to the river. The river navigation system, moreover, was completed at a time when commercial river traffic in general was falling off due to the combined impact of the

railroads and the subsequent emergence of the nation's highway system. The appearance and growth of these forms of transportation—both of which have had major effects on urban life in the river valley—also have acted to blur recognition of the continuing but "lower amplitude" contribution of river commerce to contemporary urban life, especially in the cost-effective transport of bulk commodities such as coal and steel products, petroleum, and chemicals. The contribution of the river and its navigation system, thus have been largely overlooked.

One of the few specific studies of the economic benefits of the Ohio River Navigation System was conducted by Joseph R. Hartley (Hartley 1959), at the time an assistant professor in the Indiana University School of Business. Noting the difficulty of undertaking the study due to the lack of basic economic research, Hartley set out to examine "…the economic characteristics of the river navigation industry" (Hartley 1959: Introduction). He also tested an earlier conclusion of the Hoover Commission that, in Hartley's words, "…decided in it's (*sic*) studies that benefits from river transportation were generally local and that only a few, large industrial companies used the rivers" (Hartley 1959: Introduction). He also evaluated another Hoover Commission conclusion that the lower transportation costs enjoyed by these companies probably did not result in lower consumer prices except indirectly.

In contrast to the conclusions of the Hoover Commission, Hartley's economic analysis of the status of commerce on the Ohio River and of improvements to its transportation system in the mid-1950s concluded that the country as a whole had benefited greatly from improvements to this waterway. Unfortunately, Hartley's study did not specifically address the navigation system's economic benefits to Ohio River Valley towns and cities; thus, one must extrapolate from his conclusions for the Ohio Valley as a whole.

Hartley found that river shipping had experienced a dramatic decline in the late nineteenth and early twentieth centuries due to the national growth of railroads and, beginning in the 1920s and 1930s, to the development of long-haul trucking. However, inland river shipping had made a significant comeback, growing from 20 billion ton-miles in 1939 to 120 billion ton-miles in 1957. Barge tonnage carried on the Ohio River in 1957 actually was larger than that on the Mississippi River if coastal traffic on the Lower Mississippi River was excluded (81.6 million tons vs. 74.6 million tons on the Mississippi). Hartley also was encouraged by the 9.5 percent annual growth rate in the number of ton-miles carried on the Ohio and its tributaries, rising from 1.5 billion ton-miles in 1929 to 17.2 billion ton-miles in 1957. Most of this consisted of coal and coke (32.9 percent of ton-miles and 54.7 percent of tonnage in 1957) followed by petroleum (34 percent), iron and steel (19.9 percent), chemicals (7.6 percent), and other commodities (5.6 percent). Actual tonnage had increased from just 22 million tons to 81.6 million tons over the same period.

The reasons for this dramatic economic improvement on the Ohio River system included technological developments in barge design, construction and method of towing. Steel barges had supplanted the old wooden ones, and integrated tows now permitted up to 30 barges (the equivalent of 4-5 trainloads) to be joined together in a single tow. Other technological changes included the installation of radar and the adoption of diesel engines. The result was the capacity to haul a larger number of barges at lower cost, and with fewer accidents.

Another major factor that Hartley singled out as contributing to the rebirth of Ohio River freight transportation by the mid-1950s was the improvement of the river itself. Hartley attributed much of the economic benefit resulting from improved water transportation to the removal of snags and sandbars and the construction of the system of locks and dams on the river by the U.S. Army Corps of Engineers that was transforming the river into a "superwaterway" (Hartley 1959: II).

Water transportation rates also compared favorably to railroad rates in Hartley's results. In 1957, water-borne commerce averaged about 0.4 cents per ton-mile, whereas rail rates then ranged about 1.4 cents per ton-mile. Furthermore, the gap between these rates had widened since World War II. Barge rates had increased more slowly than railroad rates, due in part to the federally supported costs of waterway maintenance and to the increased productivity that had resulted from technological changes in tows, barges, and locks. Although barge rates for coal had increased "a small amount" since the end of the war, the rates for carrying petroleum had declined about 50 percent their war-years high (Hartley 1959: II).

In contrast to the Hoover Commission's contention that cost savings of water-borne transportation were, at best, only passed on to consumers indirectly, Hartley's study found that the economic competition among the 935 individual barge lines then in operation on the Ohio-Mississippi system as well as competition from the railroads helped to keep freight rates low. Furthermore, the competitive atmosphere assured that this savings was passed on to shippers and consumers.

As of 1957, Hartley found, the states bordering the Ohio River were responsible for producing 84.8 percent of the nation's supply of bituminous coal, and the proportion of coal carried by river barge had steadily increased from 1929 onward. Hartley found that those coal mines in southern Indiana without access to Ohio River tributaries had lost market share to other areas.

Hartley also concluded that transporting coal on the Ohio River to industrial consumers, many of them electrical generating plants built on the river flood plain, had kept the cost of both coal and electrical power down for millions of ultimate consumers. Ohio River electrical plants, Hartley discovered, were producing about 12 percent of the nation's electrical supply in 1957, up from 6 percent in 1939. River transportation of coal to these plants allowed them to save nearly one-third the cost of production when compared with the national average. Since these electrical generating plants also were developing transmission lines to towns and cities within 100-150 miles of the river, the benefits of cheaper electricity was being shared with urban centers far removed from the Ohio River itself (Hartley 1959: III).

Construction of the Ohio River Navigation System also had eliminated the large seasonal variations in pool depth. This year-round availability of water directly benefited the production of electric power and the output of industrial (especially steel) plants in the Ohio River Valley. The Ohio River Valley steel industry near Pittsburgh had long used the river to ship coal from mines up the Monongahela River Valley and had begun to ship finished steel products by river in the 1920s (see Carlisle 2000b). During the industrial boom period of the mid-1950s, Hartley (1959: IV) found that a "large volume" of steel was being shipped by river as far south as Texas and that its availability at river-side towns was attracting other steel-using industries. Hartley's study found that $13 billion dollars had been spent on the construction of industrial facilities in counties bordering the Ohio River and its tributaries since 1950 (Hartley 1959: IV).

Development of the Ohio River Valley's aluminum industry also was directly related to that industry's need for large amounts of electrical energy used in smelting. Aluminum smelters were established in the Ohio River Valley for the first time during the 1950s to take advantage of lower cost electricity and to capitalize on river shipments of raw materials, especially alumina, and finished aluminum products (Hartley 1959: III).

Hartley's study also found that cheap river transportation had influenced the post-war development of the petroleum and chemical industries in the Ohio River Valley. By the mid-1950s, construction of oil pipelines had taken away a good deal of the river trade in crude

petroleum, but river barges transported higher-value petroleum products such as gasoline, diesel fuel, and refined oils to distribution points, including the towns and cities on the river. The costs of these products at the point of distribution were lowered by using cheaper river transportation rather than the railroad.

Barge transport of chemicals had grown in the post-war years, Hartley discovered, due in large part to the development of containerized shipping technology, to low transportation costs, to increasing demand, and to the chemical industry's need for large volumes of water used in chemical processing. As a result, the chemical industry on the Kanawha River, a tributary of the Ohio River in West Virginia, had grown into the one of the nation's largest (Hartley 1959: IV).

Although he did not investigate the economic specifics, Hartley (1959: IV) also proposed that construction and maintenance of the Ohio River Navigation System also may have played an important role in the continued evolution of other forms of transportation in the river valley, including the rival railroads, an idea that he felt merited additional research.

In sum, by the mid-1950s, the development of the Ohio River Navigation System had helped to sustain lower costs for delivered coal, had provided cheap but reliable water supplies, and had lower prices for steel and other industrial transportation. These economies, in turn had helped to keep down energy prices and the cost of steel-using durable goods (such as automobiles, stoves, and refrigerators) for individual consumers. River transportation also had boosted the prospects of the aluminum smelting industry and the chemical industries in the river valley. Prices for refined oil and petroleum products used in the rapidly growing number of automobiles now being driven on the nation's expanding interstate highway system were held down by lower cost barge transportation.

All of these matters were important considerations in the post-war America of the 1950s where the "baby boom" and the rapid development of suburban family housing had increased the demand for affordable energy and an ever-increasing number and variety of consumer products. Although the cost benefits of river transportation radiated outward to the nation as a whole, Hartley found that the Ohio River Valley had benefited directly from increased industrial investment, job growth, greater per capita income, higher retail sales, and urban growth. The last three categories were higher in the Ohio River Valley than for the nation as a whole even though, Hartley concluded, the overall prosperity of the Ohio River Valley still lagged the rest of the country. In general, Hartley (1959: IV) concluded, "Improvement of the River has helped provide an economic base for healthy, sustained, and rational economic growth."

COMMUNITY GROWTH AND RIVER NAVIGATION IMPROVEMENT IN THE LOWER OHIO RIVER VALLEY

Long before the first Europeans reached the Ohio River valley, Native Americans had settled along its banks and used the river to travel and trade among numerous settlements. These trade networks were quite extensive, especially during the long period of mound-building cultures, beginning with the Adena culture shortly before 900 C. E. and continuing through the Hopewell and Mississippian periods. While these cultures were extinct by the time of the arrival of the French in the Ohio Valley in the middle of the seventeenth century they point to the central role of the river, as a transportation artery, in sustaining permanent settlements of significant size.

Various Indian cultures were in the region before European contact, known sequentially as the Archaic, Woodland, and finally the Mississippian. They represent the earliest human occupation of the area. The Archaic and Woodland cultures have left little evidence with which to reconstruct their way of life. There is a great deal more evidence from the Mississippian culture which flourished in the central Mississippi and Ohio valleys before white contact, between 1200 and 1500 A. D. Distinctive earthen mounds, generally built on highlands near a river are characteristic of this culture. The mounds were part of settled villages, which were occupied for long periods by farmers whose cultivated fields were in the rich river bottomlands.

A review of the archeological literature suggests that after the decline of the Mississippian civilization around 1500 A. D. the Lower Ohio River Valley was sparsely settled. There is little evidence of settlements of any size or duration of occupation during the period following initial contact with white settlers and explorers. A number of tribes used the area as a hunting and fishing ground, using the rivers and their tributaries as well as the Buffalo traces that crossed the region. These tribes include the Creeks, Chickasaw, Choctaw, Shawnee, Yuchi, and Cherokee. All of these tribes suffered from disease during the eighteenth century that led to severe population decline. These diseases were the result of the initial exposure of Indians to European diseases from which they had been isolated for many generations. The sudden loss of population disrupted their traditional way of life and reduced their ability to resist incursions by European settlers. Klotter and Harrison in the *New History of Kentucky* estimate that by 1750 there were no more than three to four thousand Shawnee in all of Kentucky. (Klotter and Harrison,1997: 8)

The French were the first Europeans to enter the Ohio Valley and settle it. France had extended its North American possessions toward the Great Lakes very rapidly after establishing Montreal and Quebec early in the seventeenth century. They then moved down the Mississippi and along its many tributary streams, including the Ohio. Missionaries and fur traders spread across the lakes as well as the rivers and stream of the lakes region rapidly and frequently encountered Native Americans who described a great river flowing west and then south.

Whether Rene Robert Cavelier, Sieur de La Salle was the first to see the river or it was Louis Joliet and Pere Jacques Marquette, by 1674 the lower parts of the river were on French maps of America. The upper river remained unknown to the French for some years more. French interests were focused on the fur trade and looked to the Ohio and its tributaries as a transportation system to move furs to Montreal and Quebec, via the Great Lakes. The settlements established by the French were entirely concerned with protecting this trade route and operating it. The river as transportation artery was central to French settlement of the region and their economic development of it. “Early descriptions of the Ohio River emphasized its navigability, often stating that no serious problems were met in traveling except at the Falls.” (Johnson 1974: 21) Of course,

the early explorers had relatively small, shallow- draft vessels for which the natural channels were adequate and the shifting bars, rocks, and snags easily avoided. As Johnson goes on to say, "As the Ohio Valley was settled and extensive use of the rivers for marketing agricultural produce and manufactured goods developed, obstructions to navigation, because of the resultant delays and losses of boats and their cargoes, became more objectionable." (Johnson 1974: 21)

The first whites to enter the area appear to have been French fur traders following the Mississippi and Ohio river systems to the Tennessee. The French had long been active in the Mississippi Valley and had several settlements in the Illinois Country, as part of their extensive fur trade network. A 1701 French map depicts the Tennessee River accurately, indicating familiarity with the region. The French hunter and trader Timothy De Monbruen was active in the area between the rivers as early as 1769 before settling permanently at Nashville, Tennessee. He is one of the few French who were active in the area who can be identified by name.

British and American hunters, trappers, and land speculators were also active in the area, especially after the Treaty of Paris of 1763, at the conclusion of the French and Indian War, gave control of all the territory east of the Mississippi River to Great Britain. The work of Col. Richard Henderson of the Transylvania Land Company has already been mentioned. Col. John Donelson, another early settler of Nashville, was in the area from 1779-80 on a hunting expedition. Donelson met Henderson in the area between the Tennessee and Cumberland rivers in 1780 while Henderson was surveying the boundary line between North Carolina and Virginia, both of which had claims to the area. Henderson was working for North Carolina, while Dr. Thomas Walker and Daniel Smith conducted a similar survey for Virginia. The importance of the west to those in the east can be seen in the failure of the Revolutionary War to deter or delay these efforts to explore the west. The two colonies/states were unable to resolve their different interpretations of their boundary and the issue remained unresolved until 1860. By then the dispute was between the states of Kentucky and Tennessee, which had been formed from the western parts of the two coastal states.

The boundary surveyors were followed by other surveyors by 1783 when North Carolina began issuing land warrants for military serviced during the revolution. Land warrants were an established way to encourage and reward military service by cash short governments and service reward. The warrants were the vehicle for the early settlement of lower Ohio Valley. Many, if not most, of the early settlers came from North Carolina in the years after the American Revolution to take up land with warrants from their service in the Revolution. The earliest settlers built log cabins and established farms in the river bottomlands and along the creeks where the land was more fertile, there was a sure source of water, and the river provided transportation for surplus crops, once they were being produced.

The influx of settlers in far western Kentucky lead to some increase in conflict with the Indians. The United States interpreted the Treaty of Paris of 1783 that had transferred all of the land east of the Mississippi to the new government as extinguishing Indian claims and opening the land to settlement. The lack of Indian settlements in the area south of the Ohio made it easier for settlement to move forward, but conflict with the Indians continued and there was considerable interest in an agreement with the Chickasaw, the main Indian group with a claim to the area for a settlement that would make settlement safer. The Hopewell Treaty tried to do this, drawing a line at the Tennessee River, but as settlers moved into the area, they were drawn to the area west of the Tennessee as well.

Col. Richard Henderson of the Transylvania Land Company boundary agreed to the Treaty of Sycamore Shoals with the Cherokee in 1775. Henderson purchased recognition by the Cherokees

of the Transylvania Company's claim to all the land east of the watershed of the Cumberland River, opening it, he hoped, for unmolested settlement. The treaty created a line between Indian territory and lands open for settlement that followed the divide between the watersheds of the Tennessee and Cumberland rivers in the land between the rivers. In the Treaty of Stanwix in 1768 the Indians had ceded the territory between the Ohio and Tennessee Rivers. The Treaty of Sycamore Shoals was an attempt to avoid the conflict between Indians and settlers that had already become a regular aspect of life on the frontier, especially in Kentucky and Tennessee. The danger of Indian attack inhibited settlement and restricted the ability of the Transylvania Company to settle its land grants.

The Treaty of Sycamore Shoals did not accomplish what Henderson had sought. The Cherokees were not the only Indian tribe with claims to the territory and the other tribes did not feel bound by a treaty to which they had not agreed. The treaty did not eliminate Indian resistance to white settlement. In 1780, the Commonwealth of Virginia voided the treaty in the portion of the area involved that was within its boundaries.

The idea behind the treaty line reflects an important concern during early efforts to settle the region – security from Indian attack. Despite Henderson's attempt, deadly conflict between pioneer settlers and Indians was common.

The Hopewell Treaty of 1786 reserved all land west of the Tennessee River to the Chickasaw Indians. Although the Chickasaws did not occupy the territory or hunt in it with any frequency or regularity, it was closed to settlement as both the federal government and Virginia, which still claimed all of what would become Kentucky, honored the treaty. As settlement spread down the Cumberland and Tennessee Rivers pressure built to open the unoccupied and unused lands west of the Tennessee River for settlement. In 1818 Andrew Jackson of Tennessee and Isaac Shelby of Kentucky negotiated the transfer of this tract. The Chickasaw Purchase Treaty was signed in October, 1818 and ratified by the Senate in January, 1819. The treaty was known popularly as the Jackson Purchase and that name has remained attached to the westernmost sections of both Tennessee and Kentucky ever since.

While there were some settlers, primarily French and Metis and a few Americans, in the region at the time of the American Revolution, extensive settlement did not begin until approximately 1790 and the Ohio, and its tributaries, especially the Tennessee and Cumberland, were the major "highways" for settlers. The Ohio River Valley quickly passed through the pioneer, subsistence farming phase, and transportation became a critical concern for the future development of the region. Water transportation, the river, was the only practical way to ship the region's agricultural products to market or to bring in manufactured goods and other things that could not be produced locally. When local manufacturing began the river was important for bringing in raw materials and the distributing the manufactured products. The Ohio River, as the main transportation artery, played a central role in the economic development of the region from the very beginning of settlement and has played a significant role in the establishment and development of industry and communities ever since. While there were numerous settlements along the many tributary streams that flow into the river, the Ohio was the principal transportation link with the larger world and the focal point for trade and industrial development.

Such an important role for transportation and a transportation artery is not surprising. Central Place Theory, as initially presented by Walter Christaller in the 1930s, and developed by several generation of economic geographers since, considers transportation as one of the three principle factors in determining settlement location and development. Communities should appear at the interval of a day's journey, and at the mouth of tributaries, and at major obstacles to free

movement along rivers. Their development should be proportional to the productivity and size of their hinterlands. To a considerable degree the actual pattern in the lower Ohio River Valley, the focus of this essay, conforms to theoretical expectations. Pittsburgh is located where the Allegheny and Monongahela come to form the Ohio River. Louisville, the largest and most important place in the lower Ohio Valley, is located at the Falls of the Ohio, the most significant break in navigation on the river. Other lower Ohio Valley communities such as Evansville, Paducah, Smithland, Owensboro, and Henderson, among others are located at the confluence of significant tributaries. Their growth and relative size has been strongly influenced by the size and economic prosperity of their hinterlands. However, central place is not a perfect predictor. Cairo, Illinois, for example, has never reached the size and economic influence in the region that its location at the confluence of the Ohio and Mississippi Rivers would seem to predict.

There are several factors that explains this, some of them cultural. However, if we consider the concept of "points of attachment" set forth by Vance (1970), the case of Cairo and the overall urban hierarchy of the Ohio Valley becomes clearer. In a closed economic system, where most economic exchanges are internal, central place is a good predictor of location and hierarchy. In open systems, however, in which a significant portion of economic exchanges are external - with other economies - places appear that are much larger than central place would indicate. The classic example of this model is the development of colonial seaport towns in the United States, (and their non-development in the Tidewater of Virginia) whose size was related much more to their role in the a larger international maritime commercial economy, specifically as points that connected the nascent colonial economies to that larger economy than to the colonial economies themselves. The relative positions of Boston, Philadelphia, and New York in the national economy over time can best be understood in this way.

When the economy of the Ohio River Valley began to develop the Ohio River was the only effective way to move the agricultural products of the region to market or to bring in manufactured goods from the east and Europe. Because the boats available during this initial stage, flat boat, were limited to movement with the river the region developed a trade pattern that moved with the river. Agricultural products moved down river to New Orleans where they entered the world economy. Manufactured goods from the east and Europe, however, did not come to the Ohio Valley through New Orleans, but from Pittsburgh. Thus the region had two points of attachment to the world economy. New Orleans, of course, is well outside the Ohio Valley. Pittsburgh was established very early as a major city within the region because of its role as a point of connection with the larger national and international economy. When the development first of the keelboat and then, more importantly, the steamboat allowed two-way traffic on the river, Pittsburgh and several other places, principally Cincinnati and Louisville, had already established their positions as key places within the valley economy. With the exception of Lexington, Kentucky, nearly every place in the Ohio River Valley before 1850 with more than 500 people was a river town. Access to water transportation was the key factor in community formation and development. The initial advantage that these three cities gained has been a significant factor in their continuing role as the major economic centers in the region. Their relative position has also been constant.

Vance also helps to understand the growth of communities along the river. The majority of river towns served as points of attachment for their hinterlands with the larger economy. They were the places where goods were shifted from land transportation to water or from smaller vessels for navigating the tributary streams to the larger vessels of trade on the Ohio. The initial development of canals and railroads in the Ohio Valley reinforced these patterns because they were designed to facilitate shipping good to and from the river network. Seeing the communities that developed

along the Ohio River as points of attachment for their hinterlands is a much more useful approach than classical Central Place Theory.

Before turning to a discussion of the relationship between growth and river navigation in the specific communities of the lower Ohio Valley, it is important to understand the overall development of the region's economy and the role navigation of the river has played at different times.

Bigham (1991) outlines five distinct phases for the economic influence of the Ohio River on its region's development. (p. 131) The first phase, from pre-history to the American Revolution is the longest, but also the least importance for our purposes because, while navigation on the Ohio River was important to the region's growth and economic development, there few if any improvements in the natural navigability of the river. The main development of long-term importance was the increasing recognition of the richness of the resources of the Ohio Valley and the value of the river as a transportation artery that would facilitate the development of those resources.

The second of Bigham's phases, from the establishment of the American national government to the 1850s, is a critical period because it saw the establishment of numerous settlements and beginning of a regional economy. The basic patterns, both for settlements and the regional economy, that were established during this period persist to this day. While the size of communities have changed, the basic urban hierarchy of the lower Ohio Valley with Louisville at the top and Evansville as the secondary center have not changed. Similarly, the development of the economies of various communities remains largely linked to access to cheap water transportation. The three phases Bigham sets out following this, from the early 1850s to the early 1880s, the early 1880s to the First World War, and from the first world war to the present, can be seen respectively as the maturation of this river-focused economy, its decline after 1880 because of changes in transportation technology, largely involving the railroad, and finally the river's resurgence as the advantages of cheap water transportation and the region's coal reserves have brought it back to a central role in the economic development of the region.

The rediscovery of the river as central to the culture and economy of the region can be seen in the 1991 initiative of the humanities councils in the states bordering the river, "Always a River: The Ohio River and the American Experience." This initiative has resulted in the publication, to date, of two books (Reid, 1991 and Bigham, 1998) which focus in large part on the central place the river has played in the development of the region's economy. We are fortunate to have such recent, and well done studies that supplement and update Banta's classic work on the Ohio River.

Bigham (1991 and 1998) has focused on the relationship between the river and the economic development of the region more closely than any other scholar and his work is central to understanding the overall economic and community history of the Ohio Valley.

Population growth in the Ohio Valley was explosive. Despite glowing reports on the area's potential, such as that of Lewis Evans, a Philadelphian sent by the governor of Pennsylvania to scout the region in 1750, the geopolitics of mid-eighteenth century North America worked against large-scale settlement. Prior to 1763 the Ohio was controlled by the French who strongly discouraged settlement because it would interfere with the fur trade. There was also a notable lack of French people anxious to settle in North America, but that's another issue. After 1763 when Great Britain took control of the area between the Appalachians and the Mississippi, crown policy was to limit settlement to the eastern side of Appalachians. Thus, the valley was largely unsettled by Europeans at the time of the American Revolution, although its resources were very

well known from the reports of Lewis and British naval officer Thomas Hutchins who conducted a hydrographic study of the river in 1766 and a number of others.

Settlement of the region began once the restrictions of British policy were removed. It received further impetus when the port of New Orleans was permanently opened to American commerce by the Louisiana Purchase and finally Native Americans, who were encouraged to attack American settlers by the British through the early years of the nineteenth century, were defeated by General William Henry Harrison at the Battle of Tippecanoe in 1811.

In the first federal census of 1790, the population of the Ohio Valley was about 125,000. Twenty years later it was around 850,000. Further, the value goods cleared at New Orleans, which were $5 million in 1807, rose to $22 million by 1830. (Bigham, 1991, p. 135-6.) Jakle (1977) points out that in 1800 there were only 10 places in the Ohio Valley with more than 500 residents. By 1850 there were 300, including three with more than 50,000 residents - Cincinnati, Pittsburgh, and Louisville. The river, according to Jakle, was critical. "Towns grew along river routes, especially where people and commodities were exchanged between land and water routes." (p.123)

Critical to the growth of the region was the development of the flatboat trade with New Orleans, which allowed the development of commercial agriculture and commerce. With the access to markets that the Ohio River provided the region quickly moved from subsistence agriculture to commercial farming and the development of commercial houses, banks, and manufacturing, all of which support much larger populations than subsistence agriculture. The development of trade on the river led to the establishment of numerous communities along the river and its tributaries. The river trade stimulated the regional economy in two other significant ways, according to Bigham (1991), the development of a boat-building industry and the movement to improve the river and provide not only safer navigation, but the building of landings, warehouses and other structures. The boat building industry became an important part of the region's growth, not only providing transportation, but by solving transportation problems.

The earliest boats on the river after the canoes of the pioneer period were flat boats. As stated above they could only effectively move down river. An historian of urban development in the region, Allen J. Share (1982) has observed the consequences of "the difficulty of upriver travels during the age of keelboats, flatboats, and barges. The trip up the Mississippi and Ohio rivers from New Orleans to Louisville consumed between three and four months, while the journey from the Falls City to Pittsburgh required an additional month." The difficulties of moving goods upriver established the basic parameters of the region's economy -- locally produced products of all kinds went down river to New Orleans, manufactured goods also came down river through Pittsburgh. Flat boats did not allow direct exchanges between points downstream to points upstream and often required much longer journeys for goods than the simple distance between places - pork from Cincinnati, for example, had to go to New Orleans and then up the coast and overland to Pittsburgh, rather than going the much shorter distance upstream. The keel boat allowed movement both ways on the river, although they were still much more effective going with the river.

The introduction of the steamboat on the western rivers made the river a truly two-way highway and facilitated the integration of the valley's economy. It greatly expanded the potential for commercial agriculture and led communities to build landings and wharves to compete for trade. Steamboats also substantially reduced the time it took to ship goods. By 1838 travel time from Louisville to New Orleans had been cut from four months to six days. By 1860 more tonnage was

moving on the Ohio and Mississippi rivers than was carried by all the registered ships in the British Empire. (Hartley 1959: 15)

The new steamboats were larger than the flat boats and keel boats and began to call attention to the natural obstacles and inefficiencies of Ohio River navigation. The shifting channels, sand bars and snags were now harder to avoid and the seasonal fluctuations in the depth of the river became a serious concern. As the size and scale of the Ohio Valley economy grew and especially after moving large quantities of coal became an important part of that economy in the 1850s these issues became increasingly important and resolving them became more urgent.

The Falls of the Ohio at Louisville had long been recognized as the major obstacle to the free movement of shipping on the river. In a very real sense the Ohio Valley economy had been divided into two economies – the Upper Ohio Valley and the Lower Ohio Valley -- which connected at Louisville. (Jakle 1991: 123) Louisville initially benefited from this as the transshipment point for all shipments on the river. The heavy labor demands for moving goods around the falls created jobs and formed the base for the city economy. Louisville's nickname, The Falls City, reflects the significance of the falls in the city's growth and development. The completion of the Louisville and Portland Canal in 1833, combined with the introduction of the steamboat allowed Louisville to build on its initial advantage and firmly establish itself as the commercial center for the lower Ohio Valley.

Prior to 1850 problems with river navigation offered as many opportunities as they did obstacles for growth because of the generally strong commercial agricultural economy in the Valley. As the demand for coal increased, for example, the difficulties inherent in moving coal barges, which had deeper draft than steamboats during the parts of the year the river was relatively low, provided a strong incentive to develop the coal fields of the lower Ohio Valley in southern Illinois, southwestern Indiana, and far western Kentucky. General manufacturing followed a similar course in the manufacture of machinery and farm equipment. Evansville became an important regional manufacturing center in large part because of the accessibility by water of coal and iron ore.

Growth within the region spurred technological development of river craft and increased the need for improvements in the river. Periods of low water became increasingly problematic for the movement of goods. While the river remained an important, primary transportation method through the 1880s, the railroads began to develop routes that paralleled the river and competed directly for freight.

While Evansville used a packet service to communities on the upper Tennessee River to expand its wholesale trade and foundry operations into the 1920s – many Tennessee River towns have cast iron front buildings inscribed with the names of Evansville foundries -- and the shipbuilding and repair yards at Paducah continue to operate, after 1880 packet service generally declined and the railroad came to the fore as the primary, and dominant, mode of moving goods within the Ohio Valley. Most growth in Louisville, for example, was related to the railroad between the 1880 and World War I. Paducah saw its growth during the same period focus on the railroad bridge across the river and the extensive locomotive and repair shops of the Illinois Central Railroad. Except for Evansville, the Indiana river towns declined in economic importance and population. Communities, like Smithland, Kentucky, a relatively small river town at the confluence of the Tennessee and Cumberland rivers, near the Ohio, declined dramatically when they failed to secure railroad links. Henderson, Kentucky, on the other hand, received a strong boost when it did gain a rail line. (Bigham, 1991, p. 160ff.) The railroad was not affected by

fluctuations in river level, which had emerged as a significant problem as the scale of the economy had grown.

River traffic, of course, did not end, but shifted to a greater proportion of heavy bulk goods while continuing as the primary means of transportation for farm goods where the railroad was not available, or in some isolated cases, where rates heavily favored the river and where local conditions presented no serious obstacles. Call for improvements in river navigation escalated with the formation of the Ohio Valley Improvement Association in 1895 and the Inland Waterways Commission in 1907. Finally, in 1910 Congress authorized a series of lock and dams and a nine foot channel from Pittsburgh to Cairo, which would provide dependable year-round navigation, solving the problem that had given the railroads the opportunity to replace the river as the primary transportation network in the Ohio Valley.

The demands of the First World War on industrial production led to a rediscovery of the benefits of river navigation and increased funding for improvements on the river. While the full benefit of this resurgence were blunted by the economic depression that started in 1929, boat building in Paducah, Kentucky and Jeffersonville, Indiana revived. Commercial towing companies and related construction, maintenance, and repair facilities, became an important part of the Paducah economy and have remained such. (Blagg, p. 14) Several depression era projects, especially the Tennessee Valley Authority's flood control and electric generating activities, established a foundation for future growth in the region that would create new opportunities for community growth and economic development and new challenges for river navigation.

After the Second World War the Ohio Valley enjoyed an economic boom that was based on the low cost of moving bulk goods on the river and the region's low electric power costs, which were due in large part to the same factor. Between 1946 and 1953 some 2500 new industrial plants were built in the Ohio Valley on or near navigable streams, an investment of approximately $5.5 billion. (Bigham 1991:165) Steam electric plants in the region grew because of the advantages of cheap transportation for coal by water from both the Appalachian and lower Ohio fields. The ability to move large quantities of petroleum, coal, sulfur, and other raw materials led to the expansion of the chemical industry, at Calvert City, Kentucky, near Paducah. In 1951 General Electric chose Louisville for the site of its huge Appliance Park plant. One of Louisville's advantages was its ability to receive steel from Pittsburgh by water year round. Alcoa chose Evansville for a major smelter in 1957 due to water transportation and cheap electricity. A number of metal, especially aluminum, fabricating firms have located manufacturing plants facilities along the Ohio in Hancock County, Kentucky for the same reason. While river transportation has not been a major source of direct employment for some time, its indirect impact on employment and thus economic and population growth became more important after World War II, after a period of decline, and remains substantial.

Rather than operating as separate systems, a number of river-truck-rail terminals have been developed to integrate transportation within the region. Tonnage on the river has increased steadily from 34 million in 1940 to 80 million in 1960, 151 million in 1977, and 239.8 in 1997. A narrower range of products are moved on the river, principally coal and coke, but also petroleum products, aggregates, iron and steel, and chemicals. The revival of river traffic has been due to a combination of technological advances -- the diesel tow boat and larger steel barges -- but also to the canalization of the river through a series of locks and dams that has solved the problem of seasonally low water and allows larger tows to operate efficiently year round.

In a report prepared in 1964 for the Kentucky Department of Commerce, Bramlett and Pratt referred to the Ohio as one of the most important resources of the region. They went on to develop this point more fully,

"The reasons for the present growth in river tonnage are straight forward. First, industry migrates to areas where an ample supply of water and low cost power is available, and where the possibility exists for low cost transportation of either raw materials, finished goods, or both. Secondly, the modernization and construction program of the Corps of Engineers on the Ohio River System will permit the handling of bigger equipment at a faster rate and at lower cost to barge traffic. Last, the continuing improvement in the design of tow, barge, and dock equipment [permits more efficient haulage and handling of raw materials by river transportation." (Bramlett and Pratt 1964: 7)

The preceding has offered a "macro" level view of the relationship between improved river navigation and the economic growth of the communities of the lower Ohio Valley with sufficient examples to demonstrate the key role that river navigation played in the economic development of the lower Ohio Valley. There is another useful and potentially critical level of analysis, the "micro," or, specifically in this case, community-level. Communities did not benefit uniformly or automatically from improvements in river navigation. Because of location, existing industry, enhancements to river traffic, and local entrepreneurship some communities made more of the opportunities improved river navigation offered. Initial advantage is an important factor in community growth and economic development and to a certain extent acts as conservative, inertial factor.

Louisville, for example, has remained an important regional center through a succession of changes in the place of river navigation in the regional economy and appearance of other modes of transportation, some quite different from river navigation. United Parcel Service has established its major air freight service hub at the Louisville airport at least in part because of the ability to use river barges to transport jet fuel. Conversely, Cairo has remained a minor city, that struggles with a broad range of social and economic problems, despite the potential its location has offered throughout its history. While the "big picture" provides an important and necessary perspective for local development, the full impact improvements in river navigation in the Ohio Valley can only be fully understood if we look at the local level.

Along the 381 miles of river between Louisville, with a 1990 population of just under 270,00 and Cairo with fewer than 5,000 there are a range of communities. Each community has its own history of interaction with the river and its own particular insight to offer.

Louisville was founded in 1779 on the south bank of the Ohio River opposite the Falls of the Ohio. Its early growth was slow in large part because its hinterland was slow to develop due to problems with Native Americans, who were encouraged by the British in the Great Lakes area to attack settlers, thus protecting the fur trade. The potential of Louisville's location was clear. In 1783 the Commonwealth of Virginia designated it as a Port of Entry. In 1799 the federal government made the same designation. In 1800 Louisville had a population of only 359 and very little trade or commercial activity due to the limited growth of its potential hinterland. It was a regional center for the distribution of goods brought up from New Orleans and for assembling cargoes for shipment to New Orleans, but its hinterland population was so small and scattered that Louisville remained very small. In 1810 its population was 1357, a sizable increase since 1810, but still a very small community.

Two events in 1811, however, opened the way for Louisville to become the leading city in the lower Ohio Valley. The first was William Henry Harrison's victory over the Shawnee at Tippecanoe, the beginning of the end of British-inspired Indian problems for settlers in the Ohio Valley. Harrison completed the opening of the Ohio Valley to large scale settlement with his victory over Tecumseh at the Thames in 1813. The second important event was the first steamboat trip on the Mississippi and Ohio rivers by the *New Orleans*. The 1815 voyage of the *Enterprise* from New Orleans to Louisville in twenty-five days made the potential of steamboats clear. By 1817 the *Washington* had completed a round trip between New Orleans and Louisville in forty-five days. Alan Share points out the significance of steamboats for the Ohio Valley region, "By slashing distances and travel time, steam navigation transformed the Ohio Valley into a settled and cultivated region in a single generation. A northward and eastward movement of goods came to supplement downriver commerce, as steamboats and a series of canals constructed in the 1820s and 1830s connected the Ohio Valley to the Great Lakes and the Atlantic seaboard." (Share 1982: 31)

Louisville quickly became the focal point for the now rapidly expanding two-way trade between Pittsburgh and New Orleans, and all points in between, because the falls remained an obstacle to navigation. With the increase in commercial activity and river shipping came increased demand for a way around the falls. Louisville was a "break bulk" point for all cargoes. As Conrod (1976) discusses, such "break-in-transit" points require many services, such as men and equipment to move goods, warehouses and other storage facilities, hotels and restaurants, and offices to coordinate the transfer of cargoes. All of these activities create entrepreneurial opportunities and economic opportunities.

Early industrial development in Louisville was closely related to river navigation and the Falls City's place as a break-in navigation. In 1853 *DeBow's Review* succinctly summarized the important role the falls had played in Louisville early growth, "The falls in the Ohio River arrested the course of navigation, and made the stoppage necessary. This stoppage produced commercial wants – commercial wants, a city." Shipbuilding and equipping riverboats were among the first industries to develop, followed quickly by iron foundries and steam engine fabricators. In 1812 John Skidmore established the first iron foundry in Louisville and five years later Thomas W. Bakewell and David Prentice began manufacturing steam engines. These were joined quickly by flour mils and a distillery to process, in very different ways, the grain crop of the emerging city's hinterland. By 1815 the river traffic had led to the establishment of four rope walks and a like number of soap factories, two tobacco manufactories, a steam saw mill, and a stoneware factory.

In 1825 the Louisville and Portland Canal Company was incorporated and the company completed a canal around the Falls of the Ohio in 1833. While the canal made it possible to avoid the added expense of transferring goods from one ship to another, Louisville's economic growth accelerated and its population doubled between 1830 and 1840 and again between 1840 and 1850 to 43,194. Louisville became the regional metropolis for the lower Ohio Valley because of its location on the Ohio River during the period when river navigation was the only economically viable mode of transportation for the region's products.

Two things helped fuel Louisville's growth and rise to regional dominance, both of which were closely tied to river navigation. One was the expansion of established industries directly related to river navigation such as manufacturing steam engines, boat building, and servicing and supplying the river industry. The second was processing the agricultural produce of its hinterland and shipping it out into the national market. As improvements in navigation made it possible to ship goods more cheaply to market, population and agricultural products increased in the hinterlands

of Louisville, creating more opportunity for industrial growth in processing these products. Distilling, milling, tobacco and hemp processing, and food processing developed and expanded. An outgrowth of the forges and other metal factories was the development in Louisville of a stove industry. By the 1850s the Ohio Valley led the nation in the production of pork products – Cincinnati was known as Porkopolis – flour, liquor, lumber, and agricultural machinery. Louisville was a major producer of hemp rope and tobacco products. All of this was made possible by river navigation.

With the tremendous increase in commercial and industrial activity the river became a focal point of the economy and as Kreipke points out the volume of traffic on the Ohio, especially west of Louisville was dependent on the depth of water in the river and the depth fluctuated seasonally during the year. Low water made stretches of the river more hazardous, slowing and at times stopping traffic or forcing boats to carry less than a full cargo to reduce their draft. The economic impact of the depth of the river was so great that it became a matter of public attention, with the rise and fall of the river being regularly reported. In 1854 a Louisville editor wrote that the low level of the river would reduce fall trade by one-third. Louisville's business and community leaders supported river transportation improvement projects to resolve the problems caused by fluctuations in the river level. They also supported the development of packet lines on the Ohio's tributaries and more importantly for the long term future of Louisville railroads. According to Share they did not see the railroad replacing the river entirely, but rather "they perceived the beginning of a new era in river navigation in which fast packet boats would play a major role, making frequent trips on tributary waterways and serving as feeders to the railroads." (Share 1982: 67)

Louisville's growth between 1880 and the First World War was due to its rail connections rather than the river, continuing a trend that had begun in 1856 when tonnage carried by steamboats had begun to decline. (Bigham, 1991) Towboats and barges, however, continued to carry very bulky cargoes on the river and it remained an important part of the region's transportation system. The First World War refocused attention on the benefits and advantages of river navigation. After 1930 there was a resurgence in river shipping and the construction of new facilities that connected barge, rail, and truck traffic into a coherent system. The truck-barge terminal in Louisville was the last such facility moving downstream from Pittsburgh. In 1951, as mentioned earlier, General Electric located its Appliance park, a large, state-of-the art facility in Louisville because of the availability of year-round water transportation for steel from Pittsburgh to Louisville. More recently United Parcel Service chose Louisville as its major air hub because of the availability of river shipping for jet fuel.

The first large commercial center moving downriver from Louisville is Owensboro, Kentucky. The first permanent settlement at what had been called Yellow Banks by travelers on the Ohio River was in the late 1790s by William Smeathers (sometimes spelled Smothers). In 1816 community was platted and formally surveyed. The legislature named it Owensboro after Col. Abraham Owen, who died at the Battle of Tippecanoe. (Kentucky Encyclopedia, p. 700.)

Prior to the Civil War Owensboro was principally a commercial center for a rich agricultural hinterland. James Roger established the first tobacco warehouse in the city in 1837. Several others followed quickly and there were at least five operating in 1860. Following the War Owensboro became a major tobacco processing and shipping center for Green River tobacco. Humphrey's 1883 history of Daviess County lists eighteen firms established after the war and still active when he wrote. Most of the tobacco processed in Owensboro was stemmed and packed in hogsheads for shipment to London and Liverpool, with the lower grades of leaf intended for the German market. (Humphrey 1883: 336-340)

During the 1880s a number of distilleries were established in the city. Humphrey notes the very important role river shipping played in the development of this industry. “Distilleries existed here in a very early day, but it is only within the last few years that the business has increased by anything like its present proportions. There are at present [1883] eighteen distilleries within the county. With few exceptions more grain is grown here than in any other county in the State. This fact accounts for the abundance of and cheapness of material. The Ohio River furnishes shipping facilities of an unequaled character, and the railroad running south from Owensboro is always ready to carry freight on reasonable terms. It is mainly for these reasons that the large distilling business of the county has been carried on so successfully, while it has languished and died in other sections of the country.” (Humphrey 1883: 341) Humphrey goes on to identify and describe briefly the eighteen distilling firms operating in Daviess County.

Humphrey describes a number of other industries and individual firms. Wagon manufacturing and the manufacture of parts for horse-drawn vehicles was well represented by a number of firms, including Troutman, Rarick & Co., John J. Hill’s Hub and Spoke Factory, Owensboro Wheel Company, Southern Wheel and Handle Company. There were several furniture and wood products firms, including J. G. Delker, Manufacturer of Furniture and Chairs; John R. Osborne & Son’s Planing-Mill; and J. H. Taylor’s Planing-Mill. The Owensboro Foundry, doing business as Guthrie, Long & Bransford, had been established in 1868. There were also several flour mills, brickyards, and a cigar manufacturer. Most directly related to river transportation were the People’s Wharf-Boat and Transfer Company, organized around 1869; the Owensboro and Rockport Transfer Company, incorporated in 1882; and the Steam Ferry Company formed in 1882. (Humphrey 1883: 345-351)

One of the most prominent of Owensboro’s industrial fiirms, the Owensboro Wagon Company was organized in 1883 and remained in business for sixty eight years, producing 6,000 wagons a year at its peak. For a time it was the largest business in the city and nationally known for its quality products. As the automobile replaced the horse the firm shifted to producing truck bodies. (Potter 1965: 35)

By the 1890s Owensboro had become a diverse industrial center with wagon and buggy companies, foundries, brick and clay plants, as well as tobacco factories ands distilleries. The river was an important part in the city’s economic base. “Three railroads linked it to markets, and numerous packet lines offered connections by water. The towing industry opened opportunities for shipping grain and coal to markets throughout the Ohio and Mississippi systems.” (Kentucky Encyclopedia, p. 700-701.)

During the first half of the twentieth century Owensboro grew to be the third largest city in Kentucky, due to its diverse industrial economy. The largest employer in Owensboro was Ken-Rad a firm that began in the late nineteenth century as a light bulb manufacturer and moved into vacuum tubes for radios and televisions. By the 1960s Ken-Rad, which had been sold to General Electric in 1945, employed more than 6,000 people. Owensboro’s diverse industrial sector included a number of industries that centered on the river and the availability of inexpensive water transportation for their raw materials and finished products. One such firm was the Owensboro River Sand and Gravel Company, organized in 1914. They used dredges to pump river sand into barges, which were floated to Owensboro and unloaded. Later the firm developed a river-rail terminal for loading and unloading steel and other bulky, heavy goods. They also opened a quarry in Meade County and shipped crushed lime by barge to Owensboro for processing by the Owensboro Concrete Company. Throughout its development, river shipping has been central to the firm’s success. (Potter 1965: 36) Other industries that operated in

Owensboro during the first half of the century were meat packing, grain shipping and processing, steel, chemicals, plastics, electronics, and the long-established distilling and tobacco industries.

During the 1970s manufacturing in Owensboro declined and the city's economy came to be dominated more by service industries. The river, however, has continued to play an important role in the city's economy. "[T]he development of the Owensboro Riverport enabled many industrial shippers to operate their own barge-loading facilities, capitalizing on the city's primary transportation resource, the Ohio River." (Kentucky Encyclopedia, p. 701.) Processing and shipping soybeans and corn by rail and barge is a major industry in Owensboro today. Tobacco remains important through the Pinkerton Tobacco Company, the Field Packing Company, established in 1914, continues the meat packing industry in the city, and the Glenmore Distillery Company still operates.

The second largest city in the lower Ohio Valley for most of its history has been Evansville, Indiana. Col. Hugh McGary, Jr. founded Evansville in 1812. The first plat for the community was done in 1814, but it was replatted in 1817 and incorporated as a village in 1819, one year after it had been named county seat of Vanderburgh County. Evansville is located on a sharp bend in the Ohio River nine miles below the confluence of the Green River with the Ohio and about half way between Louisville and Cairo. The bend in the river combined with Pigeon Creek to give Evansville an excellent harbor. The Green River, and several navigable tributary streams, flowed generally north through land in Kentucky that was both rich agriculturally and a major coal field. In 1836 Evansville was a terminus for the Wabash and Erie Canal. In 1847 it was chartered as a city.

By 1847 Evansville was an important port on the Ohio, the most important between Louisville and Cairo, serving as the major commercial and trading center for the Green, Barren, Cumberland, Tennessee, and Wabash river valleys in southwestern Indiana and western Kentucky. Evansville served as the major transshipment point for cargoes going between the Ohio-Mississippi river system to the smaller western tributaries of the Ohio, the Green, Barren, Cumberland and Tennessee rivers in Kentucky and the Wabash and the White in Indiana. Large amounts of corn, oats, wheat, hay, pork, bacon, tobacco, and potatoes from those areas moved south from Evansville. Between 1848 and 1852 a 2000 foot wharf was constructed to accommodate the city's commerce. (Conrod, 196) It also benefited from a railroad connection with Terre Haute, which was in operation by 1854.

As in the case of Louisville the commercial activity generated by river shipping led to the early development of industry. The river allowed the movement of raw materials to Evansville and the shipment of finished goods out along the same trade routes used in moving agricultural products. Flour milling and tobacco processing, lumber and wood products, including furniture manufacture developed in Evansville as large scale industries, as fairly direct outgrowths of its river commerce. Foundries and machine shops, another large-scale industry in nineteenth-century Evansville, grew out of the needs of the river industry itself. The most interesting of Evansville's early industries in terms of the importance of river navigation was cotton processing. The boats that took the agricultural and manufactured products of Evansville returned with cotton that was spun and woven in the city. Slaughtering and meat packing, brewing, clothing manufacture, and carriage and wagon making were other important industries in nineteenth-century Evansville. Like other river cities the railroad became more important in economic development after the Civil War. However, Evansville sustained a regular packet service along the Green, Tennessee, and Cumberland rivers, areas that did not see railroad development until later.

During the Second World War, the Missouri Bridge and Iron Company built LSTs in Evansville and employed 19,500. Their subcontracts with twenty-seven local firms, many of who traced back to the industrial beginnings of Evansville, and other defense work totaled $300 million. (Bigham 1991:164.) In 1957 Alcoa established a major smelting facility at Evansville to take advantage of the water transportation offered by the river and also the region's inexpensive electric rates, which are due to a considerable extent to the ability of power generators to use coal from Appalachia and the coal fields of the lower Ohio Valley that can be cheaply transported by water.

Across the Ohio from Evansville is Henderson, Kentucky. Henderson was founded in 1797 on the site of an earlier settlement know as Red Banks, which had been established in 1791. Slightly down river from the confluence of the Green and Ohio rivers, the community was named for Col. Richard Henderson, promoter of the Transylvania Company, who had obtained a land grant to the area from the Virginia Assembly in 1778.

Very early in its history Henderson emerged as an important river port, its location on a bluff, above the flood plain, gave it an advantage over other Kentucky river towns that were periodically flooded. In 1810 the community achieved legal status as a city. Among the community's businessmen in this early period was general store keeper John J. Audubon. The steamboat *New Orleans* called at Henderson on its historic voyage on the Ohio. By 1814 a tobacco warehouse had been built in Henderson and the connection between the river and the city's industrial development firmly established. Arnett describes the relationship in a straightforward manner.

"For the first 90 years, Henderson industry was dependent on the river: dams on the Green made that river navigable on a year-round basis, but the summer droughts limited the use of the Ohio to shallow-draft vessels. This became especially critical after 1811 when steamboats came into use. A jetty dam was built south of Henderson which resulted in the loss of several hundred acres of fertile farm land, with little success in deepening the stream.

"Except for industries that catered to local needs, e.g. lumber and grist mills and blacksmiths, the two products made for export were tobacco and distilled liquor. These could be held in storage until the river was navigable." (Arnett 1976: 170)

The arrival of railroads in Henderson, specifically the Evansville, Henderson & Nashville in 1869 (connecting to Nashville in 1871) and the Louisville, St. Louis & Texas in 1889, and the construction of a railroad bridge across the Ohio in 1885 made year-round shipping possible. (Kentucky Encyclopedia: 423) The city had eighteen tobacco factories by the early 1890s with another thirty-three in the county shipping over 12 million pounds of dark tobacco each year. By the early 1920s this had risen to 40 million pounds. (Arnett 1976: 170) Few of these "factories" did more than ship tobacco. Among the exceptions were Robards-Kitchell Manufacturing Company (later J. D. Robards & Co.) which made Greenville brand chewing tobacco starting in 1883 and The Hodge Tobacco Manufactory (1884), and later the Reichert Cigar Factory. The Henderson Tobacco Extraction Works made insecticide from nicotine extracted from waste tobacco. In 1911, it was incorporated as the American Nicotine Company. (Arnett 1976:171)

Early farmers in the area made grape wine and fruit brandy and a Mr. Melton was making and shipping out via the Ohio River twenty-five gallons of fruit brandies a year before the Civil War. (Starling 1887: 517) Shortly after the War, D. R. Burbank built the first whisky distillery in Henderson. In 1872 Starling & McClain established a second distillery. In 1880 W. A. Winstead and N. B. Hill began distilling whisky as Hill & Winstead and their Silk Velvet Whisky was

produced just before World War I. A third major distilling business in Henderson was the E. W. Worsham Company, later known as the Kentucky Peerless Distilling Company, established in 1881 by E.W. Worsham and J.B. Johnson. Peerless Distilling was an extensive operation with three large aging houses, a cooper shop and barrel storage building, and grain bins. Their Peerless brand whisky stopped production to save corn during World War I and never reopened due to prohibition. The last of the large scale Henderson distilleries was Wither, Dade, & Co., established in 1881 by J. E. Withers, H. F. Dade, and Capt. Charles G. Perkins.

The Henderson Brewery opened before the Civil War and operated until prohibition, except between 1885 and 1887. Efforts to reopen in1933 were thwarted by extensive vandalism to the plant while it was closed. (Arnett 1976:171)

Another nineteenth-century industry that depended to a considerable extent on river transportation was the Henderson Coal and Mining Company, incorporated in 1875 to develop coal reserves in the Green River area. In 1882 it was renamed the Henderson Mining and Manufacturing Company and built an ice plant adjacent to the mine.

Other industries developed primarily to serve local markets, but all used the river to some extent to move raw materials in and finished product out. Data from the nineteenth century does not allow a neat distinction between river and rail as the means of transit. There were two textile mills, one woolen and one cotton, in Henderson during the nineteenth century. The Henderson Woolen Mill was incorporated in 1882 and in 1886 began producing ready-to-wear pants, known as "Kentucky Jeans." The Henderson Cotton Mills, organized in 1883, was the city's largest industry in the late nineteenth century. In 1922 it was sold and continued as part of Consolidate Textile Corporation, it operated until 1931.

Henderson was also a center for manufacturing horse-drawn vehicles. George Delker Company began making buggies in 1863. The Henderson Buggy Company was organized in 1882. A 1913 city directory listed these two and Delker Brothers and the Park Carriage Company. While the automobile essentially ended the horse-drawn vehicle industry, Delker Brothers converted to manufacturing furniture and lasted until the 1970s. The Henderson Wagon Works building was acquired by H. J. Heinz, but the tomato cannery they established was short lived. (Arnett 1976:173)

The period 1916-1937 was hard on Henderson. The rise of the automobile closed its vehicle plants and prohibition did the same for its distilleries and brewery. The tobacco market, its last "export" industry was hard hit by changes in the international market. Henderson County lost population between 1900 and 1930, falling from 33,000 to 26,295.

The revival of industry in Henderson after 1937 was related to the Ohio River, but to flooding as much as navigation. Henderson was the only major community between Louisville and Cairo that did not experience major flooding in 1937. A Board of Trade was established in 1938 and its Industrial Committee began to rebuild the city's industrial base which had shrunk significantly. During World War II the Atmospheric Nitrogen Corporation built a plant in Henderson. In 1950 the plant was acquired by Spencer Chemical Company and began producing agricultural and industrial chemicals. The inexpensive transportation for bulky goods was a key factor in the plants establishment. By 1950 it had a payroll of $1.4 million., but the plant was closed and its operations moved to Louisiana when it was acquired. The Agrico Chemical Company came to Henderson to make fertilizer for the same reason - availability of low cost water transportation. More recently the city and county have stressed development of a riverport as a central factor in

their economic development strategy, which attracted several in large firms including Anaconda Aluminum and Firestone Steel Products. (Arnett 1976: 176-177.)

Paducah, Kentucky is another Ohio Valley community whose growth and economic development have been strongly shaped by he river. Paducah is located at the confluence of the Tennessee and Ohio Rivers and near the confluence of the Cumberland with the Tennessee and the Ohio with the Mississippi. The potential of the site was recognized early on and George Rogers Clark claimed the site in September of 1795. Problems with access to the land, which was west of the territories purchased from Indians delayed settlement. The Jackson Purchase in 1818 opened the land for settlement. Clark's brother, William (the Clark of Lewis and Clark), took up the project of developing the site. A town was platted on June 18, 1830 and named Pekin. The federal census that year recorded 105 residents. The name of the small community was soon changed to Paducah, after a legendary Indian chief. Paducah's initial development was almost entirely related to its role as a river town, only slowly developing industry that was not related, directly or indirectly to the river. The river-related industries that did develop, did so very quickly. Shipbuilding and boat repair yards sprang up and encouraged the development of the second wave of industries in Paducah – iron foundries, rope and cordage factories, and lumber mills. By 1850 Paducah prospered handling the agricultural produce of its hinterland, principally tobacco, flour and meal, strawberries, livestock, and wood products including sawn lumber, railroad ties, and barrel staves. Little processing of these products was done in Paducah. These diverse and rapidly growing industries attracted many people to Paducah, including German and Jewish immigrants. By 1850 Paducah's population was 2,428 twenty times what it had been in 1830. (McCracken County: 15.)

Paducah served as an entrepot for cargoes moving along the Ohio River for communities on the Tennessee and Cumberland rivers. The larger steamboats that operated on the Ohio preferred to drop cargoes for communities on the tributaries at a convenient port on the main channel rather than sail up and down the smaller streams. This helped Paducah dominate Smithland, an early rival, that began as an entrepot to serve the Cumberland River. Initially, Paducah's complementary area was limited the Tennessee River, with Smithland, which is located at the confluence of the Cumberland and the Tennessee, performing the same function for the Cumberland. Within five years of its founding work had begun on docks and other improvements along the river. Throughout its history Paducah has served as commercial and wholesale grocery center for a substantial region in southern Illinois and far western Kentucky. By 1860 the wholesale grocery trade exceeded a million dollars. (McCracken County:15.) This region, however, has long been very poor and Paducah did not gain as much advantage from its role as cities with economically more vibrant hinterlands.

The Civil War disrupted economic development in Paducah. The same location that had fueled Paducah's rapid growth before the War made it a strategic location during the War. The Union Army, under General U.S. Grant occupied Paducah at the beginning of September 1861 and Federal troops remained in the city throughout the War. Because Paducah's economic orientation before the war had been strongly to the South, there were strong pro-Confederate tendencies in the city, especially among its business and commercial community. A number of Paducahans were arrested during the War for sedition or other crimes and many were forced to relocate.

Following the War the city pursued a conscious strategy of industrial development under the leadership of Mayor Meyer Weil, a German Jewish immigrant. (McCracken County: 15.) The transportation advantages afforded by the Ohio and its tributaries were central to this strategy. Packet services based in Paducah moved people and goods on the rivers and the city emerged as a

major shipbuilding center, with about a third of its workforce working in the industry. (McCracken County: 16.)

Throughout the nineteenth century Paducah competed unsuccessfully with Evansville for regional supremacy. The railroads contributed a great deal to Paducah's development in the second half of the nineteenth century. The first rail lines to reach Paducah were north south lines, the first the Mobile and Ohio, followed by a Nashville to the Ohio River line and the Illinois Central. Paducah emerged as a major railroad repair center and the Illinois Central locomotive shop, the third largest in the world, was the community's largest industry for several generations before it closed in the early 1950s when diesel locomotives replaced steam. While the railroad assumed a more visible role in Paducah's economy in the first few decades of the twentieth century, river industries remained an important foundation for the local economy and became increasingly important within the regional economy.

Paducah has perhaps benefited more from the revived awareness of the importance of river navigation after World War II. Just as the Illinois Central locomotive shop was closing, Paducah was chosen as one of two sites, the second also in the Ohio Valley at Portsmouth, Ohio, for a major nuclear facility, a gaseous diffusion plant to produce high grade uranium and plutonium. One important reason why Paducah was chosen was the good river transportation the city enjoyed. Another, the availability of low cost electricity is in large part due to river transportation as well. The nuclear plant attracted a large workforce and helped fuel a doubling of Paducah and McCracken county's population. (McCracken County: 17.)

Calvert City, Kentucky, just upstream from Paducah in McCracken County, is an outstanding example of the importance of river navigation in industrial development. A large number of chemical plants have located along the river to take advantage of the inexpensive transportation for their bulky raw materials and finished products as well as the region's low electric rates.

Paducah has become a major service center for the river barge industry in the last fifty years due to its location near the center of the Ohio-Mississippi system. In recent years the Seamen's Institute of New York established a river navigation safety training institute in the city and has sponsored a River Heritage Museum to highlight the city's long term relationship with the river.

The last important commercial and manufacturing center on the Ohio River is Cairo, Illinois. Cairo is located at the confluence of the Ohio and the Mississippi. In 1856 amid predictions that Cairo would soon surpass St. Louis, Louisville, and Cincinnati it was proclaimed the Pittsburgh of the west. Lantz points out that "Speculators we impressed with the fact that Cairo lay at the head of large steamboat navigation, usable in summer and winter, at the point where Missouri, Kentucky, and Illinois come together. The developers saw tremendous possibilities for a transshipment point there. The belief that these conditions would sustain Cairo's growth was reiterated time and time again. (Lantz 1972: 7)

Comeaux makes the same point, slightly more generally, when he identifies the two great themes in Cairo's history as first, its potential as an entrepot, a promising point for the gathering and dispersal of goods, and second, its potential as a gateway connecting North and South along the Mississippi and Ohio rivers. (Comeaux 1966:19)

There were several unsuccessful efforts to settle the site of Cairo beginning in 1702. George Rogers Clark visited the site in 1779 but rejected it a location for a fort due to its being "Often ten feet under water. He built Fort Jefferson on the bluff across the river near present-day Wickliffe, Kentucky instead. In 1818 an Act of Incorporation was passed but little was done beyond drawing

up a plat map. In the late 1830s the Cairo City and Canal Company was formed to build a city and a canal connecting the Cache River with Cairo. Initially successful, the community had a population of about 2,000 in 1840 and supplied many passing steamboats with firewood and other supplies. However, problems with flooding and the companies reluctance to build levees or sell, rather than lease, land brought on a severe crisis. By 1845 there were only 113 people in Cairo and the next year the Cairo Property Trust acquired the city. Much of Cairo's economic activity took place on wharf boats rather than on land because of the frequency of flooding. Charles Dickens passed through Cairo and provided a highly negative description of the city and its population in his *American Notes*. (Lantz 1972:14, 12) The population stood at only 242 in 1850.

Prior to 1856 when the Illinois Central Railroad was completed to Cairo, the city's economy was almost entirely dependent on river traffic. Such traffic was sporadic because there was little economic activity in Cairo's hinterland to create cargoes going out or demand for goods coming in. If there were no passengers for Cairo or no need for firewood or other supplies, boats simply steamed by. Conditions upstream or downstream also affected shipping volume, making it highly erratic. While there were efforts to develop a packet service and establish Cairo as a regional transshipment point, they were largely unsuccessful due to the low level of economic activity in the immediate area.

The arrival of the Illinois Central Railroad, which had selected Cairo as its southern terminus, in 1856 opened up opportunities for Cairo by combining rail and river transportation. The upsurge in activity was dramatic. "Just prior to the Civil War, about a hundred steamers per week were reported. There were about two hundred people a week arriving at the St. Charles Hotel, a good hotel by all standards. The freight office showed a business of $430,780.18 for 1860, a freight business of $200,000 was reported for a single month. The Cairo City Mill was turning out 12,000 to 20,000 feet of lumber a day. Business houses were going up rapidly. The depot was reported as loaded with 180 freight cars. By 1860 there was a total population of 2,188." (Lantz 1972: 25) The newly prosperous city had a flour mill, a whisky distillery, several slaughter houses, eight hotels, a foundry and machine shop three newspapers, several wholesale grocers, a number of forwarding houses, and a railroad depot.

The coming of the Civil War had a tremendous impact on Cairo. The city's position at the confluence of the Ohio and Mississippi and as the southern terminus of the Illinois Central made is a very strategic location. Large numbers of Federal troops were dispatched to Cairo as part of the plans for the defense of St. Louis. It was U.S. Grant's headquarters, with more than 10,000 troops, by the summer of 1861 and the base for the U.S. Army's Western Flotilla for the balance of the War. (Merrill 1983) Business improved dramatically during the early days of the war, especially in those businesses related to supplying troops or fitting out naval boats. Civilian business, however, declined as the War blocked movement on the Mississippi and disrupted trade to and from the South that had been one of Cairo's strengths. The wartime boom brought many people to Cairo, including many African Americans fleeing slavery. At the end of the war the City's population stood at 8,569, including 2,083 African Americans.

Immediately after the War there was a brief recession in Cairo because of the economic devastation the War had wrought in the South limited trade with the region. Cairo briefly declined in population to 6,267 in 1870. Other railroads made Cairo their Ohio or Mississippi river terminus, however, and the future for Cairo looked bright as a major transfer point for rail and river transportation. In 1880 the city's population reached 9,011.

Ferrying rail cars and whole trains across the rivers provided a solid economic base for Cairo. Other industries developed in Cairo after the War, the most important of which was lumber and

wood products. In 1870 there were eight lumber mills with 155 employees, in 1880 there were 10 in Alexander County with 146 employees. In 1881 Singer Sewing Machine opened a factory with 150 men to build sewing machine cabinets. By 1893 thirty-two manufacturers of wood products employed more than 1000. The Cairo Property Trust, which still owned the waterfront and a good part of the city, levied no charge for unloading logs or raw lumber. There were however high charges for loading finished products onto barges – the Property Trust has close ties to the New York Central Railroad – and most finished products left by rail. Lumber-related industries in Cairo began to decline after 1900 as supplies of raw materials – the logs that had been "towed" from within a 150 mile radius -- in the region began to decline. Flour milling was another industry that prospered in Cairo between the end of the Civil War and 1900.

The economic base of Cairo in the late nineteenth century remained, however, ferrying rail cars and whole trains and transshipping goods from river barges to rail. In 1887 four transfer steamers worked out of Cairo and there were seven railway transfer inclines. The completion of a railroad bridge across the Ohio in 1889 began the decline of Cairo, which was accelerated by the completion of a bridge across the Mississippi at Thebes in 1905. Railroad employment in Cairo declined dramatically after 1890, as did the city's economy.

Early twentieth-century efforts to revitalize Cairo's economy emphasized its location at the break of winter navigation and its fine harbor. They were, however, largely unsuccessful because of the shortage of land not susceptible to flooding. When the river warehouse district experienced a major fire in the 1940s the city was very slow to rebuild and river traffic went elsewhere, especially to Paducah. (Lantz 1972: 46.) While greatly reduced in scale and importance within the region, river-related industries remained important to the local economy in Cairo through firms such as Cairo Marine Service, Waterfront Services, Inc., and Cairo Terminal and Floating Company.

These "micro" examples of case studies of the development of the larger cities in the lower Ohio Valley show clearly that the river and navigation on the Ohio River have played a critical role in their development. In every case choice of location was related to navigation considerations. A break in navigation, as in the case of Louisville, or the confluence of tributary streams in the others being the main reason. When river transportation was the only effective, or cost-effective, means of transporting goods those places that could efficiently accumulate and distribute cargoes enjoyed significant advantages. The urban hierarchy established during the period when the river was the region's transportation link with the world has been remarkably persistent, although no more than geographical theory would suggest – initial advantage is a very significant factor. In the case of the Ohio Valley it is reinforced by the tendency to design the earliest railroads to provide access to the river, thus making the major early river towns also those with the earliest railroad links.

The early industrial development of most communities in the Ohio Valley, from Pittsburgh to Cairo, is linked with access to the inexpensive transportation the river provided. While the railroad replaced the river for a time, the highways that have largely replaced the railroad have actually set the stage for a revival of river trade, within a narrower range of products to be sure, but a revival none the less, since the 1930s. Much of the large-scale industrial development of the lower Ohio Valley since World War II is due to two factors – first and foremost the ability to move bulky raw materials and finished products cost-effectively; second and closely related the region, especially Kentucky, enjoys exceptionally low electric rates due to TVA and the availability of large quantities of low cost coal, shipped by water from the eastern and western Kentucky and West Virginia coal fields, and earlier from coals fields in Pennsylvania. This has allowed the region to develop significant chemical, aluminum, steel, and nuclear industries. The

river which made the area viable for its earliest settlers remains a solid base for its future economy.

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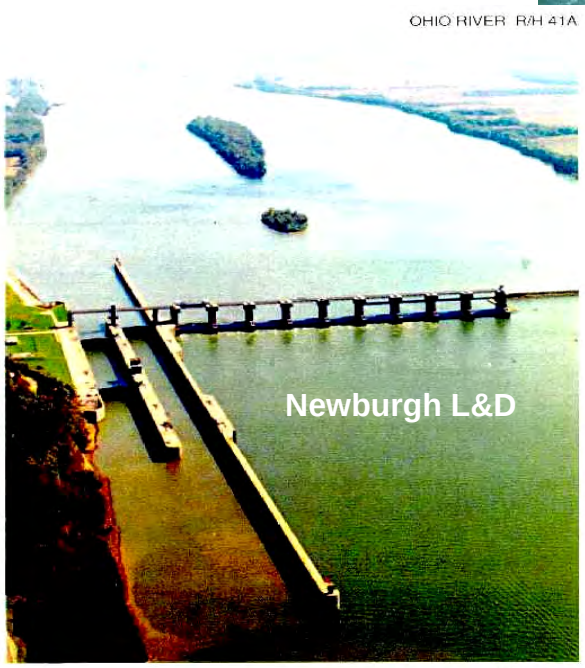
US Army Corps
of Engineers
Great Lakes and Ohio River Division
LOUISVILLE DISTRICT / HUNTINGTON DISTRICT / PITTSBURGH DISTRICT

Ohio River Mainstem Systems Study (ORMSS)

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

COMMUNICATIONS APPENDIX



May 2006

DEPARTMENT OF THE ARMY
U.S. ARMY ENGINEER DISTRICT, LOUISVILLE
CORPS OF ENGINEERS
P.O. BOX 59
LOUISVILLE, KENTUCKY 40201-0059

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Communications Appendix

May 2006

Section 1
INTRODUCTION

Communications with the public, the scientific community, and with waterway users and stakeholders has been a major effort throughout this study. The Ohio River navigation system affects many stakeholders and millions of people in the basin. Therefore, communication concerning any proposed change and the process leading to the change are vital for any project to be accepted and implemented. This is the first time that a study of the entire Ohio River Mainstem as a system has been attempted, and because of this, much of the analysis contained in this study is state-of-the-art. Throughout the study, the sharing of information as it has been developed has been an important component of the study process. It provided the Corps the opportunity to share analysis tools developed for this study with others, as well as keeping various interested groups informed as to the progress of the study. The communications process started through public meetings and the workings of interagency groups, was furthered through presentations to groups representing environmental, navigation, and economics interests, and culminates with the publication of this report. The purpose of this appendix is to summarize the communications efforts that have been a part of this study.

Section 2
MYERS/GREENUP L/D FEASIBILITY STUDY

2.1 SCOPING

Ohio River Mainstem System Study (ORMSS) public workshops were held in November 1998 in three metropolitan areas representing the lower, middle and upper reaches of the Ohio River. Three nearly identical workshops took place from 12:00 noon to 8:00 p.m. within a one-week period. These meetings were held in Evansville, Indiana on November 17, 1998; in Huntington, WV on November 19; and in Pittsburgh, PA on November 24, 1998. There were two primary purposes for these workshops:

- To obtain input from the public-at-large on future needs for Ohio River navigation and for environmental restoration opportunities along the River; and
- To fulfill (partially) requirements of the National Environmental Policy Act whichcall for such public scoping meetings.

Each workshop occurred from 12:00 pm to 8:00 pm. Each meeting had a sign-in area, three kiosks (Plan Formulation/Engineering, Economics, and Environmental), and an area closed off somewhat from the main meeting area where a looping slide show developed by the Louisville District was run continuously. There were also table and

chair arrangements set up to supplement the kiosks to facilitate discussions among participants and Corps staff. Corps staffing at each meeting was limited to the Production Team Leaders, Project Manager, and up to one support staff from the host district from Plan Formulation, Economic, Engineering, Project Management, and Public Affairs. Attendance at each of the three meetings were as follows: Evansville – 21, Huntington – 27, and Pittsburgh – 32.

2.2 NOTICE OF INTENT

The Notice of Intent (NOI) was published in the Federal Register on Wednesday October 21, 1998. A similar Public Notice announcing the 3 scoping meetings was mailed to approximately 3,700 agencies, industries and individuals. Comments from letters received regarding the NOI were addressed in the Draft EIS. One comment letter was received from a federal agency.

2.3 PUBLIC MEETINGS

The Corps of Engineers held two public meetings following preparation of the Draft EIS. The first was held at (public workshop about the draft EIS) in the Greenup Co. Ky. High School on the evening of February 9, 2000. The purpose of the workshop was to provide information about the proposed Greenup and Myers lock extension projects. Members of the local community and agencies attended the workshop. A formal presentation about the proposed projects was delivered by Col. Dana Robertson. After the presentation, the public had the opportunity to ask questions and provide comments to the agency representatives. Letters of support of the proposed projects were read into the record. At the conclusion of the questions and answers session, the public had the opportunity to visit with Corps of Engineers representatives at three different stations: engineering, economics, and environment. Similarly, the Corps of Engineers held a public workshop in the community of Mt. Vernon, near the J.T. Myers L&D, on the evening of February 14, 2000. The purpose of the workshop was for the Corps of Engineers to provide information about the proposed Greenup and Myers lock extension projects. Approximately 11 members of the local community and agency representatives attended the workshop.

No formal presentation or public questions/comments session was scheduled for the workshop. Instead, a continuously playing slide show provided information about the proposed Greenup and Myers locks extensions projects. Also, agency representatives were positioned at engineering, economics, and environmental stations to answer questions about the proposed projects for the public, state and local agency personnel, and the media.

Section 3
ECOSYSTEM RESTORATION AUTHORIZATION STUDY

3.1 FEDERAL REGISTER NOTICE

The Notice of Intent (NOI) was published in the Federal Register on Wednesday October 21, 1998. A similar Public Notice announcing the 3 scoping meetings was mailed to approximately 3,700 agencies, industries and individuals. Comments from letters received regarding the NOI were addressed in the Draft EIS. One comment letter was received from a federal agency.

3.2 INTERAGENCY COORDINATION

Soon after the public scoping meetings, the Corps of Engineers founded an interagency partnership to study the ecological needs and opportunities for the Ohio River corridor. As previously indicated, representatives of the U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency and natural resource agencies of Illinois, Indiana, Kentucky, Ohio, West Virginia and Pennsylvania, were active participants in the study process. During numerous meetings, the interagency partnership and its three working groups identified ecosystem losses and established the goals and opportunities of the proposed Ohio River ecosystem restoration program.

During the early months of the partnership, the Corps requested state natural resource agency officials to identify and prioritize potential site-specific ecosystem restoration projects along the Ohio River corridor. The states provided a list of over 250 projects. Approximately 70 of those projects were further studied to illustrate various ecosystem restoration practices and develop a range of project implementation costs.

3.5 FINAL DECISION DOCUMENT AND ENVIRONMENTAL ASSESSMENT COORDINATION & REVIEW

The Draft Ecosystem Restoration Report – a Decision Document and Environmental Assessment -- was circulated for a 30-day public comment period in August 2000. During that period, various Federal and state agencies, environmental organizations, and the public were afforded the opportunity to review a draft of this report. The Pittsburgh, Huntington and Louisville Districts of the Corps of Engineers issued News Releases regarding the public comment period. Notices of Availability were also mailed to over 3200 recipients.

Following distribution of the Notice of Availability, copies of the report (either printed, or digital copies on CDROM-disk) were also distributed to the general public (on request). The digital versions of the documents were also available to download to personal computers via the Internet from the Louisville District Internet site.

As result of public review, 32 letters and e-mail messages were received. Numerous comments were received from both organizations and individuals. The Finding of No Significant Impact was signed on 12 October 2000.

Section 4
SYSTEM INVESTMENT PLAN

4.1 COMMUNICATION PLAN

As part of the Project Management Plan for the System Investment Study, a comprehensive Communications Plan was developed. That plan laid out the strategic communication objectives for the Ohio River Mainstem System Study. The purpose of the plan was to develop a comprehensive and proactive document that would provide direction and set forth the general guidance and elements of a campaign that would educate and inform internal and external audiences about the Ohio River Mainstem System Study while publicly clarifying and correcting inaccuracies regarding the Study.

Communication with all interested concerns, especially the general public, was considered to be vital to the success of the Ohio River Mainstem Systems Study. Communication activities were unique and multifaceted for this study, making this task extremely difficult to address. Consideration of 19 locks and dams over 981 river miles and involving six states, communication activities for ORMSS did not fit into the models used for past feasibility studies focusing on one or a few facilities.

Although no recommendation for Congressional authorization will be made, the System Investment Plan (SIP) will provide a tool to help determine the timing of future modernization projects and will be used as a basis to schedule and budget future navigation studies. It was and is important that these envisioned modernization projects be subject to adequate scrutiny of key stakeholders and others at appropriate junctures in the study.

The communications strategy for ORMSS was designed to adequately and accurately communicate objectives, process, and results of the study. This included soliciting input and possibly adjusting study processes or assumptions.

The goals of the communication component of the Ohio River Main Stem Study were fourfold: 1) To fully and effectively communicate the ORMSS purpose, thoroughness, and technology applications in order to attain the most complete and effective study results, 2) To build awareness of the significance of Ohio River Navigation, the potential for its significant contribution to the basin's freight transportation capacity (i.e. relieving pressure from overstressed truck and rail modes), and anticipated water transportation problems and solutions for the next sixty years, 3) To involve diverse stakeholders early and often in order to complete an effective study with beneficial and acceptable recommendations, and 4) To communicate the results of the Ohio River SIP.

4.2 SCOPING PROCESS FOR CUMULATIVE EFFECTS ANALYSIS (CEA)

4.3.1 General

An important first step in developing a large-scale environmental impact statement, scoping is mandated by the National Environmental Policy Act whenever major federal actions can significantly affect the quality of the environment. Scoping creates opportunities for the public, agencies and other groups to provide input on potential issues related to a proposed project. By identifying significant environmental issues and potential alternatives, the scoping process directs the course of the study team's efforts in the development of the CEA.

4.3.2 Notice of Intent Federal Register

Scoping for the CEA began with publication of a notice in the Federal Register on June 26, 2001. It also was publicized through a press release announcing the CEA scoping process and inviting comments, a mailing to all addressees on the ORMSS mailing list, and legal ads in major regional newspapers. Interested parties also were encouraged to provide written comments or submit questions to the CEA Project Manager at USACE Louisville District by regular mail or e-mail (celrl-ormss@usace.army.mil) by August 31, 2001. Information about the CEA also was available on the project web site: http://www.lrl.usace.army.mil/ormss/. Additionally, a color brochure was developed and provided to those who attended the public meetings and to others upon request.

4.3.3 Public Meetings

A series of six public scoping meetings (one set in each state along the Ohio River) was held during Summer 2001. Each set consisted of a daytime meeting with governmental agencies and an evening meeting open to the public. Meetings were scheduled as follows:

July 10, 2001 - Banterra Bank, Metropolis, IL
July 12, 2001 - Victory Theater, Evansville, IN
July 31, 2001 - Mid-Ohio Valley Regional Council , Parkersburg, WV
August 1, 2001 - Community College of Beaver Co., Monaca, PA
August 6, 2001 - Kenton Co. Public Library, Covington, KY
August 7, 2001 - Shawnee State University, Portsmouth, OH

Forty-four people attended the six meetings with agency representatives. More than half the participants represented federal and state resource or regulatory agencies. The remaining participants represented various public agencies or business interests.

A total of 141 people signed in at the six public meetings. Nearly 50 percent of the participants were interested citizens. Approximately 25 percent represented business or development interests, with the largest representation from the shipping industry. The remaining participants included fishermen, elected officials, and representatives of environmental groups, the media and government agencies.

Questionnaires also were available at the meetings and online. Nineteen completed questionnaires were submitted. Additionally, written comments received during scoping consisted of several personal and agency letters and e-mail messages. By late summer, 24 written responses had been received.

4.5 INTER-AGENCY WORKING GROUP

At the outset of the study, the environmental team established an Interagency Working Group (IWG) made up of State and Federal natural resource agencies and regulatory personnel. Later in the process non-governmental organizations were also represented in the IWG. The IWG met quarterly during the study to identify issues to be addressed, provide input to the study process, help determine effects, and review results. Although not a part of the formal ITR team, the reviews provided by the IWG were especially valuable to the PDT.

The IWG consists of approximately 40 members representing federal and state agencies with responsibilities for environmental management, as well as several NGOs. Six members were from the U.S. Fish and Wildlife Service, with one serving as the coordinator for the USFWS group; two were from the U.S. Geological Survey; and one was from the U.S. Environmental Protection Agency. Members from NGOs include one person from the Sierra Club, one from the Ohio River Advocacy, and two from The Nature Conservancy. The remaining members are from natural resources or environmental management agencies in the six states bordering the Ohio River. The IWG had two to three meetings annually with the environmental team. These one-day joint meetings included information dissemination and updates related to the status of the CEA study, status reports on specific research projects, and working sessions on integrative topics such as impact matrices for Reasonably Foreseeable Future Actions, or RFFAs,

and indicators and a process for analyses of environmental sustainability (AES). More specifically, the IWG fulfilled the following purposes in the CEA study:

- Aided in identifying key issues and cumulative effects that should be addressed in the CEA study.
- Assisted the CPT in delineating and prioritizing key research needs relative to environmental issues and natural resources. Examples of completed research include fish passage studies at selected locks, determination of winter habitat requirements for selected fish species, and surveys of freshwater mussel populations at various River locations. In addition, the IWG has reviewed the completed research reports.
- Participated in the completion of RFFA matrices for Valued Environmental Components (VECs) and their subcomponents related to aquatic ecological resources, floodplain/riparian ecological resources, and threatened/endangered/protected species.
- Reviewed work plans for addressing cumulative effects on the VECs and their subcomponents; in addition, reviewed the identified methods and procedures relative to "best practice tools" for the specific issues and cumulative effects to be addressed. It should be noted that "best practice tools" infer both scientific validity and cost-effectiveness relative to their application.
- Conducted systematic reviews of draft chapters and appendices for the CEA study report and the SIP/PEIS.
- Provided periodic and continuing scientific information on emerging issues; examples include the incorporation of the environmental sustainability analyses and the need to consider nonstructural measures for navigation traffic management, along with proactive repair and rehabilitation of existing locks and dams, and lock extensions.
- Participated in the planning and implementation of a coordinated and collaborative long-term strategy for environmental monitoring and adaptive environmental management for the aquatic and floodplain/riparian ecological resources within and along the Ohio River mainstem. In fact, the IWG could become part of a long-term decision-making structure and process related to enhancing the environmental sustainability of key resources.

Throughout the study process, environmental considerations were on equal footing with engineering and economics. The extensive communication, outreach, and public/agency inclusion through the Interagency Working Group helped ensure accountability, full disclosure, acceptability, and credibility of environmental considerations prior to recommending or making decisions.

Throughout the ORMSS study, including preparation of the earlier interim feasibility studies, the environmental team maintained regular communication with resource agencies through regularly scheduled meetings with an Interagency Work Group (IWG) held at various locations along the Ohio River. **Table 4-1**, lists the locations and attendees at each of the meetings starting in April 2001, at which time the preparation of the SIP, PEIS, and CEA began in earnest. **Table 4-1** also includes eight meetings (shown

by asterisk) with other professional or multi-agency groups with interests in environmental management.

TABLE 4-1. Environmental Meetings

Date(s) / Meeting/Location	Audience
October 29, 1996/Interagency Team Meeting/Wheeling, WV	USFWS, State Resource Agencies, EPA, NGOs
October 31, 1996/ Interagency Team Meeting/Louisville, KY	USFWS, State Resource Agencies, EPA, NGOs
January 23, 1997/Cincinnati	State Historic Preservation Officers
February 6, 1997/Interagency Team Meeting/Columbus, OH	USFWS, State Resource Agencies, EPA, NGOs
May 21, 1997/In-Progress Review Meeting-/Cincinnati, OH	USFWS, State Resource Agencies, EPA, NGOs, Navigation Industry
August 27, 1997/NAVPAT Model Explanation/Vicksburg, MS	USFWS, State Resource Agencies, EPA, NGOs
November 13, 1997/Interagency Team Meeting/Columbus, OH	USFWS, State Resource Agencies, EPA, NGOs
February 24, 1998, Interagency Team Meeting/Parkersburg, WV	USFWS, State Resource Agencies, EPA, NGOs
April 14-15, 1998, In-Progress Review Meeting/Pittsburgh, PA	USFWS, State Resource Agencies, EPA, NGOs, Navigation Industry
August 7, 1998/Interagency Team Meeting/Cincinnati, OH	USFWS (w/directors), State Resource Agencies, EPA, NGOs
May 27-28, 1998/Interagency Team Meeting/Louisville, KY	USFWS, State Resource Agencies, EPA, NGOs
July 21, 1998/Interagency Team Meeting/Huntington, WV	USFWS, State Resource Agencies, EPA, NGOs
August 12, 1998/Scoping Meeting/Pittsburgh, PA	Pennsylvania Resource Agencies
August 27, 1998/Scoping Meeting/Columbus, OH	Ohio Resource Agencies
October 20-21, 1998/Interagency Team Meeting/Louisville, KY	USFWS, State Resource Agencies, EPA, NGOs
January 26-27, 1999/Interagency Team Meeting/Parkersburg, WV	USFWS, State Resource Agencies, EPA, NGOs
March 30-31, 1999/Interagency Team Meeting/Ashland, KY	USFWS, State Resource Agencies, EPA, NGOs
July 21-22, 1999/Interagency Team Meeting/Evansville, IN	USFWS, State Resource Agencies, EPA, NGOs
October 28-29, 1999/Interagency Team Meeting/Cincinnati	USFWS, State Resource Agencies, EPA, NGOs
January 19, 2000/Ecosystem Restoration Presentation/Frankfort, KY	Ohio River Fish Management Team

January 20-21, 2000/Interagency Team Meeting/Frankfort, KY	USFWS, State Resource Agencies, EPA, NGOs
January 26, 2000/Ecosystem Restoration Presentation/Crittenden, KY	State Resource Agencies
February 9, 2000/Recommendations for Greenup & Myers/Greenup, KY	Environmental Agencies, Navigation Industry & General Public
February 14, 2000/Recommendations for Greenup & Myers/Mt. Vernon, IN	Environmental Agencies, Navigation Industry & General Public
February 15, 2000/Study Update/Somerset, PA	PA Fish and Boat Commission
April 3-4, 2000/Interagency Team Meeting/Frankfort, KY	USFWS, State Resource Agencies, EPA, NGOs
June 13-15, 2000/Ecosystem Restoration Study Update/Marietta, OH	USFWS, State Resource Agencies, EPA, NGOs
July 18-19, 2000/Interagency Team Meeting/Pittsburgh, PA	USFWS, State Resource Agencies, EPA, NGOs
August 4, 2000/Coordination Meeting/Cincinnati, OH	ORSANCO
September 15, 2000/Aquatic Studies Update/Frankfort, KY	USFWS and Ohio River Fish Management Team
October 12, 2000/Recommendations for Ecosystem Restoration Program/Cincinnati, OH	Environmental Agencies, Navigation Industry & General Public
October 24-25, 2000/Interagency Team Meeting/Crittenden, KY	USFWS, State Resource Agencies, EPA, NGOs
November 27-29,.2000/Environmental Monitoring & Assessment/St. Louis, MO	EPA
January 30-31, 2001/Interagency Team Meeting/Columbus, OH	USFWS, State Resource Agencies, EPA, NGOs
February 6-8, 2001/Ecosystem Restoration Meeting/Columbus, OH	USFWS
March 14-16, 2001/Ecosystem Restoration Update/Bettendorf, IA	Mississippi River Conservation Committee
March 26, 2001/Lock Design Workshop (Environmental Considerations) Vicksburg, MS	Corps of Engineers employees
March 31, 2001/Ecosystem Restoration Update/California, PA	Western Pennsylvania Conservancy
April 5, 2001/ Interagency Team Meeting/Frankfort, KY	USFWS, State Resource Agencies, EPA, NGOs
June 5-6, 2001/Ecosystem Restoration Meeting/Louisville, KY	USFWS
July 10, 2001/ORMSS Scoping Meeting/Metropolis, IL	Resource Agencies and General Public
July 11, 2001/Interagency Team Meeting/ Paducah, KY	USFWS, State Resource Agencies, EPA, NGOs

July 12, 2001/ORMSS Scoping Meeting/Evansville, IN	Resource Agencies, Navigation Industry and General Public
July 31, 2001/ORMSS Scoping Meeting/Parkersburg, WV	Resource Agencies, Navigation Industry and General Public
August 1, 2001/ORMSS Scoping Meeting/Beaver, PA	Resource Agencies, Navigation Industry and General Public
August 6, 2001/ORMSS Scoping Meeting/Covington, KY	Resource Agencies, Navigation Industry and General Public
August 7, 2001/ORMSS Scoping Meeting/Portsmouth, OH	Resource Agencies, Navigation Industry and General Public
October 2-3, 2001/Poster Session/Rend Lake, IL	State DNR Directors
October 11, 2001/Poster Session/Louisville, KY	Ohio River Consortium
October 17, 2001/ORMSS Presentation/Covington, KY	Cincinnati Propeller Club
October 25, 2001/Cumulative Effects Assessment Course/Memphis, TN	
November 14-15, 2001, Interagency Team Meeting Cincinnati, OH	USFWS, State Resource Agencies, EPA, NGOs
November 20, 2001, Portsmouth, OH	Shawnee Nature Club, Quarterly Meeting
December 18-19, 2001/ORMSS Presentation/Cincinnati, OH	ORSANCO Advisory Committee
February 1, 2002, Interagency Team Meeting Frankfort, KY	USFWS, State Resource Agencies, EPA, Non-Governmental Offices (NGOs)
February 28-29, 2002, MV MISSISSIPPI	Midwest Natural Resource Leaders Group
March 19-21, 2002, Anstedt, WV	USFWS, Ecosystem Team
June 11, 2002/Interagency Team Meeting/Paducah, KY	USFWS, State Resource Agencies, EPA, NGOs
August 26, 2002/Green River-Ohio River Confluence/Louisville, KY	USFWS, Kentucky DFWR, Kentucky DOT
November 7, 2002/N. Kentucky University	Ohio River Basin Consortium for research and Education
November 13, 2002, Interagency Team Meeting Columbus, OH	USFWS, State Resource Agencies, EPA, NGOs
November 20, 2002/Columbus, OH	TNC
Feb 5, 2003/Cincinnati, OH	Ohio River Fish Management Team
Mar 1, 2003/Cincinnati, OH	Midwest Natural Resources Leaders Group
Apr 23, 2003/Interagency Team Meeting/Cincinnati, OH	USFWS, State Resource Agencies
Jul 9, 2003/Pittsburgh, PA	PA Environmental Council
Sep 9, 2003/Interagency Team Meeting/Marietta, OH	USFWS, State Resource Agencies, EPA, NGOs
Feb. 10-11, 2004/Interagency Team Meeting/Frankfort, KY	USFWS, State Resource Agencies

May 11, 2004/Interagency Team Meeting/Pittsburgh, PA	USFWS, State Resource Agencies
Aug. 18-20, 2004/Ohio River Basin Consortium for Research & Education, St. Louis, MO	USFWS, State Resource Agencies

4.6 WEBSITE

The Corps used two primary means to regularly update the general public with progress and issues throughout development of the SIP. The URL site on the Louisville District Web Page cited above for the Scoping Meeting Comments also contained links to a general fact sheet and compilations of Frequently Asked Questions (FAQs). Two FAQ sheets were maintained, one solely relating to economic modeling and analysis issues, the other for all other types of concerns.

For the time period for which data is available, 14 April 2003 to 21 July 2004, the URL site averaged 9 visits per day on weekdays and 15 visits per weekend. For this time period, the web site had 4,254 visits. Out of these 4,254 visits, 2,137 visits were by unique visitors. This means that the difference between these two numbers, 2117 visitors, or roughly half, were repeat visits. The average number of visits per four-week period is 151, with an average of 76 unique visitors per four-week period.

4.7 FAQs

Sets of Frequently Asked Questions (FAQs) were developed and placed on the ORMSS website. There were three categories of questions; general questions about the study, questions about the Ohio River Ecosystem Restoration authorization study, and questions about the economic analyses conducted for the SIP.

4.8 FACT SHEET

A fact sheet about the ORMSS was developed and placed on the website. The fact sheet contained information about the navigation system on the river and the ORMSS study. The fact sheet was updated as information developed.

4.9 MAIL LIST

A mailing list was developed for the purpose of disseminating information related to the release of the System Investment Plan. This mailing list was develop by starting with mailing lists that were used for the Myers/Greenup study and the Ecosystem Restoration Authorization study. Additional entries were added to the mailing list and obsolete entries deleted as the information on interested parties became available. The

resulting mailing list had over 3,000 entries on it, and was composed of the following major categories:

- City and state officials from the study area, including mayors, governors, and state agencies
- Senators and Members of Congress from the study area
- Non-governmental organizations
- Companies doing business along the river, such as shippers, towing companies, and other users of the navigation facilities on the river
- Organizations of waterways users, such as the Waterways Council
- Other federal agencies
- Libraries in the study area
- Media in the study area
- Other Corps of Engineers districts and divisions
- Private individuals interested in the study

4.10 BROCHURE

A brochure was developed by the Public Affairs office of the Great Lakes and Ohio River Division of the Corps of Engineers. This brochure is entitled, "Ohio River – Future Navigation and Environmental Improvements." The brochure summarizes the ORMSS, focusing on the importance of the navigation system to the region and the System Investment Plan. The brochure also discusses the Ecosystem Restoration Program authorized in the Water Resources Development Act of 2000. This brochure has been distributed at meetings with the general public, environmental interest groups, and state and local officials.

4.11 DISPLAYS

To complement the brochure, a three panel display was developed. This display was a duplicate of the brochure, containing information on the navigation system and the study. This display has been used in a number of venues, including an Ohio River tour of the Motor Vessel Mississippi and a regional convention of the U.S. Fish and Wildlife Service.

4.12 PRESENTATIONS AND TECHNICAL PUBLICATIONS

4.12.1 General Meetings

Besides the Interagency Working Group, other presentations directed to specific technical audiences were accomplished as described in **Table 4-2**. In additional to informing the public and interested parties about the study, any comments generated were considered in technical analyses conducted for this study.

TABLE 4-2. General Meetings

Dates/Meeting/Location	Audience	ORMSS Team Presentation(s)
January 2004/Transportation Research Board/Washington, D.C.	Academic and Business Transportation Officials	ORNIM
July 16-17, 2002/ Economic and Environmental Conference, US Army Corps of Engineers/New Orleans, LA	Water resource professionals from the Corps, academia, government agencies, and various NGOs	Traffic Management
June 2-5, 2005/International Association of Impact Assessment (I.A.I.A.) Conference/Boston MA	Environmental Agencies and NGOs	Study Status, Traffic Forecast Scenarios, Environmental Sustainability, Mussels, Monitoring and Adaptive Management, and Potential Applications of Methodologies

4.12.2 Corps Interaction with Industry

Coordination with industry consisted of several briefings to groups including DINAMO and the Waterways Council, Inc. that focused on progress and preliminary findings. All meetings are listed in Table 4-3.

TABLE 4-3. Meetings and Briefings with Industry Representatives

Dates/Meeting/Location	Audience	ORMSS Presentation(s)
March 2, 2001/Inland Waterways Conference	Inland Waterways Conference Panel	
Nov. 30, 2001/Inland Waterways User Board Meeting/Fort Lauderdale, FL	Inland Waterways User Board	
Apr. 25, 2002/Inland Waterways User Board Meeting/Chattanooga, TN	Inland Waterways User Board[1]	Study Status and Commercial Traffic Forecasting
July 2002/DINAMO[1]/Ligonier, PA	DINAMO (River Transportation)	

	Representatives	
October 31, 2002/DINAMO/Emsworth, PA	DINAMO officials	
March 11-12, 2003/Inland Waterways Conference/Cincinnati, OH	River Transportation Officials	
July 30, 2003/DINAMO/Pittsburgh, PA	DINAMO officials	Study Methodology
September 23, 2003/Houston, TX	National Waterways Conference	
January 13, 2004/Washington, DC	Waterways Council, Inc.	
March 2004/Inland Waterways User Board Meeting/	Inland Waterways User Board	
September 2, 2004/Washington, DC	Waterways Council, Inc., Great Lakes and Ohio River and Mississippi River Divisions of the Corps	
February 23-24, 2005/Tampa, FL	Waterways Council, Inc., Great Lakes and Ohio River and Mississippi River Divisions of the Corps	
March 2005/Inland Waterways User Board Meeting/	Inland Waterways User Board	

[1]Industries represented by IWUB attending meeting included Cargill Marine & Terminal, Alter Barge, Inc. MEMCO Barge Line, Ingram Barge Co., Parker Towing Co., Peabody COALSALES Co., Shaver Transportation, Holcum (US), Inc., CONSOL Energy, Inc., Kirby Corp., and American Barge Line. Also attending was Volunteer Barge & Transport, Inc.

[2]Presentations also made by representatives from HDR, Inc., Balch & Bingham, LCC, J. Simmons Group, Transportation Institute (Houston), Atlantic Intracoastal Waterways Assoc., Transportation Research Board, and House Energy & Water Development Subcommittee.

4.12.3 Motor Vessel Mississippi

During the M/V Mississippi tour of summer 2005, three districts and one division, Huntington, Louisville, Nashville and Great Lakes and Ohio River, hosted events where more than one thousand community members, navigation industry, and families learned about the Ohio River, the importance of navigation and the ORMSS. The annual M/V Mississippi tour is an opportunity for members of the Mississippi River Commission (MRC) to learn about issues associated the Mississippi River and its tributaries. In 2005, the focus of the tour was the Ohio River.

An ORMSS display, handouts and personnel with expertise were made available to the public and special interest representatives aboard the vessel and at scheduled stops down the Ohio River. The vessel was open to touring during scheduled open houses. During these guided informational tours, the ORMSS study was presented and discussed. The study was briefed to USACE HQ representatives and other internal and external

dignitaries – local, state and national. More than 15 briefings on ORMSS, Ecosystem Restoration Program and the current condition of Ohio River navigation were given to congressional delegates, navigation industry leaders, news media and other stakeholders and public interest groups. Environmental agencies were represented in the audiences.

A regional mailing went out to more than 3,000 people to visit the vessel. The Motor Vessel served as an educational river-study "open book" floating down the river. The newly opened National Rivers Institute, Hanover College, Indiana sent their new executive director and a fleet of students to engage leadership and program managers about river biology and navigation. The Louisville Courier Journal ran a regional front-page story and pictorial that circulated to 250,000 homes on riverine ecosystem issues spurred by the Vessel's tour. Spirited dialogue and exchange resulted from the mix of diverse interest groups on how reinvestments could be made to protect and improve the 20 locks on the Ohio River. At the heart of these discussions, was the importance and future impact of the ORMSS and accompanying System Investment Plan.

Participants included the ORMSS project manager, Division and District Public Affairs Officers, and other ORMSS team members, civil project managers, lock personnel and those with navigation expertise.

Table 4-4 contains a listing of activities where ORMSS was presented, discussed or highlighted.

TABLE 4-4. Meetings and Briefings during the M/V Mississippi Tour

Event	Location	Comment
Ribfest	David W. Harris Park, Huntington, West Virginia	Public tours, Open House, presentations
MRC Commissioner's Meeting	On board	
MRC, LRD, Pittsburgh and Huntington, Louisville District Briefings	On board	
Greenup Lock and Dam briefing/tour	On site	
Meldahl Lock and Dam Briefing/tour	On site	
Public Open House and tours	Cincinnati Riverfront	
ORMSS, Ecosystem Restoration briefs, Markland Major Rehabilitation brief	Markland L&D - On site, on board	Stakeholders, Congressional staff, public interest group representation, Waterways Council
History of navigation on the Ohio River	On board	

briefing		
Media visits, public tours on site, open house	Louisville Riverfront	
McAlpine Lock Replacement Project tour	On site	
Louisville Repair Station and Falls of the Ohio tour	On site	
Cannelton Locks and Dam tour	On site	
Southwinds Indiana Port tour and navigation updates	Mt. Vernon, Indiana	
Olmsted Lock and Dam construction project tour	On site	
John T. Myers Lock and Dam tour	On site	
Smithland Lock and Dam	On site	
Cumberland River	On board	
Barkley Lock and Dam	On site	
Tennessee River	On site	
Kentucky Lock and Dam	On site	
Paducah Riverfront Public open house, tours	Paducah, Kentucky	

4.14 REPORT RELEASE INFORMATION

As the report was readied for release to the public, a roll-out plan was developed. The prime objective of this roll-out plan was to develop strategies to effectively inform target audiences of release of draft report, particularly to notify target audiences of 60-day comment period, tell target audiences where they can access report, and explain how they can submit written comments. Toward that end, a goal developed in the roll-out plan was to package and present preliminary study findings in a concise and comprehensive format. Additionally, the roll-out plan was developed to help all members of the study team focus on key messages related to the findings contained in the report, particularly:

- To highlight the innovative nature of the of study methodology.
- To emphasize the appropriateness of the study methodology for the Ohio River System.

- To relay the information that the report does not seek any additional authorization
- To explain study methodology, forecasting and economics
- To emphasize the use of outside agency/university review during the study development
- To explain how the cumulative effects analysis was conducted

To announce the availability of the System Investment Plan, a direct mailing will be made to all of the members of the mailing list. A post card will be used for the majority of the mailing list, primarily those individuals and agencies not required to receive a copy of the report. The post cards will be mailed one week prior to planned release of draft report. This post card will contain the following information:

- Availability of the draft SIP for review
- Web site address of report
- How to view a copy of report
- How to obtain a copy of report
- Dates and locations of public meetings
- Dates of the public review period

As throughout the entire study period, the ORMSS website will continue to function as a primary communications tool. The mailing will direct interested parties to the website. Both the mailing and the website will explain how to obtain paper or electronic copies of the report. The website will also continue to contain Frequently Asked Questions, updated at the time to the report release to summarize the report findings, answer questions about how to obtain a copy of the report, and inform interested parties about public involvement activities. Additionally, the report itself will be placed on the website, so that interested parties may be able to view it. An e-mail link will be provided for those who wish to submit comments.

Public meetings will be held at six sites, in six different states. The locations are listed below:

- Metropolis, Illinois
- Evansville, Indiana
- Covington, Kentucky
- Huntington, West Virginia
- Marietta, Ohio
- Beaver, Pennsylvania

Visual aids will be developed for the public meetings: maps, handouts, PowerPoint presentations, etc. Press releases will announce the release of the draft report and provide information on the report's results. These press releases will also announce public meetings and provide information about viewing the report and obtaining a copy.

Media training was conducted for the Project Delivery Team, in order that those most familiar with the report, its methodology, and the results be trained to help disseminate information to the media and public effectively.

4.15 DATABASE MANAGEMENT

In the course of preparing this System Investment Plan, a considerable quantity of data and analyses has been developed, particularly for the Cumulative Effects Analysis. Many of the agencies that participated in the Interagency Working group have expressed interest in the availability of this information. During future phases of this study, the possibility of making this data available to interested agencies will be investigated.