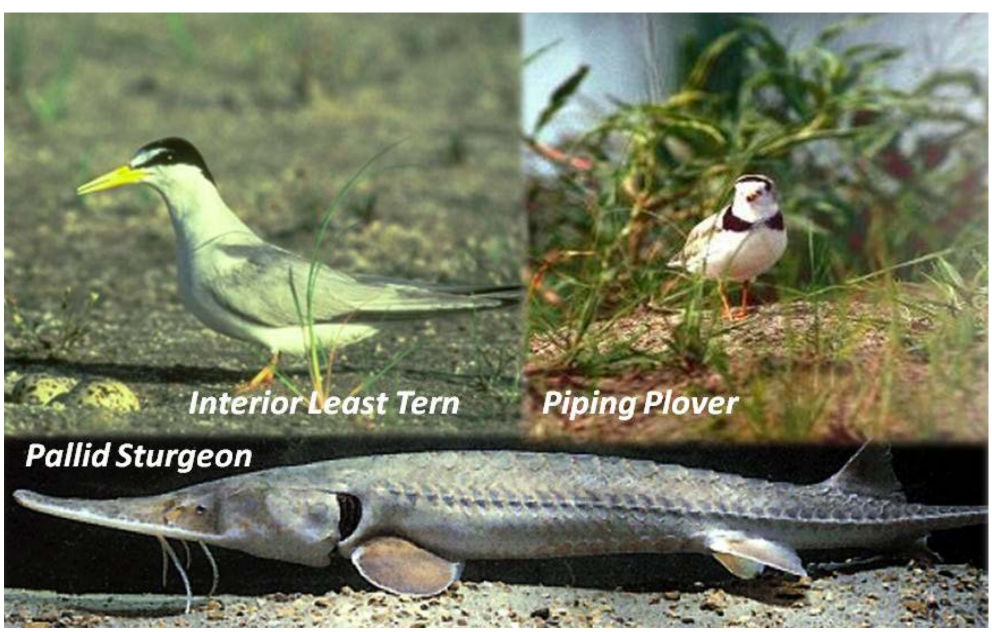
Missouri River Recovery Program Management Plan Environmental Impact Statement
Summary of Hydrologic Engineering Analysis DRAFT



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USACE, Northwestern Division
Omaha and Kansas City Districts

EXECUTIVE SUMMARY

Hydrologic analysis was performed to support the Missouri River Recovery Program (MRRP) evaluation for the Management Plan (ManPlan) and integrated Environmental Impact Statement (EIS) which are reported in the Missouri River Recovery Management Plan and Environmental Impact Statement (MRRMP-EIS). The purpose of this document is to provide basic background information on the various hydrologic modeling efforts and the relationships between those modeling efforts.

The hydrologic modeling documentation presented in this report and the reports for the individual modeling efforts are focused on describing in detail only the conducted hydrologic analysis. Refer to the actual integrated EIS for a thorough description of the integrated study. Detailed discussion on hydrologic evaluation and results from the various modeling efforts are presented in the reports specific to each of the conducted efforts.

The hydrologic modeling evaluation involved the creation and use of a detailed suite of models for the Missouri River basin to aid in evaluating jeopardy avoidance strategies for the least tern, piping plover, and pallid sturgeon. Multiple hydrologic evaluations consisted of the following:

Model Development and Calibration

HEC-ResSim (ResSim) Model Development and Calibration. Analysis was performed to develop a ResSim computer reservoir model capable of simulating operations at the six mainstem United States Army Corps of Engineers (USACE) dams on the Missouri River. A separate ResSim analysis was conducted for the Kansas, Chariton and Osage River systems. Prior to ResSim model creation, much effort was spent developing required input data such as local inflow, hydrologic routing parameters, evaporation, and dam and reservoir physical parameters.

HEC-RAS (RAS) Model Development and Calibration. Five separate RAS models were developed for the Missouri River reaches from downstream of Ft. Peck Dam to the mouth at St. Louis (Ft Peck Dam to Lake Sakakawea, Garrison Dam to Lake Oahe, Ft Randall Dam to Lewis and Clark Lake, Gavins Point Dam to Rulo, NE, and Rulo, NE, to the mouth at St. Louis). The inter-reservoir reaches Oahe to Big Bend and Big Bend to Ft Randall were deferred from RAS modeling due to the lack of riverine conditions between the dams. The RAS models were based on the best available geometry and were calibrated to current conditions using the best available information.

Alternative Analysis

Period of Record Flow. Hydrologic analysis utilized a period of record (POR) methodology to evaluate alternative conditions. The POR procedure preserves the seasonality, persistence, and dependence or independence of basin hydrologic inputs. The method enables model results and alternative comparisons to be displayed in a manner easily understood. Flows were developed for the Missouri River basin for the POR used in the analysis from 1931 through 2012. All flows were corrected to current level depletions to reflect

basin water development. Therefore, comparison of hydrologic model results from either ResSim or RAS to observed conditions is not appropriate other than for model calibration and validation purposes.

ResSim Alternative Conditions Evaluation. Alternative conditions were simulated through the reservoir system using ResSim. The results were used to provide reservoir releases to the RAS models.

HEC-RAS Alternative Conditions Evaluation. Alternative analysis was performed using the five separate RAS calibrated current condition models. The RAS models were revised as needed to reflect alternative conditions. All RAS modeling efforts are for the current geomorphic condition only. No adjustments were made to the models to reflect future aggradation / degradation.

Interior Drainage Analysis for Alternative Conditions. Interior drainage analysis for four selected locations were performed using the RAS alternative condition model and HEC-HMS models that were used to develop inflows.

Climate Change. A qualitative climate change assessment for the Missouri River Recovery Management Plan was performed by the USACE in accordance with Engineering and Construction Bulletin (ECB 2016-25): Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects (USACE 2016a).

Modeling Results. Results from the hydrologic modeling were evaluated at key locations and provided to Human Considerations (HC) team members for the comparison of alternative conditions. Comparison was limited to key locations due to the basin size, number of hydrologic models, model complexity, and the number of alternatives developed.

Use of Model Results. The performed hydrologic evaluation of the complex Missouri River System provides a powerful alternative analysis tool for assessing differences between alternatives. However, comparison between alternatives should recognize that minor and insignificant differences can occur due to many factors. All model results are based on a simulated period of record routed through reservoir models to test reservoir rule changes and alternative condition river geometries. POR flows represent a hypothetical condition with all flows corrected to current water development levels within the basin. The POR methodology would require additional effort to make it suitable for use with developing revised hydrologic statistics such as flow-frequency curves or reservoir pool probability. Model geometry for all alternatives, including the no action, has been altered from the current condition to reflect hypothetical future habitat added to the river. Variations in the stage-flow relationship due to past and future aggradation / degradation, ongoing improvements to privately owned levees, and in some cases ongoing habitat construction activities are not included. In summary, ***model results are only suitable for comparison between study alternatives. Comparison to historic events or observed conditions is not meaningful.***

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ACRONYMS

BiOp......................... Biological Opinion of the US Fish and Wildlife Service

BSNP........................ Bank Stabilization and Navigation Project

EIS…………………….Environmental Impact Statement

HC .... Human Considerations

HEC .... Hydrologic Engineering Center

ManPlan………………Management Plan

MRRP .... Missouri River Recovery Program

MRRMP-EIS Missouri River Recovery Management Plan and Environmental Impact Statement

NWK…………………. Northwest Division Kansas City District

NWO………………… Northwest Division Omaha District

POR .... Period of Record

RAS .... River Analysis System (computer model distributed by HEC, referred to as HEC-RAS)

ResSim……………....Reservoir Simulation Software (computer model distributed by HEC, referred to as HEC-ResSim)

UMRSFFS .... Upper Mississippi River System Flow Frequency Study

USACE……………… United States Army Corps of Engineers

USGS .... United States Geological Survey

1 INTRODUCTION

The U.S Fish and Wildlife Service 2003 Amended Biological Opinion (BiOp) concluded that the Corps' operation of the Missouri River Mainstem Reservoir System, the Bank Stabilization and Navigation Project (BSNP) and the Kansas River Reservoir System jeopardizes the continued existence of the endangered pallid sturgeon, interior least tern and threatened piping plover. The Missouri River Recovery Program (MRRP) will address the environmental needs of the Missouri River as required for BiOp compliance while allowing the Corps to operate the Missouri River for all eight congressionally authorized purposes. The Missouri River Recovery Management Plan (ManPlan) and integrated Environmental Impact Statement (EIS) is being developed through the National Environmental Policy Act to address mitigation efforts, BiOp compliance, and cumulative effects of Corps actions along the river. Study results are reported in the Missouri River Recovery Management Plan and Environmental Impact Statement (MRRMP-EIS).

The purpose of this document is to provide basic background information on the various hydrologic modeling efforts and the relationships between those modeling efforts. Detailed discussion on hydrologic evaluation and results from the various modeling efforts are presented in the reports specific to each of the conducted efforts.

The hydrologic modeling evaluation involved the creation and use of a detailed suite of models for the Missouri River basin to aid in evaluating jeopardy avoidance strategies for the least tern, piping plover, and pallid sturgeon.

The hydrologic analysis effort is part of a larger study effort using a variety of conceptual and quantitative models to simulate the effects of changes to river management under the ManPlan on species recovery as well as effects to human considerations. These changes in river management include both physical changes to the river channel as well as changes to reservoir and flow management. The hydrologic models simulate how proposed alternatives and management measures effect river stage and discharge over a wide range of basin hydrologic conditions. The hydrologic modeling documentation presented in this report and the reports for the individual modeling efforts are focused on describing in detail only the conducted hydrologic analysis. Refer to the actual integrated EIS for a thorough description of the integrated study.

Development of the hydrologic and hydraulic modeling component of the larger ManPlan and EIS consists of three parts:

1. Development of reservoir simulation models for managed federal reservoirs that impact management for the three species. These models will be used to assess the benefits and effects of changes in water management (reservoir operations) at these reservoirs. Hydrologic Engineering Center's Reservoir Simulation Model (HEC-ResSim) was chosen for this modeling**.**
2. Development of hydraulic models for free-flowing reaches of the river. Hydrologic Engineering Center's River Analysis System Model (HEC-RAS) was chosen for this modeling. Unsteady RAS will be used to more accurately route discharges from

reservoirs and tributaries to points downstream and to simulate impacts of mechanical changes in river channel geometry.

3. Development of a complete, sufficiently long period of gage records for the Missouri River and its principle tributaries, to be used in the hydrologic and hydraulic models. Regression methods were used to estimate missing data in older parts of the gage record. The goal was to have a record that realistically represents runoff conditions in the basin back to 1930. The record was also adjusted for depletions and other significant changes in the basin over time.

Outputs from the hydrologic and hydraulic modeling effort are used by conceptual and quantitative ecological models for evaluating species responses to management actions in the Environmental Effects Analysis portion of the study, and evaluation of the effects to basin stakeholder interests and authorized purposes in the Management Plan Analysis. Figure 1 illustrates the modeling framework for the Effects Analysis and Management Plan Analysis.

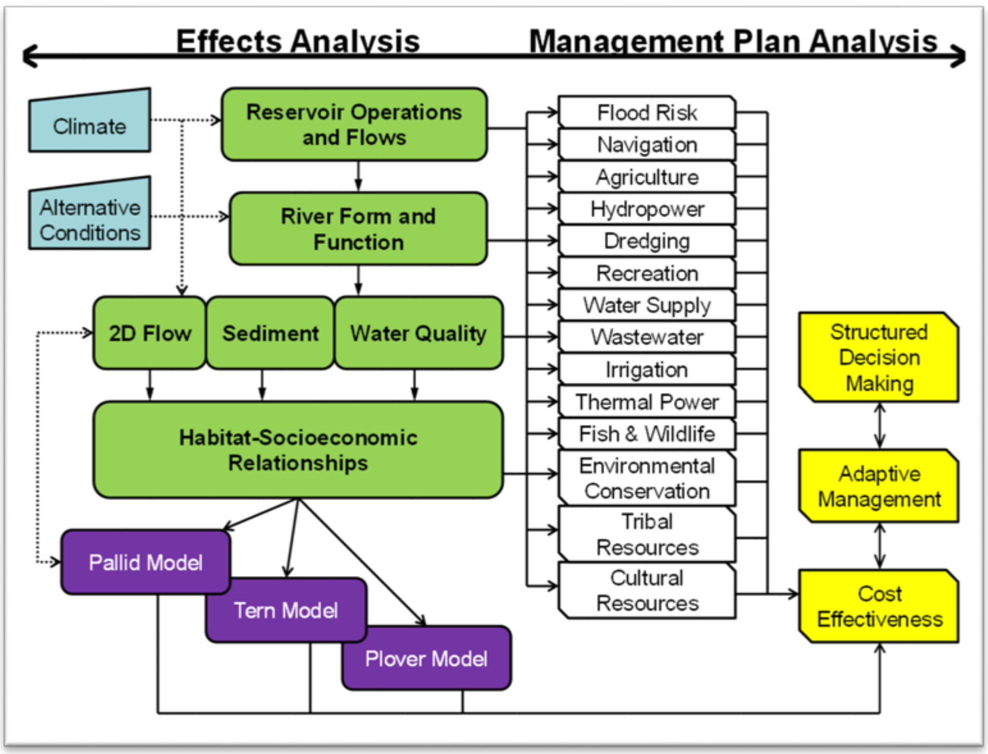

Figure 1. Model Framework for Effects Analysis and Management Plan Analysis
(Fischenich, 2014)

2 HYDROLOGIC EVALUATION OBJECTIVES

In order to meet the requirements of the MRRP, the USACE is undertaking an evaluation of proposed ManPlan actions and alternatives to be implemented over a 15 year horizon. Proposed ManPlan alternatives would be developed using a passive and active adaptive management framework to reduce uncertainty relative to specie-specific actions, aimed at avoiding jeopardy for the least tern, piping plover, and pallid sturgeon. These efforts are supported by an Effects Analysis and a Management Plan Analysis (Fischenich, 2014).

The very large geographic scope, varied geographic conditions and complex system of river reaches, reservoirs, levees and navigation structures, coupled with a dynamic river system, present significant modeling challenges. A key objective of hydrologic analysis was to develop models capable of simulating the full range of alternatives proposed for evaluation, while limiting complexity of the models so that they can be developed in a reasonable time period. Model outputs must have sufficient quality and accuracy to support comparative analysis using the conceptual and quantitative human considerations and ecological models.

Significant hydrologic analysis model objectives, development phases, and assumptions include:

- Construct and calibrate hydrologic models using the best available data for current conditions (e.g. 2010 to 2012).
- State of the art USACE ResSim and RAS hydrologic models.
- Develop period of record (POR) inflows from 1931 to 2012 that include current level of basin water development flow depletions.
- Follow the standard practice of the EIS study plan to define base line conditions as the current condition plus future USACE pallid habitat construction acreage goals.
- Consider potential for future change such as climate change influence on flows and river stage-discharge variation due to aggradation / degradation, and other factors.
- Provide model outputs suitable for use by the human considerations models to compare no action and alternative conditions.
- Assume future habitat construction of each alternative can be represented by adding it instantaneously to the RAS model geometry without correction for future aggradation or degradation.
- Assume flood risks can be adequately described between alternatives using the developed, stationary, 82 year period of record. A Monte Carlo based risk analysis to quantify uncertainty with future flows downstream of the reservoir system was scoped, but deferred at this time. Additional uncertainty analysis may be required if alternatives with flood pulses are considered for implementation.
- Risk from non-riverine flooding from underseepage and localized runoff within the interior area of levee systems downstream from Omaha, Nebraska, was analyzed for four representative levee systems for each alternative. Full quantification of flood damage from non-riverine flood sources within the hundreds of Missouri River levee systems was considered beyond the scope and schedule of the study.

Hydrologic model outputs were used in effects analysis species modeling and in human considerations impacts models. The term human considerations (HC) is used to address the interests of stakeholders. These include the authorized purposes as well as the many other services afforded by the System. Human considerations to be assessed when evaluating alternatives are rooted in the economic, social, and cultural values associated with the natural resources of the Missouri River. Refer to Chapter 2 of the Draft EIS for further discussion on HC analyses methods.

3 MISSOURI RIVER BASIN

The Missouri River is 2,341 miles long and drains one sixth of the contiguous United States, encompassing an area of 529,350 square miles. Average annual rainfall varies from 8 inches per year to 40 inches per year across the basin, with a total average annual runoff of 25,000,000 acre-feet above Sioux City.

3.1 MAINSTEM RESERVOIR SYSTEM

The Missouri River Mainstem Reservoir System (System), which became fully operational in 1967, includes six USACE mainstem dams with a total storage capacity of 72.4 million acre-feet (MAF) and carry-over storage of 38.5 MAF, which makes it the largest reservoir system in North America. Dozens of other Federal dams regulate flow on tributaries to the Missouri River and are managed in concert with the mainstem dams. Storage capacities for all Corps reservoirs is shown in Figure 2.

The Missouri River System is managed by the U.S. Army Corps of Engineers to serve eight congressionally authorized project purposes; flood control, navigation, irrigation, hydropower, water supply, water quality, recreation, and fish and wildlife. Runoff is stored in the six reservoirs where it is managed to serve these project purposes. Water is released from the dams as prescribed by the System's Master Manual. Figure 3 shows the Missouri River Basin including the locations of the Missouri River mainstem dams.

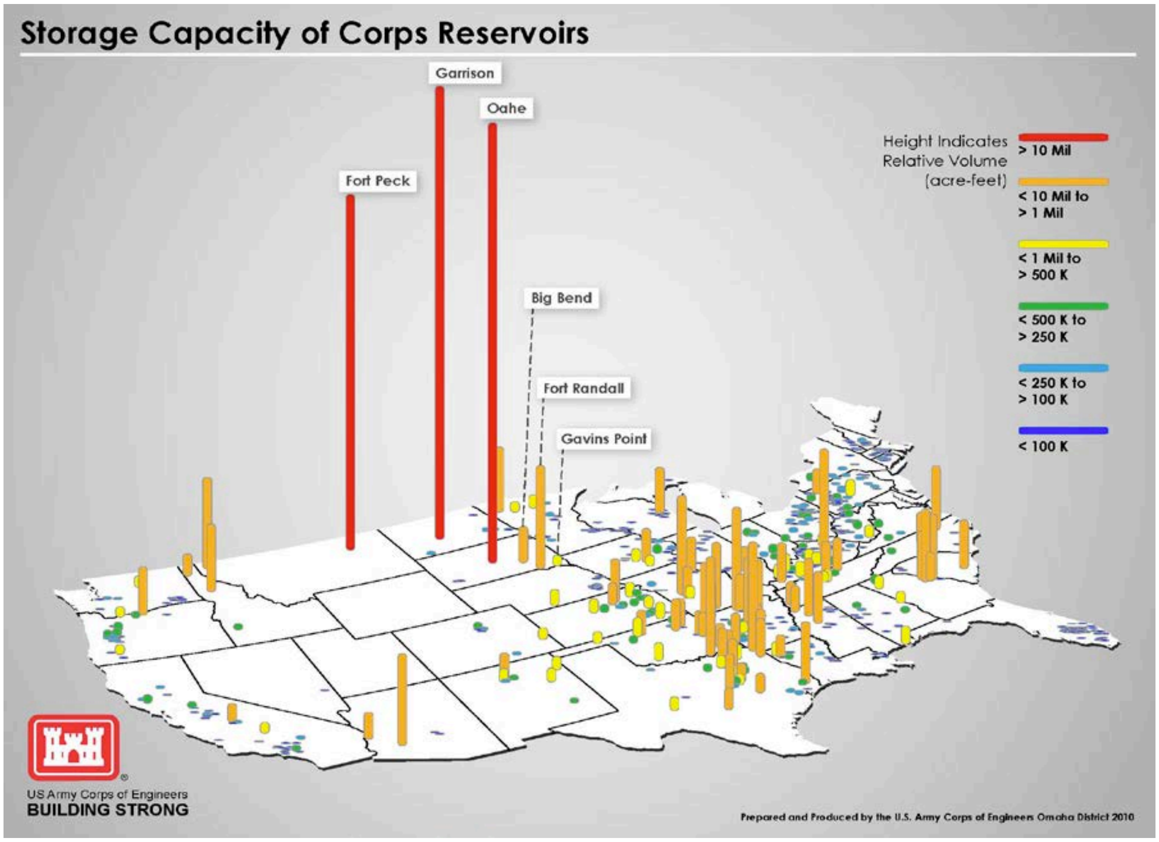

Figure 2: Storage Capacity of Corps Reservoirs

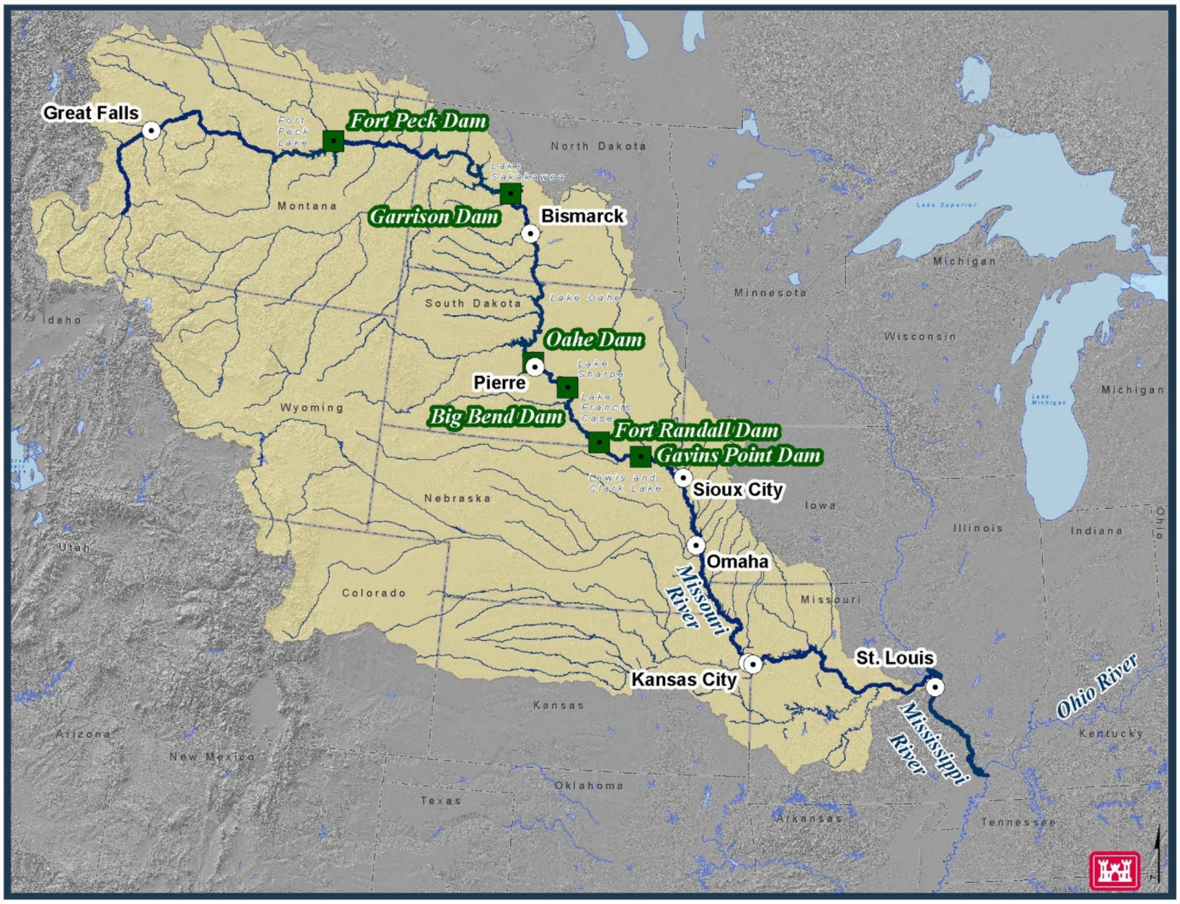

Figure 3. Missouri River Basin and Mainstem Reservoirs

3.1 MODEL EXTENTS

The Missouri River Basin encompasses over one half million square miles. Although the MRRP is focused on the main stem Missouri River, the hydrologic and hydraulic response of the river is influenced by the watershed as a whole. Under the scope of the ManPlan Study not every sub-watershed or tributary needs to be evaluated explicitly in the hydrologic models. Large areas of the watershed, including some upstream reservoirs, do not have sufficient water management potential to significantly support restoration alternatives, create significant social or economic effects, or be significantly impacted by restoration alternatives within the scope of ManPlan. Reservoirs that have potential to impact management for the three listed species are modeled using ResSim with model computed reservoir releases used as inputs to the RAS models. Basins are captured as inputs to the RAS model through analysis of historic gage data and outputs from reservoir models. In some cases portions of tributaries are included in the RAS models in order to more accurately route flows from the tributary gage to the mainstem and improve model calibration.

4 HYDROLOGIC MODEL DEVELOPMENT AND CALIBRATION

Hydrologic model development was conducted to create a robust suite of models suitable for study use. These models were initially developed for the current condition with the intent to revise the models in the future for alternative condition analysis.

4.1 HEC-RESSIM

ResSim is a reservoir operations model developed by the USACE Hydrologic Engineering Center (HEC). The model incorporates user defined rules with other conditions (i.e., inflow, pool elevation, and downstream flows) to determine reservoir outflow. The model also performs downstream hydrologic channel routing. Water managers, water control manuals, and other documentation all help in determining the rules necessary to simulate a reservoir within the model.

The Missouri River Main Stem ResSim model was simulated using a daily time interval. The modeling includes the Mainstem Missouri River reservoir System and extends downstream to target gages on the lower river. Two models are used to simulate the Missouri River mainstem reservoir operations: a Downstream and System model. The Downstream model assumes that storage from all six reservoirs is located within one reservoir at Gavins Point. This is done because the mainstem reservoir operations are performed in a downstream to upstream manner where Gavins Point releases are first set, and then all releases from the upper reservoirs are set so enough storage remains in Gavins Point to meet required releases and maintain desired pool elevations. Therefore, the downstream model contains all the rules needed for downstream operations: service level, navigation season length, flood constraints, water supply, etc., and calculates Gavins Point releases for the period-of-record. Once Gavins Point releases have been calculated for the period-of-record, the System model sets releases for the other five reservoirs upstream of Gavins Point to ensure that enough storage remains in Gavins Point to meet Gavins Point releases calculated from the downstream model. The Missouri River Mainstem System is very large and complex. Several of the management actions and alternatives formulated for this draft MRRMP-EIS would require changes to current System operations. USACE (2015a) describes the model in detail including System operations, scripting rules and an evaluation of model performance.

The Missouri River Mainstem System ResSim model was developed for the hydrologic assessment of various operational changes to the mainstem reservoir system (System). System operations for each alternative assessed for the Recovery Program are described for four seasons: spring (March-April), summer (May-September), fall (October-November), and winter (December-February). Operational criteria are further described based on operational decisions for the System downstream of Gavins Point and operational decisions for the System upstream of Gavins Point. Operation criteria in the ResSim model closely follows the Master Manual (USACE 2006) that is used during real-time operations of the System; however, the model does have limitations and cannot capture all real-time decisions that occur. A separate ResSim analysis was conducted for the Kansas, Chariton, and Osage River systems. Prior to ResSim model creation, much effort was spent developing required input data such as local inflows, evaporation, and dam and reservoir physical parameters. Refer to the *Mainstem Missouri River Reservoir*

Simulation Report (USACE 2015a) for a detailed description of ResSim model development and calibration.

4.2 HEC-RAS

RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. Common outputs include stage, duration/timing of inundation, water velocities, flow areas/routes, water temperature, and sediment loads. Unsteady flow analysis was chosen as the method of hydraulic modeling due to the need to analyze time series stage and flow data. Both the biological considerations (e.g., seasonal habitat requirements) and the human considerations (e.g., potential agricultural impacts) are affected by the timing of river flows. RAS was used to more accurately route discharges from reservoirs and tributaries to points downstream and to simulate impacts of mechanical changes in river channel geometry. These models simulate how proposed alternatives and management actions would impact river stage and discharge over a wide range of basin hydrologic conditions.

The purpose of the RAS models was to create a baseline that closely represents current river conditions and to provide a tool to evaluate potential hydraulic changes resulting from proposed management actions or alternatives (e.g. channel reconfiguration and/or flow management). The baseline or existing conditions models were modified to represent a future condition under the No Action and action alternatives. Outputs of the RAS models were used in concert with other modeling programs such as HEC-Ecosystem Functions Model (HEC-EFM) and HEC-Flood Impact Analysis (HEC-FIA) to perform impacts analysis.

Varying availability of terrain and bathymetric data, the presence of the Mainstem reservoirs, and the need to take advantage of local knowledge of river conditions led the staff in the Kansas City and Omaha Districts to develop 5 separate RAS models for discrete reaches of the Missouri River. These reaches are: Fort Peck Dam to Garrison Dam; Garrison Dam to Oahe Dam; Fort Randall Dam to Gavins Point Dam; Gavins Point Dam to Rulo, Nebraska (district boundary) and Rulo, Nebraska the mouth of the Missouri River at St. Louis, MO. Because the boundary between the Kansas City and Omaha Districts is at Rulo, NE, the Gavins Point to the mouth models contain an overlap from Nebraska City, NE, to St. Joseph, MO, in order to facilitate calibration and a clean transition of flows between the two separate models. The RAS models for the calibration condition within each reach were based on the best available geometry and were calibrated to current conditions using the best available information. Refer to the *Missouri River Recovery Program Management Plan Environmental Impact Statement Existing Conditions Unsteady HEC-RAS Model Calibration* Report (USACE 2015b) for a detailed description of RAS model development and calibration.

Figure 4 illustrates the individual RAS model locations. The Oahe to Big Bend and Big Bend to Randall reaches were not modeled in RAS due to the lack of riverine conditions between the dams.

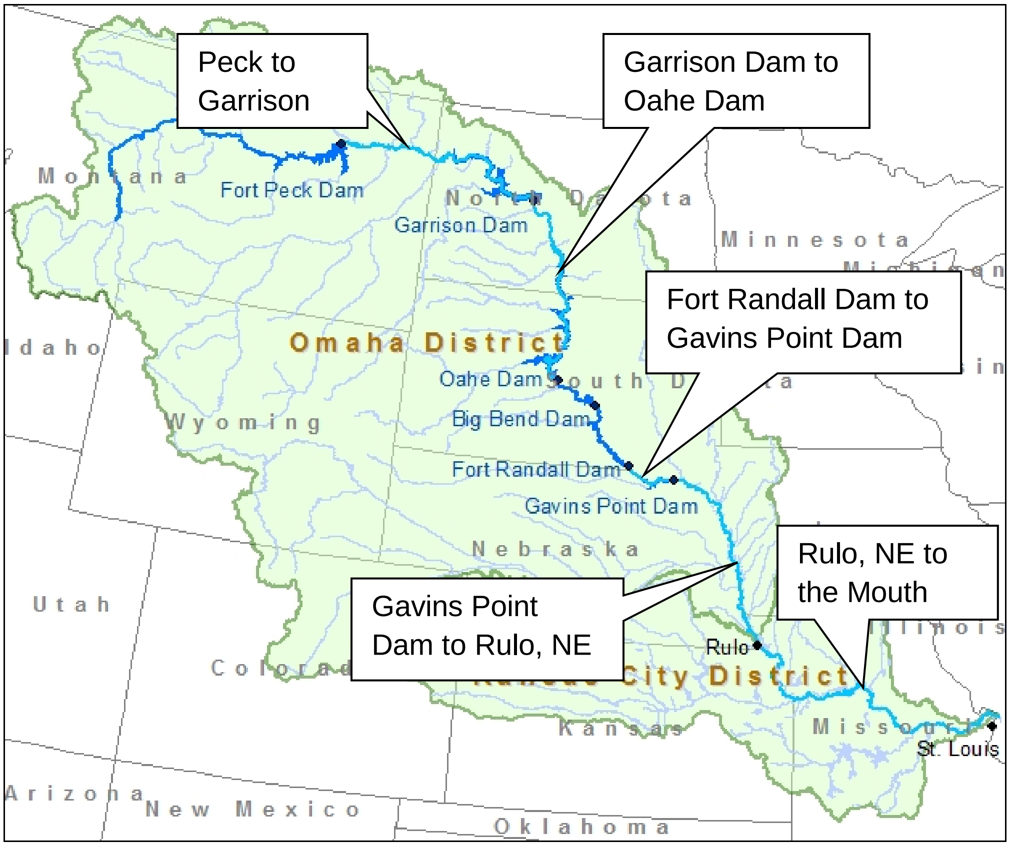

Figure 4**. Location of HEC-RAS Modeled Reaches**

For the three RAS models within the reservoir system, the model reach includes a substantial degradation reach that extends downstream from the dam and a large aggradation zone in the headwaters of the downstream reservoir. The extreme 2011 flow event significantly altered the river stage-flow relationship and model calibration to observed stages in flood years prior to 2011 is not valid in most areas upstream of Rulo, NE.

5 PERIOD OF RECORD ANALYSIS

A POR modeling approach was selected for use with the RAS and ResSim modeling effort and subsequent hydrologic analyses for the MRRMP-EIS. As used in hydrologic models for flood-runoff analysis, period of record analysis refers to applying a hydrologic model to simulate a continuous period of record of streamflow. POR development requires relatively sophisticated hydrologic models capable of simulating all extremes of the hydrologic cycle, including detailed simulation of flood events, drought years, and seasonal fluctuations. A POR analysis is one of several hydrologic evaluation methods discussed in USACE guidance documents (USACE 1994, USACE 1995).

The POR hydrologic evaluation uses the continuous historic records of hydrologic events. The POR procedure preserves the seasonality, persistence, and dependence or independence of basin hydrologic inputs. The method enables model results and alternative comparisons to be displayed in a manner easily understood. Results can be supplied in a simple comparative format for other evaluations and analysis programs such as those employed by the HC team to evaluate economic differences between alternatives. Potential drawbacks that are typical to the methodology include 1) the historic record being unrepresentative of basin hydrology; 2) the procedure requires significant information needs and extensive calibration. For the Missouri River system, the POR includes severe, long term, drought as well as extreme floods which addresses typical drawbacks with basin hydrology. Due to the size and complexity of the Missouri River Mainstem System, the POR methodology was selected as superior compared to other methods such as precipitation runoff modeling and frequency analysis. Where possible, engineering judgement was applied to the results to mitigate the limitations of the POR approach, or potential additional future analysis was recommended to reduce uncertainty depending on the nature of alternatives considered

Detailed documentation of the data development methods and data sources conducted to create the POR for all hydrologic models is provided in *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling* (USACE 2016d).

5.1 METHODOLOGY

Flows for all required inflow points to all hydrologic models were developed for the Missouri River basin for the period of record used in the ManPlan Study analysis for the period from March 1930 through December 2012. POR flows were used in the Upper Missouri River ResSim models, the Mainstem Missouri River ResSim models, the Kansas City District (NWK) ResSim models, and the local inflows for the RAS models. When gage data was unavailable, other methods were used to determine inflow for the entire POR. Estimated daily flow for the POR was used to provide all RAS model inflows.

Due to study needs, the POR was assembled using daily flow values. Assembling the immense data set within the large Missouri River basin study area to accurately include all inflows, evaporation, and other consumptive water use required extensive data collection and processing from multiple sources. The final POR input data set allows accurate simulation of the MRRMP-EIS base condition and alternative conditions.

5.1 POR SIMULATION PERIOD

The hydrologic model POR simulation period includes a portion of 1930 while the HC analysis reported simulation is from 1931 through 2012. The 1930 portion of the POR was simulated to provide for model stability and a hydrologic model convergence period for the unsteady flow simulation prior to January 1, 1931. Although the hydrologic models provided results from a portion of 1930, HC team analysis was only performed for the 82 year period from January 1, 1931 through December 31, 2012.

5.2 RESULTS

Summary results are presented in the POR documentation report (USACE 2016d). Regarding the POR flow data set:

- Various methods were used to assemble the POR flow record for each model.
- All flows were corrected to current level depletions to reflect water use within the basin. Therefore, comparison of hydrologic model results from either ResSim or RAS to observed conditions is not possible.
- Although the hydrologic models provide results from a portion of 1930, an 82 year POR was used for HC analysis from 1931 through 2012.

6 OVERVIEW OF HYDROLOGIC MODELING OF MANAGEMENT ACTIONS

Management actions, and the intended environmental effects, are described in detail within the EIS study documentation. These actions are briefly summarized in this document to provide context for the conducted hydrologic evaluation.

6.1 LEAST TERN AND PIPING PLOVER

Numerous management actions were developed to benefit the least tern and piping plover by providing suitable emergent sandbar habitat (ESH) within the reservoir and open-river reaches. Flows that are high relative to the elevation of existing sandbars have the potential to mobilize and deposit sediment at high enough elevations to create new sandbars when water levels recede. High flows must be of sufficient duration to build sandbars to a high enough level to provide suitable habitat at more typical flows. Mechanical creation using standard techniques including dredging and heavy construction equipment was also evaluated as a management action. Omaha District has an existing ESH Program and has mechanically constructed ESH in the Gavins Point river reach and upper Lewis and Clark Lake at various locations during the period from 2004 to 2010.

Both methods to create new ESH (flow manipulation and mechanical construction) are conducted by redistributing sand within the existing river cross section. No stabilization of sandbars is included. Therefore, sandbar habitat tends to decay with time as sandbar elevation decreases due to normal sediment processes. Experience has also shown that the conveyance of the river flow cross section is the same with no net change in flow area.

- Multiple management actions, consisting of revisions to reservoir flow releases intended to create emergent sandbar habitat, were evaluated with ResSim.
- Since the sediment processes are dynamic, the ESH creation actions were not evaluated with the RAS models.
- ResSim computed flow releases for ESH objectives were evaluated with the RAS models.

6.2 PALLID HABITAT

Despite considerable effort during the effects analysis process, the identification of the specific factors causing recruitment failure for pallid sturgeon and a clear nexus between management actions and population response was not identified for the lower river (downstream of Gavins

Point Dam) (Jacobson et al. 2016). As a result, development of alternatives for pallid sturgeon was a collaborative process between the USACE, U.S. Fish & Wildlife (USFWS), and the effects analysis team relying on the best available science to develop pallid habitat creation actions. During the course of the effects analysis, a leading concept emerged that was termed interception and rearing complex (IRC). Spawning cue flows were also considered. The creation of pallid habitat (IRC or other) results in significant changes to Missouri River channel geometry. Alternatives were formulated to achieve variable pallid objectives which resulted in three levels of habitat construction.

- The extent of created pallid habitat varies with three levels of construction
- Pallid habitat geometry changes were evaluated with the RAS models
- Spawning cue flows were considered and included in several alternatives

7 ALTERNATIVE CONDITION MODELING

After developing the calibration condition ResSim and RAS models and assembling the POR flows, alternative conditions were simulated. Refer to the ResSim and RAS alternative condition reports for detailed description of alternative condition modeling (USACE 2016b and USACE 2016e). A total of six different alternative conditions were evaluated.

The previously developed Missouri River Mainstem ResSim Model was used to simulate System operation of historical flows during the period-of-record (March 1930 – December 2012). Flow related management actions or alternatives that include altering reservoir operations were simulated and compared to a simulation of current operations to assess effectiveness towards meeting species objectives and the effects on natural, social, cultural, and economic resources of interest. The ResSim simulations provided pool elevations, regulated inflows and outflows of each of the mainstem projects for each alternative simulation. This data was used directly as input to impacts assessment models (i.e., human considerations models) and available RAS models that estimate inundation and discharges at locations on free-flowing reaches of the Missouri River.

7.1 HEC-RAS Model Geometry Alternatives

Alternative analysis was performed using the five separate RAS calibrated current condition models with modifications to reflect the various alternatives as needed.

Each flow alternative, described in the following section, was paired with a geometry alternative to produce six total alternatives that were run through the suite of RAS models. For example, the No Action geometry was paired with the No Action flow for Alternative 1.

Three geometries were created for the alternatives analysis within the suite of RAS models. Since no pallid habitat actions are necessary upstream of Ponca, NE, only the two RAS models used for study analysis that are located downstream of Gavins Point Dam (Gavins to Rulo, NE, and Rulo, NE, to the mouth) were modified with geometry revisions. The pallid habitat configurations that were modeled included:

1. **No Action** - Assumes habitat construction activities follow current practices to achieve 20 acres/mile of SWH, the minimum target specified in the 2003 Amendment to the 2000 Biological Opinion.
2. **Biological Opinion as Projected (BiOp)** - Guidance from the USFWS was provided to create a geometry which represents an ideal implementation of the 2003 Biological Opinion. It assumes habitat construction accomplishes 30 acres/mile of SWH, and performs at a wider range of flows including a summer low and spring pulse. Floodplain connectivity goals in the BiOp were evaluated using the RAS models to determine inundated acreage for the 20% annual chance exceedance event (20% ACE or 5-year). Analysis results determined the existing river geometry met the BiOp goals so no changes to the river geometry were necessary to provide additional floodplain connectivity.
3. **Interception-Rearing Complexes (IRC)** – Pallid habitat construction activities were based on findings made by the Effects Analysis (EA) team. It assumes habitat construction accomplishes 260 acres/year over a 13 year period based on current annual habitat construction rates.

7.2 Flow Alternatives

Revisions to reservoir releases were a primary component of all six alternatives. The flow changes were modeled in ResSim as described in the alternative modeling detailed documentation *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report* (USACE 2016b). Flow alternatives are conducted for the purposes of ESH creation and pallid spawning benefit. No geometry change due to ESH creation is included within the RAS suite of models.

The reservoir pool elevations and dam outflows determined with the ResSim model were used as input for the various RAS models for each of the six flow alternatives. The following sections provide a more detailed description of flow changes related to each alternative.

7.2.1 Alternative 1 (No Action)

Under Alternative 1 (Alt 1), the Missouri River Mainstem Reservoir System would continue to be operated following current guidelines. Operations within the ResSim model were set up to closely follow the Master Manual that is used during real-time operations of the System; however, the model does have limitations and cannot capture all real-time decisions that occur. In addition, this alternative includes a plenary bimodal spawning cue attempt each year, one in March and one in May. The No Action pallid habitat geometry was used with this alternative.

7.2.2 Alternative 2 (U.S. Fish & Wildlife Service 2003 Biological Opinion Projected Actions)

Alternative 2 (Alt 2) represents the USFWS interpretation of the management actions that would be implemented as part of the 2003 Amended BiOp RPA (USFWS 2003). Operational criteria include different early and late spring spawning cues (March and May), low summer flows, and a maximum winter release limit. The BiOp as projected pallid habitat geometry was used with this alternative.

7.2.3 Alternative 3 (Mechanical Construction Only)

Alternative 3 (Alt 3) consists of mechanical construction of ESH. Operational criteria consist of removing the early and late spring spawning cues in Alt 1. The IRC pallid habitat geometry was used with this alternative.

7.2.4 Alternative 4 (Spring ESH Creating Release)

Under Alternative 4 (Alt 4), the early and late spring spawning cues in Alt 1 are removed from the operational criteria and a spring ESH-creating reservoir release from Gavins Point and Garrison is added. While the ESH-creation release is occurring from Gavins Point, flood targets are increased to allow the ESH-creation release the opportunity to run. The IRC pallid habitat geometry was used with this alternative.

7.2.5 Alternative 5 (Fall ESH Creating Release)

Alternative 5 (Alt 5) removes the early and late spring spawning cues in Alt 1 and adds a fall ESH-creating reservoir release from Gavins Point and Garrison to the operational criteria. While the ESH-creation release is occurring from Gavins Point, flood targets are increased to allow the ESH-creation release the opportunity to run. The IRC pallid habitat geometry was used with this alternative.

7.2.6 Alternative 6 (Pallid Sturgeon Spawning Cue)

Alternative 6 (Alt 6) replaces the early and late spring spawning cues with different spawning cues. The early spring spawning cue in Alt 6 occurs at the same time as the early spring spawning cue in Alt 1 but with a higher peak release. The late spring spawning cue in Alt 6 occurs later in May than the late spring spawning cue in Alt 1 and has a larger peak release. The IRC pallid habitat geometry was used with this alternative.

7.3 MODEL RESULTS

Hydrologic model results, consisting of computed daily flow and elevation information, was compiled from the ResSim and RAS models at key locations throughout the basin. Results from the hydrologic modeling were provided to the Human Considerations (HC) team members for the comparison of alternative conditions. Due to the basin size, number of hydrologic models, model complexity, and the number of alternatives developed, typical hydrologic model outputs such as flow frequency, profiles and flood area mapping were not developed. Comparison and summaries of the hydrologic model results at key locations were developed and evaluated. Refer to the ResSim and RAS alternative analysis reports for detailed documentation of the results for each modeling effort (USACE 2016b, USACE 2016e).

7.4 SOURCES OF UNCERTAINTY

Factors that contribute to uncertainty in the ResSim and RAS model results include the dynamic nature of the river system itself, model representation of actual reservoir operations, estimation of depletions, river response to flood events and construction projects, the availability and quality of terrain data to represent the channel and floodplain geometry, and the variable quality and quantity of hydrologic data through the period of record. Actions of others building or improving features such as roads, bridges, or levees may also influence future water surface profiles or inundation area that are not accounted for in the analysis. Once again it should be emphasized that the current modeling effort represents existing river conditions.

Specific details regarding model limitations are presented in the ResSim and RAS calibration and alternative analysis reports (USACE 2015a, USACE 2016b, USACE 2015b, and USACE 2016e).

8 INTERIOR DRAINAGE EVALUATION

Interior drainage refers to the conveyance of flow from interior, or landward side, of the levee to the Missouri River channel. Typical Missouri River levee systems have culverts or pump stations to allow local drainage to exit the interior of the levee and drain to the river. Each culvert typically would include one or more closures, such as a flap gate or sluice gate, to prevent river water from backing up into the leveed area. When river levels are higher than the culvert outlets and this coincides with heavy local rainfall, ponding water can cause flooding on the interior of the levee. Additionally, when river levels are above the interior ground level, seepage through the ground under the levee can also cause flooding on the interior. Conveyance of flow to interior areas during very high Missouri River periods as a result of levee overtopping was accounted for in the primary RAS modeling effort.

To evaluate potential impacts of the change in river levels for each alternative on interior drainage, detailed modeling was conducted on a sub-set of the seven sites evaluated for the Master Manual (USACE 1998). Four sites were selected, L-575 and L-536 in the Omaha District and L-488 and L-246 in the Kansas City District.

The interior drainage evaluation was conducted using the alternative condition RAS models. Refer to the *HEC-RAS Modeling Alternatives Report* (USACE 2016e) for a detailed discussion of model creation and results. All sites are located downstream of Omaha, NE, within the reach in which federal levees were constructed. Consequently, only the Gavins to Rulo and Rulo to the mouth RAS models were used in the interior drainage analysis. Figure 5 shows an area map with the locations of the four sites on the river.

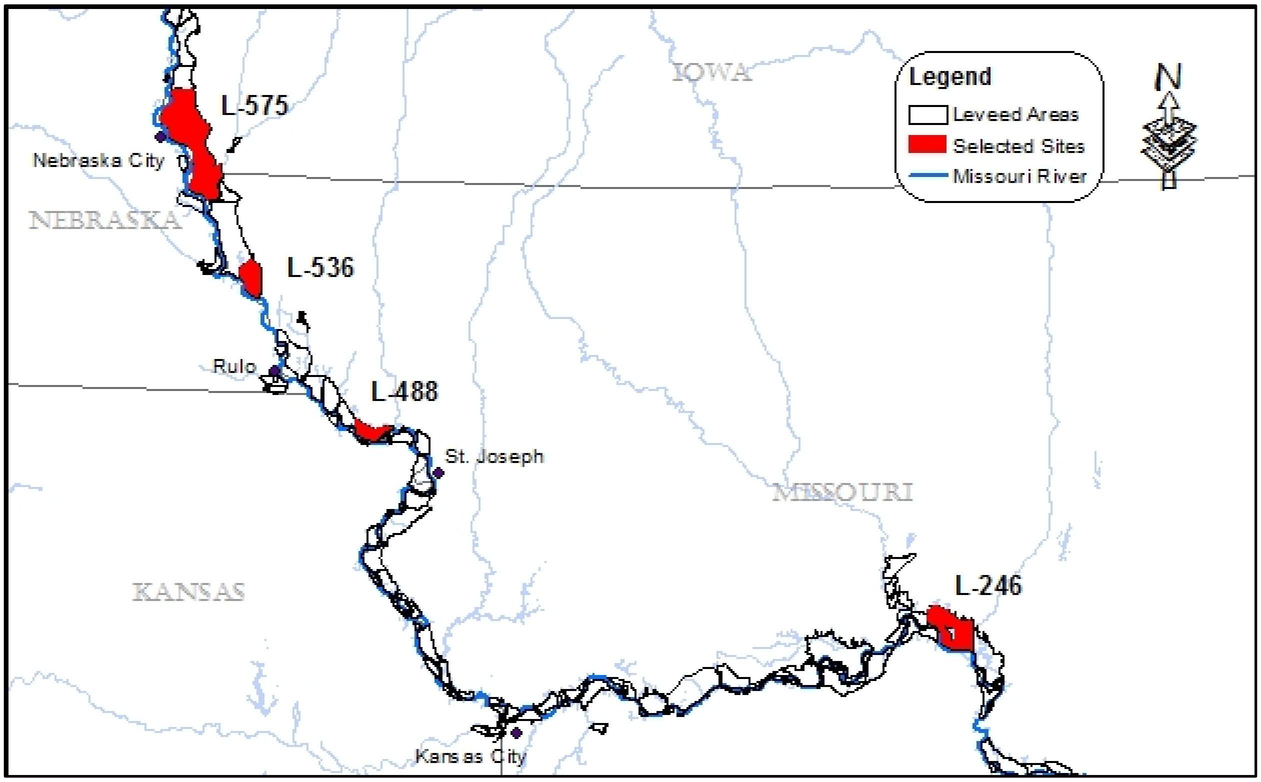

Figure 5. Interior Drainage Sites

9 CHANNEL CAPACITY EVALUATION

Channel capacity estimates were performed to provide an indication of the flow rate at which bank elevations are overtopped and flow begins to leave the main channel and enter the floodplain. Channel capacity was compared to alternative flow condition reservoir releases and downstream inflow at two locations, near Nebraska City and downstream of Fort Randall Dam near the Niobrara River, to provide an assessment of a change in flood potential. Refer to the *HEC-RAS Modeling Alternatives Report* (USACE 2016e) for a detailed discussion of the channel capacity evaluation.

10 CLIMATE CHANGE

A qualitative climate change assessment for the Missouri River Recovery Management Plan was performed by the USACE in accordance with *Engineering and Construction Bulletin 2016-25: Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects* (USACE 2016a).

The climate change assessment results were examined to determine their effects on various plan alternatives being considered at this phase of the study. See *Missouri River Recovery Management Plan - Climate Change* (USACE 2016c) for more details.

10.1 PHASE 1 - RELEVANT CURRENT CLIMATE AND CLIMATE CHANGE

Numerous publications on climate change from varying sources were reviewed and summarized during Phase 1. The consensus was that temperature and precipitation in the Missouri River basin have increased. The increased temperatures cause less winter precipitation to fall as snow and more to fall as rain resulting in less mountain snowpack accumulation throughout the western portion of the basin. With more winter precipitation falling as rain, runoff increases during the winter months. The snowpack that does accumulate during the winter months is melting earlier resulting in earlier peaks in the seasonal mountain runoff patterns. The northern plains are experiencing similar changes with more rainfall and less snowpack accumulating during winter months resulting in earlier peaks in seasonal plains runoff patterns. Annual rainfall amounts have increased during the summer months, but rainfall events have become sporadic for the entire Missouri River basin. Large rain events are more frequent and interspersed by longer relatively dry periods. Sediment loading and inflows are expected to increase into Garrison Reservoir in the upper basin for all climate scenarios evaluated.

10.2 PHASE 2 - PROJECTED CHANGES TO REGIONAL HYDROLOGY AND ASSESSMENT OF VULNERABILITY TO CLIMATE CHANGE

This portion of the analysis focused on projected changes in the study area and watershed(s) of interest using various tools. The USGS National Climate Viewer identifies observed and projected climate trends for a desired watershed or county. The USACE Nonstationarity Detection Tool applies a series of statistical tests to assess the stationarity of annual instantaneous peak streamflow data series for any United States Geological Survey (USGS) streamflow gage site with more than 30 years of annual instantaneous peak streamflow records through Water Year (WY) 2014. The USACE Climate Hydrology Assessment Tool identifies projected changes in annual maximum monthly flows for the Hydrologic Unit Code (HUC) 4 watershed(s) most relevant to the project. The USACE Watershed Vulnerability Assessment Tool provides information on the relative vulnerability of a given watershed to climate change.

10.3 CLIMATE CHANGE CONCLUSIONS

USACE climate change guidance and most references from other sources for the Missouri River Basin agree that future climate trends are likely to have increased temperatures and precipitation. USACE climate tools and some other sources point towards increased streamflow trends as well. The increased temperatures are likely to result in earlier spring snowmelt, decreased snowmelt season duration, and decreased peak SWE. Increased air temperatures could also have impacts on water temperatures and water quality, which could exacerbate impacts of alternatives with low summer flows. Rainfall events are likely to become even more sporadic for the entire Missouri River basin. Large rain events are likely to become more frequent and interspersed by longer relatively dry periods. Extremes in climate will also magnify periods of wet or dry weather resulting in longer, more severe droughts, and larger more extensive flooding. These increased sporadic flood and drought periods could prove challenging for reservoir regulation, and have impacts to all the proposed alternatives summarized previously. The sporadic flooding would increase the risk of downstream flooding during periods of pulse releases. Sediment loading is expected to increase for at least one mainstem reservoir in the basin, also adding to regulation challenges and impacting alternatives. More precise environmental impacts to study alternatives due to future climate change trends were determined by study team members, including members with environmental expertise, and are summarized in a table within the report *Missouri River Recovery Management Plan - Climate Change* (USACE 2016c).

11 RISK ANALYSIS

The Missouri River System as currently operated provides substantial flood damage reduction and benefits to the entire basin. The current ResSim and RAS analysis, which employs an 82 year period of record simulation, shows the potential for negative impacts to flood damage reduction and dam safety for alternatives that include changes in reservoir flow releases. However, the current study methodology does not simulate a sufficient number of events and possible runoff combinations within the large Missouri River basin to allow quantification of flood risk change. Risk analysis would evaluate changes in reservoir pool levels, downstream flood risk, impacts to flood risk management projects (e.g. levees and floodwalls), and possible implications for dam safety.

Flow release magnitude for the alternatives which include a flow change exceeds the maximum power plant flow capacity at all projects except Big Bend. Past operation experience has shown that using the spillway or flood tunnels to release flow for a prolonged period results in the need for additional maintenance of these features and adds cost to operating the system. Long term reliability of flow release features (spillway and/or flood tunnel) may also be affected. Minor changes in dam safety risk may occur due to the additional flow releases through the spillway / power tunnels and changes in pool levels.

Scoping efforts were conducted to determine a Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood risk as a result of flow release changes. The risk analysis primary components include further development of the period of record flow data set, ResSim and RAS model modifications, development of levee fragility curves, assignment of uncertainty, assembly and debugging of models, Monte Carlo simulation, analysis of results, and reporting. The Monte Carlo methodology better assesses the effects of the alternative operation changes because it increases the sample size of flow data and number of combinations of flow periods that may occur in the future so that impacts can be characterized with greater confidence. Without such analysis, the impacts of operational changes will only be known for events and combinations of events that have already occurred.

The Monte Carlo risk analysis procedures are in accordance with risk based plan formulation and evaluation regulations described in USACE guidance materials, in particular ER 1105-2-101 (*Risk Analysis for Flood Damage Reduction Studies*, USACE, 2006) and ER 1105-2-100 (*Planning Guidance Notebook*, USACE, 2000). Risk evaluation principles employed in scope development follow procedures further explained within EM 1110-2-1619 *(Risk Analysis for Flood Risk Management Studies, USACE, 2012).*

- The conducted hydrologic and HC evaluation is suitable for alternative comparison but does not allow quantification of change in flood risk

- Potential impacts to flood risk management were identified by evaluation of the outputs from the ResSim and RAS analysis
- A Monte Carlo based risk analysis, that could estimate the magnitude of potential changes to flood risk management and associated uncertainties, was deferred and not included within hydrologic modeling conducted for the Draft EIS

12 QUALITY CONTROL

The quality control process for the hydrologic models is documented in the Kansas City Quality Management Plan (USACE, 2014) and Omaha District Design Quality Control Plan (USACE, 2013). Quality control has been an on-going process throughout model development. Team discussions were conducted through bi-weekly project calls involving the RAS modeling team and supervisory staff to resolve issues and maintain common standards. Periodic model peer reviews were conducted at key model development milestone such as low flow calibration, and occasional meetings were held with modeling experts from HEC.

Due to the time between efforts, a separate ATR was held for the calibration models that was completed in 2015 and the remainder of the hydrologic evaluations conducted for the alternative analysis. Formal District Quality Control (DQC) and Agency Technical Review (ATR) were conducted as prescribed in the Quality Management Plans and documented in Dr. Checks.

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