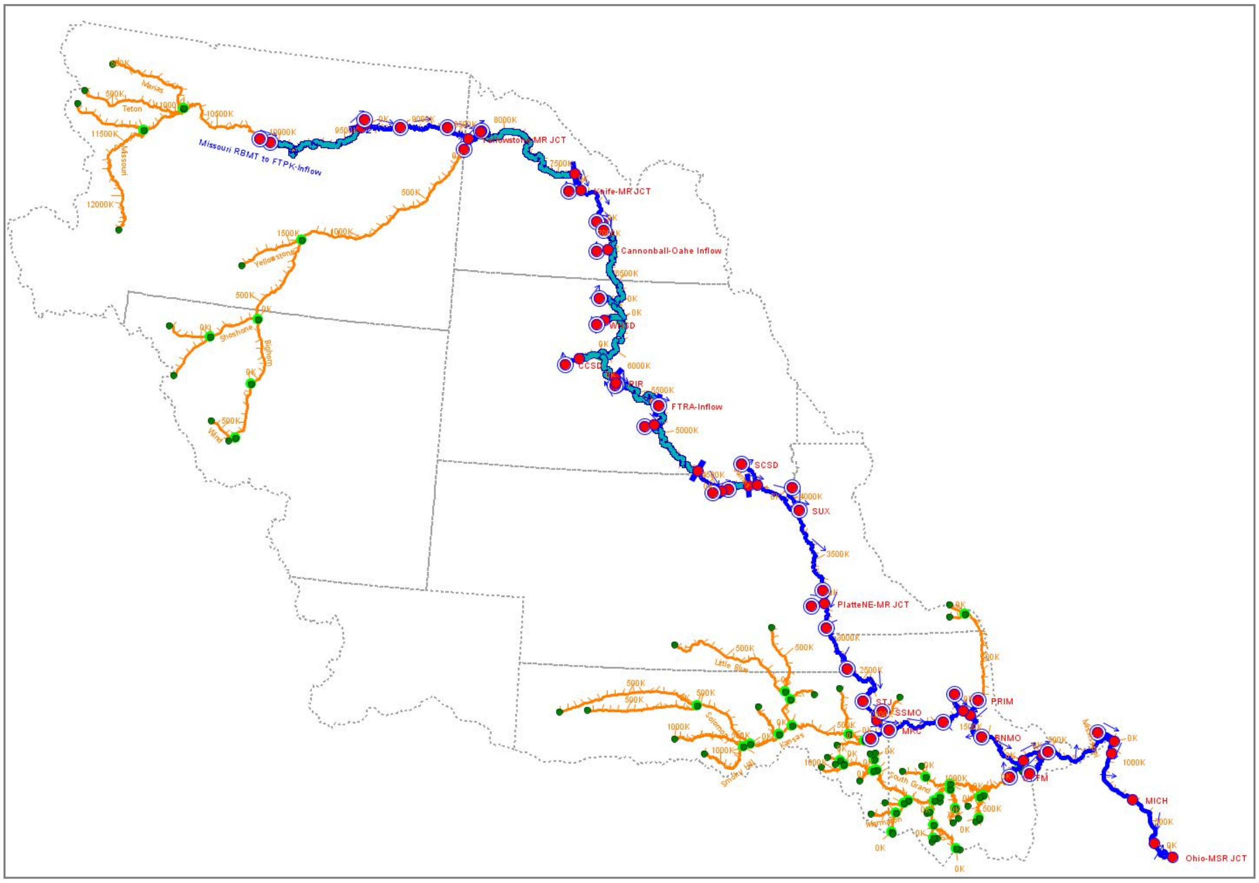
US Army Corps of Engineers ®

Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling

DRAFT



Northwestern Division
Omaha and Kansas City Districts
Hydrologic Engineering Branch
Engineering Division
September 2016

EXECUTIVE SUMMARY

The purpose of the Missouri River Recovery Management Plan and integrated Environmental Impact Statement (MRRMP-EIS) is to develop a management plan that includes a suite of actions to meet Endangered Species Act (ESA) responsibilities for the piping plover, the interior least tern, and the pallid sturgeon using USACE authorities. The project involved the creation of a detailed suite of models for the Missouri River basin to evaluate existing condition and proposed alternatives. This report documents the development of the time series data sets for local inflows and evaporation to be used as input for the HEC-ResSim (ResSim) and HEC-RAS (RAS) models.

Various data development methods were used based on available data sources at different locations. This report describes the data development methods and data sources in detail for the reservoir modeling time series input data sets of local inflows and evaporation 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. This report also describes the various routing methods used to determine the local inflow data sets. For a more detailed discussion on individual methods/results at a particular location, please see the pertinent full summary report. Information for all reports are included in the References section.

The period of record (POR) selected for study purposes was initially set as January 1898 to December 2012. January 1898 was selected as the starting date to coincide with previous data development done as part of the *Upper Mississippi River System Flow Frequency Study* (USACE, 2003) completed in 2003. December 2012 was selected as the end date because that was the most recent data readily available during this phase of the study. After the POR time series data sets were completed and thoroughly reviewed, the decision was made to use only the data after January 1930. Several reasons were weighed to reach this decision, which are explained in detail in this report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AOP…………………. . Annual Operating Plan

CMA…………………. Centered Moving Average

CR…………………… Coefficient Routing

CRREL……………... Cold Regions Research and Engineering Laboratory

CWMS………………...Corps Water Management System

DCP…………………. Data Collection Platform

DRM .... Daily Routing Model

DSSVue…………….. Data Storage System (by HEC)

ESA…………………...Endangered Species Act

ESOP………………... Emergency Systems Operation Plan

FEMA………………... Federal Emergency Management Agency

FERC………………....Federal Energy Regulatory Commission

GIS .... Geographic Information System

HEC .... Hydrologic Engineering Center

MAF………………….. Million acre-feet

MO…………………… Missouri

MOA…………………..Memorandum Of Agreement

MOVE…………………Maintenance of Variance Extension

MR…………………… Missouri River

MRADS……………… Mass Random Access Data Storage

MRBWM…………... .. Missouri River Basin Water Management Division (previously RCC)

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

MRRP…………………Missouri River Recovery Program

MS…………………… Mississippi

MVS…………………. Mississippi Valley Division St Louis District

NCDC…………………National Climatic Data Center

NOAA CPC…………National Oceanic and Atmospheric Administration Climate Prediction Center

NRCS……………….. Natural Resources Conservation Service

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

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

NWS .... National Weather Service

POR......................... Period of Record

RAS…………………..HEC-RAS, Hydrologic Engineering Center River Analysis System

RCC......................... Reservoir Control Center

ResSim……………....HEC-ResSim, Hydrologic Engineering Center Reservoir Simulation Software

RM…………………… River Mile

SS…………………...... Straddle-Stagger Routing

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

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

USBR....................... United States Bureau of Reclamation

USGS .... United States Geological Survey

WCM………………… Water Control Manual

1 INTRODUCTION

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.

This report documents the development of time series input data sets for local inflows and evaporation to be used in the HEC-ResSim (ResSim) and HEC-RAS (RAS) models in support of the Missouri River Recovery Management Plan and integrated Environmental Impact Statement (MRRMP-EIS).

Time series input data sets of local inflows and evaporation were developed for every reservoir modeled using ResSim in this study, and flows were developed for every tributary modeled using HEC-RAS. The different reservoir projects, their corresponding rivers, and the ResSim models containing each project are shown in Table 1-1 below, listed from upstream to downstream. The HEC-RAS models for the Missouri River Basin were broken down into five separate projects: Fort Peck to Garrison, Garrison to Oahe, Fort Randall to Gavins Point, Gavins Point to Rulo, and Rulo to the mouth of the Missouri River at St. Louis.

Table 1-1: Missouri River Basin Reservoirs Modeled in ResSim

Project or Lake Name	River	ResSim Model	Owner
Canyon Ferry Dam	Missouri River	Upper Missouri	USBR
Tiber Dam	Marias River	Upper Missouri	USBR
Fort Peck Dam	Missouri River	Mainstem Missouri	USACE
Boysen Dam	Wind River	Upper Missouri	USBR
Buffalo Bill Dam	Shoshone River	Upper Missouri	USBR
Yellowtail Dam	Bighorn River	Upper Missouri	USBR
Garrison Dam	Missouri River	Mainstem Missouri	USACE
Oahe Dam	Missouri River	Mainstem Missouri	USACE
Big Bend Dam	Missouri River	Mainstem Missouri	USACE
Fort Randall Dam	Missouri River	Mainstem Missouri	USACE

Gavins Point Dam	Missouri River	Mainstem Missouri	USACE
Wilson Lake	Saline River	Kansas	USACE
Kanopolis Lake	Smoky Hill River	Kansas	USACE
Waconda Lake	Solomon River	Kansas	USBR
Milford Lake	Republican River	Kansas	USACE
Tuttle Creek Lake	Big Blue River	Kansas	USACE
Perry Lake	Delaware River	Kansas	USACE
Clinton Lake	Wakarusa River	Kansas	USACE
Rathbun Lake	Chariton River	Chariton	USACE
Melvern Lake	Marais des Cygnes River	Osage	USACE
Pomona Lake	Hundred Ten Mile Creek	Osage	USACE
Hillsdale Lake	Big Bull Creek	Osage	USACE
Stockton Lake	Sac River	Osage	USACE
Pomme de Terre Lake	Pomme de Terre River	Osage	USACE
Truman Lake	Osage River	Osage	USACE
Lake of the Ozarks	Osage River	Osage	Ameren

Data were developed independently for the five separate ResSim models (Upper Missouri, Mainstem Missouri, Kansas, Chariton, and Osage) using somewhat varying, but similar, methods.

Data were also developed independently for the five separate HEC-RAS models for the Missouri River Basin (Fort Peck to Garrison, Garrison to Oahe, Fort Randall to Gavins Point, Gavins Point to Rulo, and Rulo to the mouth of the Missouri River at St. Louis). Multiple tributary inflow records were used in the RAS models and are further detailed in the individual RAS sections of this report, Section **Error! Reference source not found.**.

2 POR SELECTION

A period of record (POR) modeling approach was selected for use with the RAS and ResSim modeling effort 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. This method 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. 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.

The POR selected for study purposes was initially set as January 1898 to December 2012. January 1898 was selected as the starting date to coincide with previous data development completed as part of the *Upper Mississippi River System Flow Frequency Study* (USACE, 2003). December 2012 was selected as the end date because that was the most recent data readily available during this phase of the study. After the POR time series data sets were completed and thoroughly reviewed, a decision was made to use only the data after January 1930. Several reasons were weighed to reach this decision, which are explained in detail in Section 8.

3 MODEL AREA BACKGROUND

The following sections give brief backgrounds on the different models. The individual ResSim and RAS model reports should be consulted for more detailed information on other aspects of the models not related to time series data input. Figure 3-1 shows a map of the basin with all ResSim computation points modeled in this study. Computation points are common points where data can be transferred between models, and sometimes include observed data at those locations. Five of the seven river reaches labeled in the figure were modeled in RAS.

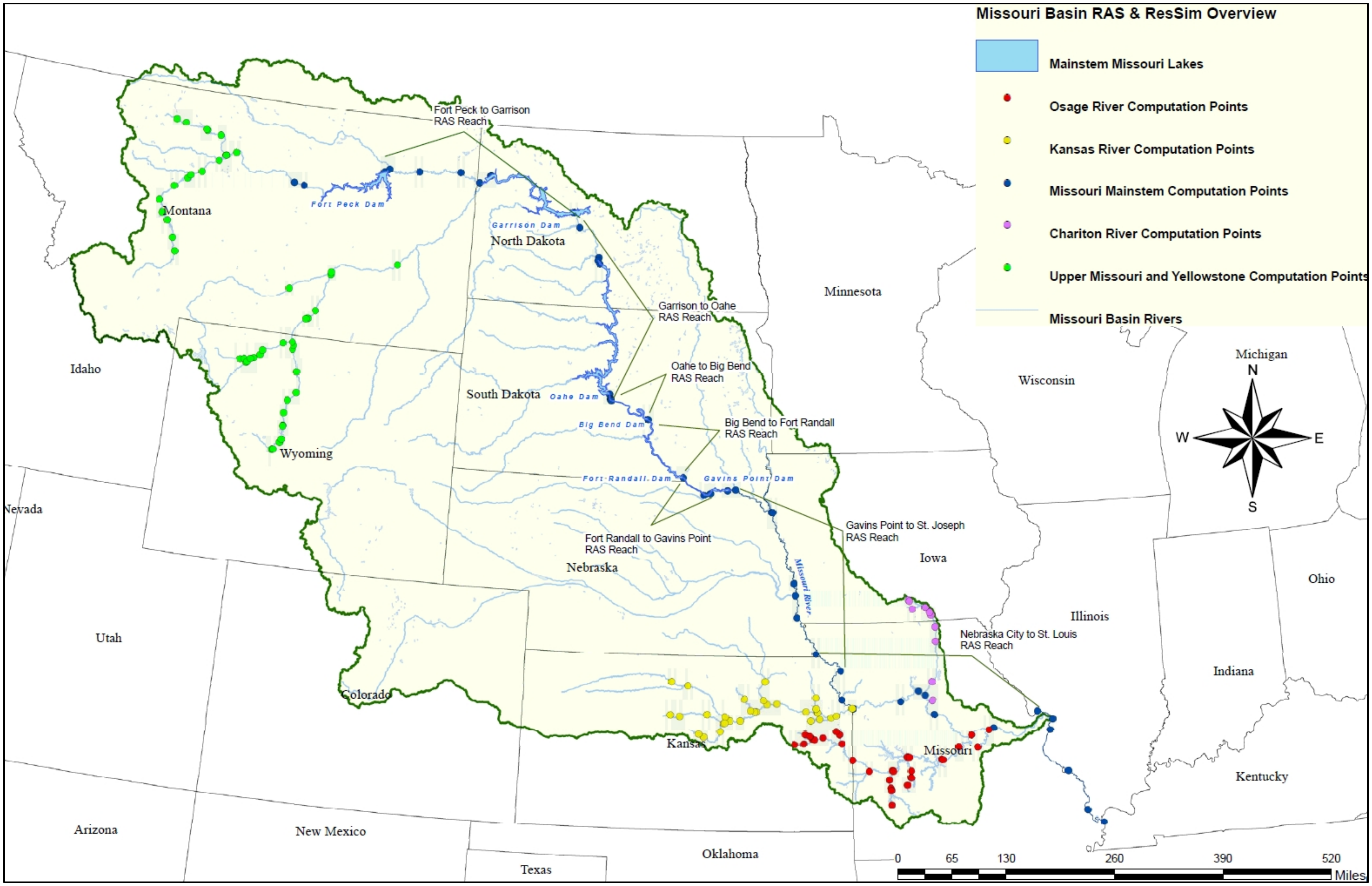


Figure 3-1: Basin Map with ResSim Modeled Reservoirs

3.1 Upper Missouri and Yellowstone Projects

Five dams were deemed critical to the success of the upper Missouri reservoir modeling effort (USACE, 2014). While other dams do exist within the study area, they were eliminated from this modeling effort for varying reasons including, but not limited to, geographic location, reservoir size, and Missouri River Recovery Program project objectives. The five dams modeled include: Canyon Ferry Dam, Tiber Dam, Buffalo Bill Dam, Boysen Dam, and Yellowtail Dam. Canyon Ferry and Tiber dams are located in the upper Missouri River basin along the Missouri and Marias rivers, respectively. Buffalo Bill, Boysen, and Yellowtail dams are located within the Yellowstone River basin. Buffalo Bill Dam is located along the Shoshone River, Boysen Dam along the Wind River, and Yellowtail Dam along the Bighorn River.

All five of these dams are owned and operated by the U.S. Bureau of Reclamation (USBR) for multiple purposes including irrigation, water supply, recreation, and fish and wildlife. Four of the dams have exclusive flood control zones. When the reservoir elevation is in this zone, management of the reservoir becomes the responsibility of the U.S. Army Corps of Engineers (USACE). The four dams are: Canyon Ferry, Tiber, Boysen, and Yellowtail. Exclusive flood control storage in these reservoirs ranges from 100,000 to 250,000 ac-ft. All five dams are of relatively large size. When full to the top of conservation storage, the dams fall into a storage range of approximately 600,000 to 1,000,000 ac-ft.

3.2 Mainstem Missouri Projects

The six Corps dams spanning the Mainstem Missouri River control runoff from approximately half of the basin. Those six dams – from the upper three giants of Fort Peck (FTPK) in eastern Montana, Garrison (GARR) in central North Dakota, and Oahe (OAHE) in central South Dakota, to the lower three smaller reservoirs of Big Bend (BEND) and Fort Randall (FTRA) in South Dakota, and Gavins Point (GAPT) along the Nebraska-South Dakota border – comprise the largest system of reservoirs in the United States. The reservoirs have a combined capacity of over 73 million acre-feet (MAF). The distribution of storage among these six reservoirs is shown in Figure 3-2. The System storage capacity is divided into four unique storage zones for regulation purposes, as shown in Figure 3-3.

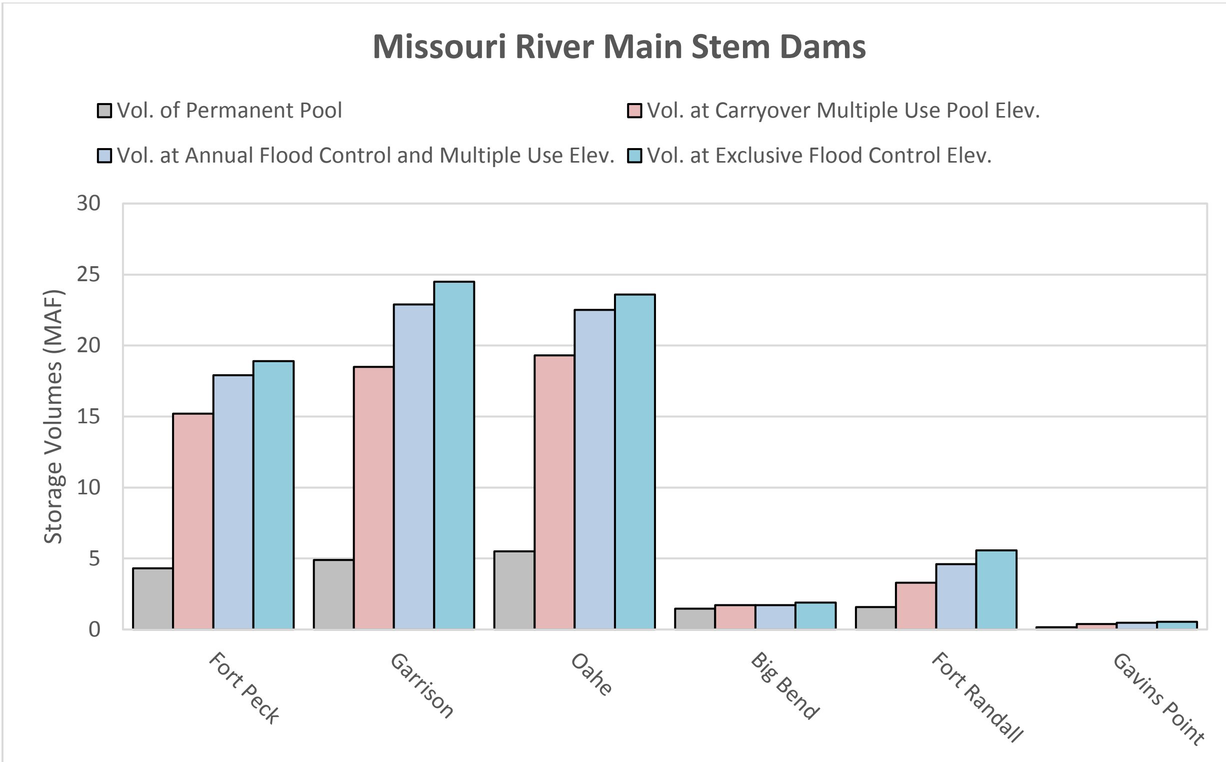


Figure 3-2: Distribution of Mainstem Dams' Volume

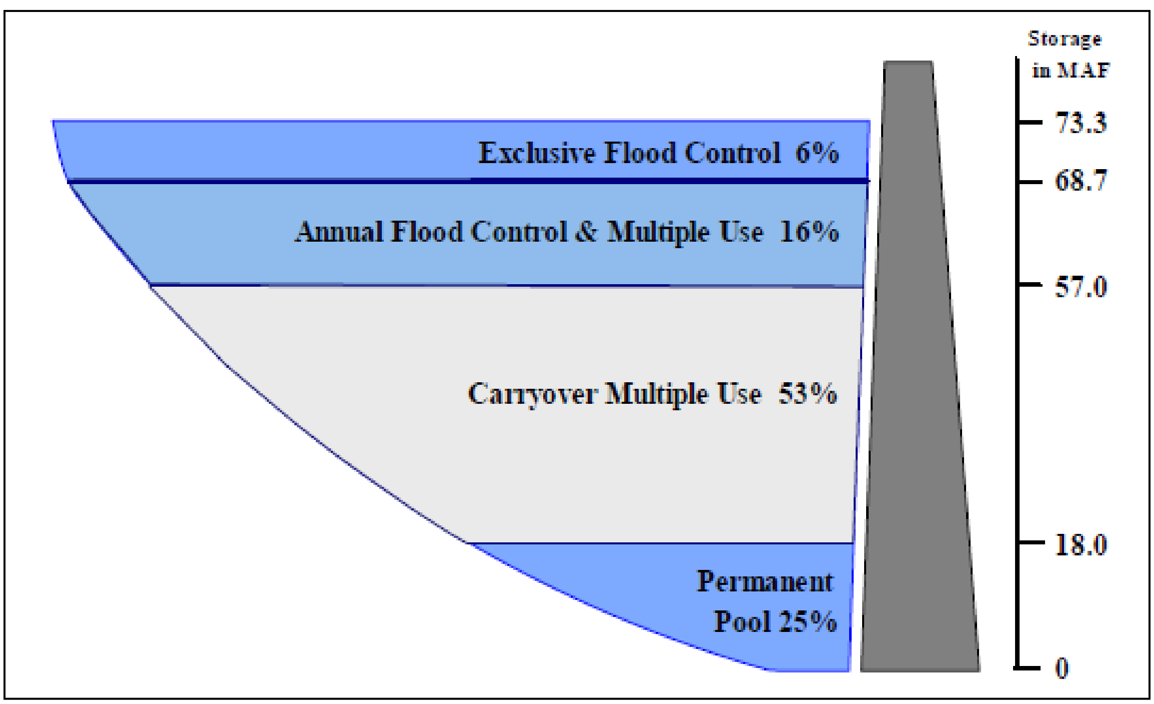


Figure 3-3: Mainstem Missouri System Storage Zones

The storage capacity of the six individual reservoirs ranges from over 23 MAF at Garrison and Oahe, to less than 0.5 MAF at Gavins Point. The System is also unique in the fact that 88 percent of the combined storage capacity is in the upper three reservoirs of Fort Peck, Garrison, and Oahe. As a result, these three projects experience the bulk of the impacts during periods of very high runoff or extended drought. The lower three projects; Big Bend, Fort Randall, and Gavins Point are regulated in much the same manner year after year regardless of the runoff conditions.

3.3 KANSAS PROJECTS

The Kansas River ResSim Model includes operation of the Lower Kansas River projects (Milford, Tuttle Creek, Perry and Clinton Lakes), and the most downstream Smoky Hill River Basin projects (Kanopolis, Wilson, and Waconda Lakes). The Model does not include those lake projects upstream of the modeled lakes in the Smoky Hill and Republican River basins (Cedar Bluff, Kirwin, Webster, Norton, Lovewell, Harlan County, Enders, Swanson, Bonny, Red Willow, and Medicine Creek). All of these upstream lakes except Harlan County are Bureau of Reclamation Section 7 projects that are primarily operated for irrigation. The releases from these lakes are captured by the downstream projects included in the Model. Under current conditions, these lakes do not significantly contribute to flow modification at the lower end of the Kansas River. Therefore, changes in their operation are believed to be insignificant to Missouri River flows.

3.4 CHARITON PROJECT

The Chariton River ResSim Model consists of the headwater USACE Rathbun Lake project and the downstream river gages to the confluence with the Missouri River. Rathbun Lake is authorized for flood reduction both on the Chariton River and the Missouri River and for navigation flow supplementation on the Missouri River. There are no other control structures in the Chariton River basin.

3.5 OSAGE PROJECTS

Of the seven reservoirs modeled in the Osage River ResSim model, six are USACE projects, with one privately owned hydropower lake located near the mouth of the basin. The projects modeled include: Melvern, Pomona and Hillsdale Lakes in east central Kansas, and Stockton, Pomme de Terre and Truman Lakes in central Missouri. The last reservoir in the system is the Lake of the Ozarks above Bagnell Dam, operated by Ameren Corporation out of St. Louis. Lake of the Ozarks has minimal flood control capabilities and is operated in accordance with its Federal Energy Regulatory Commission (FERC) license and a Memorandum of Agreement (MOA) between Ameren and USACE in conjunction with Truman Reservoir. The Lake of the Ozarks was only included in the model as a pass through for flows going to the downstream flood control river gage near St. Thomas, MO.

3.6 RAS MODELS

The HEC-RAS models for the Missouri River Basin were broken down into five separate projects: Fort Peck to Garrison, Garrison to Oahe, Fort Randall to Gavins Point, Gavins Point to Rulo, and Rulo to the mouth of the Missouri River at St. Louis. The upper 4 models were completed by the

NWO, and the lower model was completed by the NWK. The upper three models do not directly model the dams; cross sections start just below the dam and continue downstream until just upstream of the next dam. Dam outflow is used as the upstream boundary condition while the reservoir pool elevation is used for the downstream boundary condition.

4 DATA SOURCES

To create complete local inflow discharge data sets and evaporation data sets for the entire POR for use in the ResSim and RAS models, several different sources of data were necessary. The following sections summarize the different data sources. Table 4-1 provides the primary gages on the Mainstem Missouri River, their identifying abbreviation, and their location. All 5 ResSim and all 5 RAS models refer to one or more of these gages.

Table 4-1: Mainstem Missouri Discharge Gage ID and Locations

ID	Location
HEMO	Missouri River at Hermann, MO
BNMO	Missouri River at Boonville, MO
WVMO	Missouri River at Waverly, MO
MKC	Missouri River at Kansas City, MO
STJ	Missouri River at St. Joseph, MO
RUNE	Missouri River at Rulo, NE
NCNE	Missouri River at Nebraska City, NE
OMA	Missouri River at Omaha, NE
SUX	Missouri River at Sioux City, IA
GAPT	Missouri River at Gavins Point Dam
FTRA	Missouri River at Fort Randall Dam
BEND	Missouri River at Big Bend Dam
OAHE	Missouri River at Oahe Dam
BIS	Missouri River at Bismarck, ND
GARR	Missouri River at Garrison Dam
CLMT	Missouri River at Culbertson, MT
WPMT	Missouri River at Wolf Point, MT
FTPK	Missouri River at Fort Peck Dam
RBMT	Missouri River at Landusky (Robinson Bridge), MT

4.1 USGS

United States Geological Survey (USGS) data were considered the most accurate data option and were used for flow data at all locations and time periods for which they were available. USGS data were imported from the USGS website using HEC-DSSVue. USGS data were used in all ResSim and RAS models.

4.2 MISSOURI RIVER BASIN WATER MANAGEMENT (MRBWM) CWMS DATABASE

The Missouri River Basin Water Management (MRBWM) Division data were used for reservoir inflow, outflow, storage, and energy at each Mainstem reservoir location after that reservoir was online. Data was pulled from the Corps Water Management System (CWMS) database and had an F-part pathname "MRRPPCS-REV". These files had separate data sets for evaporation-flow and inflow at each Mainstem Missouri reservoir. In other words, water lost due to evaporation had already been separated out from the inflow data sets and they did not need to be adjusted for precipitation or evaporation over the pools before the data could be used for local flow calculations. These were the best data available at Mainstem reservoir locations, since the USGS does not calculate or gage reservoir inflows and outflows for these locations. Observed storage and energy data were not used by the ResSim model computations as input data sets, but were only used for model accuracy verification. MRBWM was previously called the Reservoir Control Center (RCC), and this old label may still appear on data file sets in this project.

Observed reservoir data in the CWMS database were also the primary data source for NWK lake projects. However, numerous missing value periods, especially prior to 1980, and corruption of portions of the CWMS database prior to 1997 and for 2007-08 required a review comparison of the database against the more reliable paper monthly R0168 reports. Data used in the ResSim analysis was accumulated in data spreadsheets before transfer to DSS files for use in the modeling. Historic data from the R0168 reports predating 1980 were also digitized to the data spreadsheets. NWK is gradually transferring its daily operations from a legacy process to a fully compatible CWMS system, and at some point the values in the data spreadsheets will be transferred to the CWMS database.

4.3 UPPER MISSISSIPPI RIVER SYSTEM FLOW FREQUENCY STUDY (UMRSFFS)

The *Upper Mississippi River System Flow Frequency Study* (UMRSFFS) was completed in 2004 (USACE 2004) by a task force consisting of team members from USACE, USGS, NWS, USBR, NRCS, FEMA, Tennessee Valley Authority, and the states of Minnesota, Wisconsin, Iowa, Illinois, Missouri, Kansas, and Nebraska. The study used unsteady flow models to update the flow frequencies for the Illinois River, the Upper Mississippi River mainstem, and the Missouri River below Gavins Point Dam. This flow data was used in the ResSim model for locations downstream of Gavins Point dam when USGS data were not available. All ResSim models except the upper Missouri model used these data at one or more locations. Portions of the UMRSFFS record extensions were used in the NWK modeling for this study as well. More information on modeling associated with the UMRSFFS can be found in the study report.

4.4 DAILY ROUTING MODEL (DRM)

The Daily Routing Model (DRM) was completed by MRBWM in 1997, and was only used as a data source for the Mainstem Missouri ResSim model. It is used for long range forecasting and is generally only simulated by MRBWM once a year. DRM data were the only data available for most Mainstem locations upstream of Gavins Point prior to the completion of the reservoirs.

These data were used for locations and time periods when USGS, MRBWM, and UMRSFFS data were unavailable. Two different DRM simulations were used: “No dams and no current depletions,” and “Observed”. The DRM “No dams” data was used at Mainstem reservoir or gage locations prior to completion of dams or the start of USGS gages at the current or upstream locations. After one or more reservoirs or gages were completed at an upstream location, the DRM “Observed” data was used until the reservoir or gage at that location was complete. More detail on the assumptions and operation of the DRM program can be found in the *DRM User’s Manual (USACE, 1997), Programmer’s and Technical Manual for the Daily Routing Model (USACE, 1998),* and the *Mainstem Master Manual (USACE, 2006)*.

4.5 USBR

USBR data for inflows and outflows at reservoirs owned by them were used in some models. The data were also used in the calculation of evaporation for some models.

USBR provided depletion estimates for irrigated agriculture, public surface water supply, USBR reservoir holdouts, and basin transfer depletions at an 8-digit Hydrologic Unit (HUC8) scale within the Missouri River basin. These estimates were split into two periods of water use: historic condition and present condition. Historic condition depletions were categorized as an estimated amount of water removed from the system based on historical water usage; present condition depletions were categorized as an estimated amount of water that would have been removed from the system based on present water usage. The USBR HUC8 depletions were used to calculate local and total depletions at the Data Collection Platform (DCP) gage locations. Total depletions were the sum of all depletions upstream of a DCP location and local depletions were the incremental depletions that occurred between two DCP locations. Since the USBR depletions were based on a HUC8 resolution and some of the DCP locations do not lie on a HUC8 boundary, ArcGIS was used to determine what percentage of a HUC8, in terms of drainage area, contributed to the DCP location. Using a 30m DEM, a watershed was delineated upstream of a DCP location that was not positioned on a HUC8 boundary. The watershed was then clipped using the HUC8 boundary producing a shapefile that represented the drainage area of the HUC8 upstream of the DCP location. The area of this drainage area was divided by the total area of the HUC8 to produce a depletion adjustment factor, shown in Table 4-2. This percentage of drainage area was then used to factor the depletions of the HUC8 that contained the DCP to estimate the amount of HUC8 depletions that should be included at a DCP location to ensure depletions were not counted twice. For example, the RBMT DCP location was not located on the boundary of HUC8 10040104. Only 16 percent of HUC8 10040104’s drainage area was upstream of the RBMT DCP location, so only 16 percent of HUC8 10040104’s total depletion was included in RBMT’s total depletion. The remaining 84 percent of HUC8 10040104’s total depletion is included in the next downstream DCP location, FTPK. Table 4-2 lists the factors associated with the DCP locations and corresponding HUC8’s.

Table 4-2: HUC8 Depletion Adjustment Factors Based on DCP Drainage Area.

DCP ID	Adjusted HUC8	Local Drainage Area (sq mi)	Total Drainage Area (sq mi)	Depletion Adjustment Factor	Note
RBMT	10040104	40,694	40,694	**0.16**	
FTPK	10040104	16,676	57,370	**0.84**	
WPMT	10060001	24,694	82,064	**0.79**	
CLMT	10060001	10,086	92,150	**0.21**	Contains a closed basin, which was removed from total drainage area
	10060005	10,086	92,150	**0.61**	
GARR	10060005	87,757	179,907	**0.39**	
BIS	#N/A	5,030	184,937	**#N/A**	Poor watershed delineation using 30m DEM. Approximately all of HUC8 10130101 is upstream of DCP
OAHE	#N/A	56,277	241,214	**#N/A**	USGS gage was downstream of dam
BEND	10140101	5,801	247,015	**0.26**	
FTRA	10140101	14,288	261,303	**0.74**	
GAPT	10170101	16,238	277,541	**0.59**	
SUX	10170101	33,908	311,449	**0.41**	
	10230001	33,908	311,449	**0.01**	
OMA	10230001	8,617	320,066	**0.99**	
	10230006	8,617	320,066	**0.34**	
NCNE	10230006	86,870	406,936	**0.66**	
	10240001	86,870	406,936	**0.72**	
RUNE	10240001	4,961	411,897	**0.28**	
	10240005	4,961	411,897	**0.51**	
STJ	10240005	4,677	416,574	**0.49**	USGS drainage area is incorrect. Use listed drainage area
	10240011	4,677	416,574	**0.12**	
MKC	10240011	63,452	480,026	**0.88**	
	10300101	63,452	480,026	**0.00**	
WVMO	10300101	1,972	481,998	**0.73**	
BNMO	10300101	14,600	496,598	**0.27**	
	10300102	14,600	496,598	**0.08**	
HEMO	10300102	22,181	518,780	**0.92**	
	10300200	22,181	518,780	**0.27**	

4.6 NOAA

Pan evaporation estimates from the National Weather Service (NWS) were utilized at select stations to aid in the development of free water surface evaporation datasets for the upper Missouri projects. Where station pan evaporation data were not available, information from *NOAA Technical Report 34* (NWS, 1982) was utilized. Once time-series pan evaporation estimates were developed at each reservoir, pan coefficients from the *Upper Mississippi River System Flow Frequency Study* (USACE, 2003) were used to convert the pan evaporation estimates to free-water surface evaporation. Where possible, a small amount of measured free-water surface evaporation estimates were available through the USBR. These were integrated into the evaporation time-series where appropriate at both Boysen and Buffalo Bill reservoirs.

National Climatic Data Center (NCDC) precipitation records were also used for development of the NWK ResSim project net evaporation datasets (lake evaporation minus effective lake precipitation) for the reservoirs. The NCDC and NWS are both part of the National Oceanic and Atmospheric Administration (NOAA).

4.7 USACE R0168 Monthly Report

R0168 records are monthly reports with checks of the daily reservoir inflow, outflow, elevation, and evaporation values regularly completed by the individual Districts of USACE. These reports are considered the final and definitive data for each reservoir, with any corrections of the daily entries replacing the raw or original values in the CWMS database. NWK data in CWMS only extends back to 1980, and some of the data are not reflective of the paper R0168 reports. As noted earlier, NWK digitized all of the paper R0168 records from their pre-1980 historic files for the reservoirs used in their tributary ResSim models. They also ran a comparison of the data in the CWMS database against the R0168 reports to detect significant errors in the post -1980 database. Eventually, the NWK digitized and corrected data will be added to the CWMS database for future reference. All NWO R0168 reports and associated finalized data are already stored in CWMS. Therefore, NWO did not need to refer to their R0168 records for dataset construction.

5 RESSIM TIME SERIES DATA SET DEVELOPMENT

Since some models had different available data sources and data set construction methods, data development is described in individual sections for the Upper Missouri Reservoirs, the Mainstem Missouri Reservoirs, and the NWK Reservoirs.

5.1 UPPER MISSOURI AND YELLOWSTONE RESERVOIRS DATA SET DEVELOPMENT

5.1.1 Data Extension

Due to the limited data available, streamgage and reservoir inflow/outflow data sets had to be processed for completenesss before attempting to determine local inflows. This processing effort involved filling in missing values and extending (extrapolating) values beyond the available POR. This was performed using single or multiple linear regression techniques within Microsoft Excel. Reservoir data were adjusted for evaporation prior to the regression analysis. At times, gages were extended and then used to extend other gages. This was necessary due to the limited amount of data available from 1900 to 1930 in certain locations.

Small amounts of data were filled using daily average values from the gage in question when no other data were available. This was also done in cases where the amount of filled data required didn't justify the labor involved in creating and analyzing the regression relationships. The procedures used to complete the datasets were documented in Appendix B – Upper Missouri and Yellowstone Data Development Summary.

5.1.2 Local Inflows

Incremental or local inflows are flows that enter the river between two gages or reservoirs. Incremental flow between gages was computed at several locations. The incremental flow was computed by routing the upstream flow to the downstream location, and then subtracting the routed upstream flow from the downstream flow. The locations where incremental flow was calculated include: Yellowtail inflow, WY and Bighorn, MT for the Bighorn River; Miles City, MT and Sidney, MT for the Yellowstone River; and Holter Dam, MT; Great Falls, MT; Fort Benton, MT; Virgelle, MT; and Landusky, MT for the upper Missouri River. Landusky and Sidney, MT are where results are passed between the upper Missouri and mainstem Missouri models.

Incremental flow computations were not completed along the Shoshone or Marias Rivers. The local flow components for those rivers are included in the Yellowtail inflow and Virgelle computations, respectively. Flow data at computation points other than those listed above should be used with caution as model results won't represent the impact of incremental flow. The additional computation points were added in case further model resolution was required within those model reaches. The points often correspond to water resource features such as irrigation diversions, so the possibility exists that additional detail may be required at some point.

At any location where two modeled rivers converge, the incremental flow computations had to be adjusted slightly. These locations include the Shoshone/Bighorn River confluence, the

Bighorn/Yellowstone River confluence, and the Marias/Missouri River confluence. At these locations, flow from the most downstream tributary point where period of record flow was developed had to be routed to the downstream main river incremental flow location. Incremental flow computed at this downstream location was then adjusted to ensure tributary flow was not double-counted. This was necessary because the tributary was being modeled directly, so the contribution of the tributary to the incremental flow must be removed.

Routing coefficients used in the incremental flow computations were the same as those used for the flow data extension process. The coefficient routing method was used, and the routings were in full day increments with the coefficients being determined through observation of flow data from the gages in question. The coefficients can be found in Table 5-1.

Table 5-1: Coefficients used for Routing in Upper Missouri ResSim Models

Yellowstone Basin				
	Coefficient Routing - Timestep			
Reach Name	1	2	3	4
Boysen IN	Null			
Boysen OUT to Thermopolis	1.00	0.00	0.00	0.00
Thermopolis to Basin	0.00	1.00	0.00	0.00
Basin to Kane	1.00	0.00	0.00	0.00
Kane to Yellowtail Dam	1.00	0.00	0.00	0.00
Buffalo Bill IN	Null			
Buffalo Bill OUT to Lovell	1.00	0.00	0.00	0.00
Lovell to Yellowtail	1.00	0.00	0.00	0.00
Yellowtail to St. Xavier, MT	1.00	0.00	0.00	0.00
St. Xavier to Bighorn, MT	0.00	1.00	0.00	0.00
Bighorn to Y.R. Confluence, MT	1.00	0.00	0.00	0.00
Billings to B.R. Confluence, MT	0.00	1.00	0.00	0.00
Confluence to Miles City, MT	0.00	1.00	0.00	0.00
Miles City to Sidney, MT	0.00	1.00	0.00	0.00
Upper Missouri Basin				
	Coefficient Routing - Timestep			
Reach Name	1	2	3	4
Canyon Ferry IN	Null			
Canyon Ferry OUT to bl. Canyon Ferry	1.00	0.00	0.00	0.00
Bl. Canyon Ferry to Hauser Dam	1.00	0.00	0.00	0.00
Hauser to Holter Dam	1.00	0.00	0.00	0.00
Holter Dam to Cascade	0.00	1.00	0.00	0.00
Cascade to Ulm	1.00	0.00	0.00	0.00
Ulm to Sun River mouth	1.00	0.00	0.00	0.00
Sun River mouth to Great Falls	1.00	0.00	0.00	0.00
Great Falls to Fort Benton	1.00	0.00	0.00	0.00

Fort Benton to Marias River mouth	1.00	0.00	0.00	0.00
Tiber IN	Null			
Tiber OUT to Chester	1.00	0.00	0.00	0.00
Chester to Brinkman	1.00	0.00	0.00	0.00
Brinkman to Loma	0.00	1.00	0.00	0.00
Loma to Teton River mouth	1.00	0.00	0.00	0.00
Teton River mouth to Marias River mouth	1.00	0.00	0.00	0.00
Marias River mouth to Virgelle	1.00	0.00	0.00	0.00
Virgelle to Landusky	0.00	1.00	0.00	0.00

5.1.3 Evaporation

Inflow and outflow data for all reservoirs in the Upper Missouri and Yellowstone reservoirs were collected from USBR's database. USBR inflow data already reflected evaporation losses in the estimates. As a result, evaporation data were added to the inflow estimates at each reservoir to better represent what the actual reservoir inflow might have been.

The evaporation data period of record was compiled using several techniques. First, data from the NWS pan evaporation stations identified in the *UMRSFFS* were collected. To fill the missing data, an evaporation analysis using *NOAA Technical Report 34* (National Weather Service, 1982) was conducted. To develop an annual distribution, Table 1 of *NOAA Technical Report 34*, which provided pan evaporation data collected at the projects, was used in conjunction with Table 2 of *NOAA Technical Report 34*, which provided annual calculated (Penman equation) pan evaporation at various locations. Table 1 only provides data for the non-winter months, so that data was compared to an equivalent timeframe in Table 2. The ratio of the two was applied to the entire Table 2 distribution. This resulted in evaporation for the entire year while taking advantage of collected data at the projects to adjust the Table 2 distributions.

Once the period of record pan evaporation estimates were complete, pan coefficients from the *UMRSFFS* were used to convert the pan evaporation estimates to free-water surface evaporation. By using the reservoir's elevation/volume/area relationship, the evaporation estimates were converted to cfs and added to the inflow estimates at each reservoir. The free-water surface evaporation as a depth also was used in the HEC-ResSim model.

In addition to this analysis, a limited amount of free-water surface evaporation estimates were available through the USBR database. The data were available for both Boysen and Buffalo Bill reservoirs, and represented parts of the periods Oct 1999 through Oct 2011 and May 1996 through December 2011, respectively. Where present, these data were merged with the aforementioned NWS evaporation datasets for use with reservoir inflow adjustments and within the HEC-ResSim model.

5.2 MAINSTEM MISSOURI RESERVOIRS DATA SET DEVELOPMENT

5.2.1 Data Extension

To create a complete discharge data set for the Mainstem Missouri River Reservoirs, several different sources of data were necessary. USGS gage data and observed inflow/outflow data from MRBWM (MRRPPCS-REV data) were used when available. To fill in missing POR data upstream of Sioux City (SUX), data from the DRM was utilized. Two different DRM simulations were used: "No dams and no current depletions," and "Observed". The DRM data had to be used for the upstream reaches since the UMRSFFS data did not extend upstream of SUX. The DRM "No dams and no current depletions" data was used at reservoir or gage locations prior to completion of dams or the start of USGS gages at the current or upstream locations. After one or more reservoirs or gages were completed at an upstream location, the DRM "Observed" data were used until the reservoir or gage at that location was complete. For all locations at SUX and downstream, the UMRSFFS "observed" data were used to fill in missing data at USGS gage locations. It was felt the UMRSFFS data were more reliable than the DRM data, since the UMRSFFS data precisely matched observed USGS gage data after the gages came online. The DRM "Observed" data do not match the USGS gage data quite as well, but were the only available data at the reservoir locations and gages upstream of SUX prior to system completion.

Final POR data for use in the Mainstem Missouri River ResSim model is stored in the DSS file "Final POR.dss" under the F-part pathname "POR-OBS." The data used for the final POR construction at each gage is shown in Table 5-2.

Table 5-2: Sources for NWO ResSim POR Data Set Construction.

Gage	Time Period	Source
RBMT*	1934-2012	USGS
FTPK	1898-1937	DRM, no dams no depletions
	1938-2012	MRBWM
WPMT	1898-1928	DRM, no dams no depletions
	1929-2012	USGS
CLMT	1898-1938	DRM, no dams no depletions
	1938-1941	DRM, observed
	1941-1952	USGS
	1952-1958	DRM, observed
	1958-2012	USGS
GARR	1898-1938	DRM, no dams no depletions
	1938-1954	DRM, observed
	1954-2012	MRBWM
BIS	1898-1927	DRM, no dams no depletions
	1928-2012	USGS
OAHE	1898-1929	DRM, no dams no depletions
	1930-1959	DRM, observed
	1959-2012	MRBWM
BEND	1898-1929	DRM, no dams no depletions
	1930-1963	DRM, observed
	1963-2012	MRBWM
FTRA	1898-1929	DRM, no dams no depletions
	1930-1952	DRM, observed
	1953-2012	MRBWM
GAPT	1898-1929	DRM, no dams no depletions
	1929-1955	DRM, observed
	1955-2012	MRBWM
SUX	1898-1928	UMRSFFS
	1929-1931	USGS
	1932-1938	UMRSFFS
	1938-2012	USGS
OMA	1898-1928	UMRSFFS
	1928-2012	USGS
NCNE	1898-1929	UMRSFFS
	1929-2012	USGS
RUNE	1898-1949	UMRSFFS
	1949-2012	USGS
STJ	1898-1928	UMRSFFS
	1928-2012	USGS
MKC	1898-1928	UMRSFFS
	1928-2012	USGS
WVMO	1898-1928	UMRSFFS
	1928-1977	USGS
	1977-1978	UMRSFFS
	1978-2012	USGS
BNMO	1898-1925	UMRSFFS
	1925-2012	USGS
HEMO	1898-1928	UMRSFFS
	1928-2012	USGS
MISL	1898-2012	USGS

*For ResSim alternative runs, RBMT data was pulled from the Upper Missouri ResSim models. The data used in these models is discussed in the previous section.

5.2.2 Local Inflows

To calculate local inflows from the constructed gage discharge records, routing parameters had to be determined. Various hydrologic routing methods were analyzed to determine the most appropriate methods and parameters. The process was involved and complex, and therefore, is explained in complete detail in Appendix A – Mainstem Missouri River Routing Parameter Determination Summary. The final selected routing parameters using the Coefficient Routing method are shown in Table 5-3.

Table 5-3: Coefficient Method Final Routing Parameters.

Reach	A1 (d)	A2 (d-1)	A3 (d-2)
RBMT_FTPK	0	1	0
FTPK_WPMT	0.10283	0.65925	0.23792
WPMT_CLMT	0.18943	0.55198	0.25858
CLMT_GARR	0	0.5	0.5
GARR_BIS	0.05704	0.50308	0.43988
BIS_OAHE	1	0	0
OAHE_BEND	0.766	0.234	0
BEND_FTRA	0.647	0.353	0
FTRA_GAPT	0.005	0.637	0.358
GAPT_SUX	0.17532	0.53734	0.28734
SUX_OMA	0.16794	0.72176	0.1103
OMA_NCNE	0.5879	0.4121	0
NCNE_RUNE	0.58837	0.41163	0
RUNE_STJ	0.77547	0.22453	0
STJ_MKC	0.42647	0.44863	0.1249
MKC_WVMO	0.47605	0.52395	0
WVMO_BNMO	0.3542	0.61748	0.02832
BNMO_HEMO	0.38146	0.43382	0.18472
HEMO_MISL	0.22208	0.77792	0

Local flows at each Missouri River gage and reservoir location were computed by subtracting the upstream routed flow from the observed flow at the downstream gage or reservoir. Some of the computed local flows have one or more days with large negative discharges. One reason for this is the compatibility of using multiple different data sources. Another possible reason for the large negative flow is routing parameters that don't fit that particular event the best. However, the routing parameters used are the parameters that were tested and worked best for recent events. Examples of locations and periods of slightly unusual local flows are discussed further below.

When using UMRSFFS data to compute local flows, the resulting local flows sometimes look slightly more irregular than the local flows produced using only the USGS data. These local flows are felt to be reasonable estimations for a time period when no USGS gage data were available, but should still be mentioned. The local flows at RUNE are an example of this. UMRSFFS data was used upstream at NCNE and routed to RUNE, then subtracted from the UMRSFFS data at RUNE. The USGS gage at NCNE came online in 1929, which can be easily seen in the local flows (green) on the graph below.

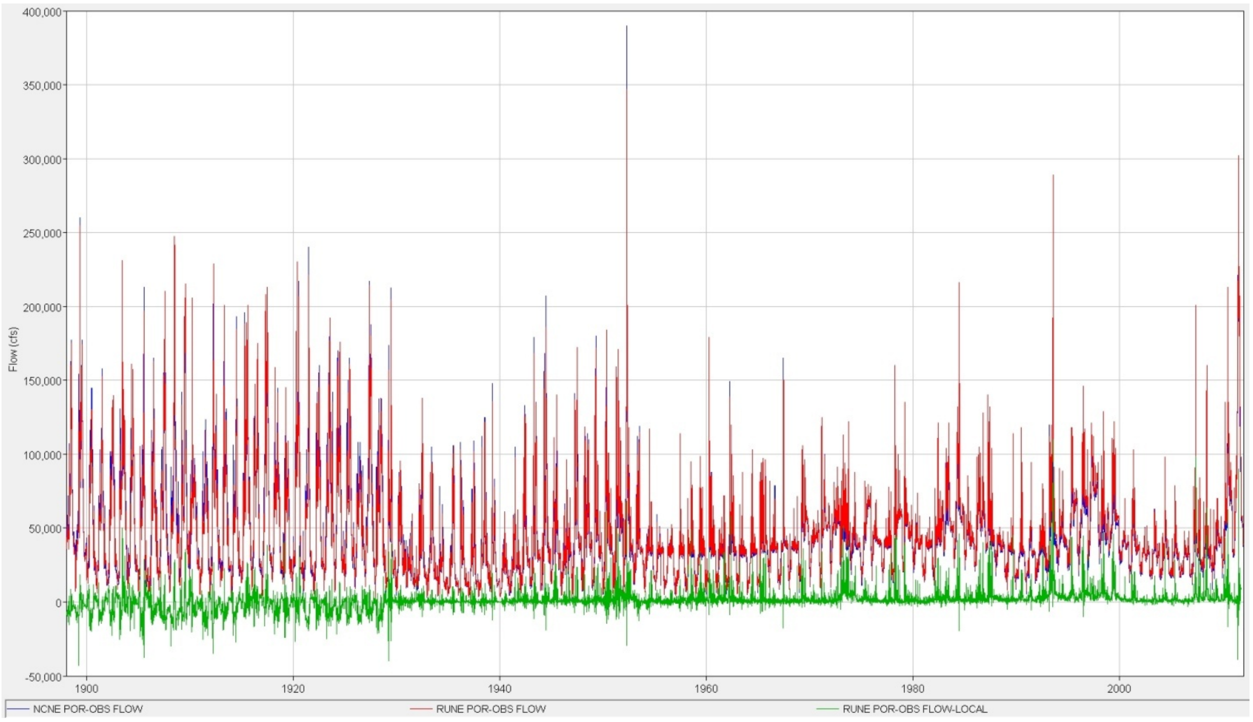


Figure 5-1: RUNE Unadjusted Local Flow for POR.

The resulting local flow irregularities are not due to improper routing or timing. The irregularities are due mainly to the datasets (UMRSFFS) used. Since the only other data available for use before gages/reservoirs were online is the DRM data, it is recommended that the UMRSFFS data still be used and the irregular local flows be cautiously accepted. The UMRSFFS data is thought to be more reliable than the DRM data, since a significant amount of time and effort went into developing the discharges for the UMRSFFS.

While the local flows may not look as ideal as the local flows calculated using only observed USGS data, the local flows are still believed to be reasonable. The data sets used to calculate the local flows are the best available data, and are felt to be more reliable than synthetic data based on statistics and basin characteristics.

ResSim is capable of handling large negative flows. However, decisions in the Missouri River System require making releases to meet downstream targets. Flow travel times can exceed six days to the most downstream target at Kansas City. Accounting for large negative flows produces unrealistic reservoir releases. Some of the negative flows are representative of reality where large withdrawals of water from the basin (especially upper portions) actually occurred. However, often due to assumptions with routing parameters, the negative flows are not natural. To correct this problem, the local flow data sets were adjusted using several different methods to reduce the large negative local inflows.

As a minimum, a 3-day centered moving average (CMA) was used on all local inflow data sets. For certain events and historic time periods, where alternate routing parameters could reduce large negative inflows (such as flood events), different routing coefficients were used. If the large negative local inflows were small in duration and could not be corrected by alternate routing coefficients, the large negative flows were zeroed out and the volume was redistributed over the surrounding month (15 days on either side of the largest negative local inflow). If large negative local inflows occurred frequently in a data set and alternate routing parameters could not correct for this, up to a 31-day CMA was used. A 31-day CMA was only used for periods prior to 1930 (with UMRSFFS data). Table 5-4 summarizes all the changes made to every data set. Year dates are from January 1st of the first year listed through December 31st of the last year listed, unless otherwise specified in the notes.

Table 5-5 summarizes the alternate routing coefficients used for different time periods. If no routing coefficients are listed in the table, no changes to routing parameters were made at that location. The first line of routing coefficients for each location is the original coefficients used (and the coefficients used for POR and future modeling in ResSim).

Table 5-4: Local Flow Adjustments Summary.

Gage	Time Period	Adjustment	Notes
FTPK	1898-1928	13-Day CMA	June 1908 zeroed and redistributed.
	1929-2012	3-Day CMA	
WPMT	1898-2012	3-Day CMA	
CLMT	1898-2012	3-Day CMA	
GARR	1898-2012	3-Day CMA	
BIS	1898-1928	3-Day CMA	
	1928-1929	31-Day CMA	15 Mar 1928 - 15 Oct 1929
	1929-2012	3-Day CMA	Routing adjusted 1930-1953. November 1955 GARR outflow corrected (MRBWM entered data incorrectly).
OAHE	1898-1928	3-Day CMA	
	1928-1929	31-Day CMA	15 Mar 1928 - 15 Oct 1929
	1929-2012	3-Day CMA	Routing adjusted 1930-1953.
BEND	1898-2012	13-Day CMA	Very cyclic with 3-day cma. Used 13-day for smoothing.
FTRA	1898-1929	3-Day CMA	
	1930-1956	13-Day CMA	Different routings did not improve. DRM data is issue, but only data available.
	1957-2012	3-Day CMA	
GAPT	1898-1929	3-Day CMA	
	1930-1953	13-Day CMA	Different routings did not improve. DRM data is issue, but only data available.
	1954-2012	3-Day CMA	
SUX	1898-1929	31-Day CMA	
	1930-2012	3-Day CMA	April 1943 & June 1944 zeroed and redistributed. Different routings did not improve.
OMA	1898-1929	31-Day CMA	Different routings did not improve. Didn't want to average over longer period than this.
	1930-2012	3-Day CMA	Routing adjusted Mar-Apr 1952, 31 Mar-20 Apr 1943, & Apr 1944. Jun-Jul 1944 zeroed and redistributed.
NCNE	1898-1929	31-Day CMA	
	1930-2012	3-Day CMA	Mar-Apr 1943, Apr 1950, & Mar-Apr 1952 zeroed and redistributed. Different routings did not improve.
RUNE	1898-1929	31-Day CMA	
	1930-2012	3-Day CMA	Routing adjusted Apr 1952. May-Jun 1944 & Jun-Jul 2011 zeroed and redistributed, different routings did not improve.
STJ	1898-1928	31-Day CMA	Still massive negatives, but don't want to average over longer period than this.
	1929-2012	3-Day CMA	Routing adjusted 1898-1928, Apr 1952, Jun 2010, & Jun-Jul 2011.
MKC	1898-1928	31-Day CMA	
	1929-2012	3-Day CMA	Apr 1952 & May-Jul 2011 zeroed and redistributed. Different routings did not improve.
WVMO	1898-1914	3-Day CMA	Routing adjusted 1898-1914.
	1915-1929	31-Day CMA	Different routings did not improve.
	1930-2012	3-Day CMA	Routing adjusted Jul 1951.
BNMO	1898-1929	31-Day CMA	Still -50,000 cfs in one area, but don't want to average over longer period than this.
	1930-2012	3-Day CMA	Routing adjusted July 1951, Jul-Aug 1981, & Jul-Aug 1993.
HEMO	1898-2012	3-Day CMA	July 1993 & May 2007 zeroed and redistributed.

Table 5-5: Routing Coefficient Adjustments used in Local Flow Determination.

Reach Name	Routing Coefficients						
	A1 (d)	A2 (d-1)	A3 (d-2)	A4 (d-3)	A5 (d-4)	A6 (d-5)	A7 (d-6)
FTPK_GARR							
GARR_OAHE							
OAHE_BEND							
BEND_FTRA							
FTRA_GAPT							
GAPT_SUX							
SUX_OMA	0.16794	0.72176	0.1103	0	0	0	0
Mar-Apr 1952	0.05	0.1	0.15	0.4	0.15	0.1	0.05
31 Mar - 20 Apr 1943 & Apr 1944	0	0.05	0.15	0.6	0.15	0.05	0
OMA_NCNE							
NCNE_RUNE	0.58837	0.41163	0	0	0	0	0
Apr 1952	0.35	0.33	0.32	0	0	0	0
RUNE_STJ	0.77547	0.22453	0	0	0	0	0
1898-1928, Apr 1952, Jun 2010, & Jun-Jul 2011	0.2	0.5	0.3	0	0	0	0
STJ_MKC	0.42647	0.44863	0.1249	0	0	0	0
MKC_WVMO	0.47605	0.52395	0	0	0	0	0
1898-1914	0	0.2	0.8	0	0	0	0
July 1951	0.1	0.9	0	0	0	0	0
WVMO_BNMO	0.3542	0.61748	0.02832	0	0	0	0
Jul 1951, Jul-Aug 1981, & Jul-Aug 1993	0	0.3542	0.61748	0.02832	0	0	0
BNMO_HEMO							
HEMO_STL							
FTPK_WPMT							
WPMT_CLMT							
CLMT_WSN							
BIS_OAHE							
GARR_BIS							

The adjusted local inflow data sets are stored in DSS. They have a part F pathname of "POR-OBS FINAL." The original local inflow data sets with large negative flows are also still in the DSS file, for comparison, with part F pathname "POR-OBS."

5.2.3 Evaporation

Best available evaporation data for the Mainstem Missouri River POR was from the DRM. Assessment of the data was performed prior to incorporation into the ResSim model. According to the *DRM User's Manual and Technical Appendix*, all evaporation in the DRM is net evaporation, which is total evaporation minus precipitation. The DRM evaporation was compared with the CWMS MRRPPS-REV evaporation data, and both data sets were nearly identical. Since the DRM evaporation data record was more complete, it was used for evaporation calculations. After consulting with MRBWM personnel, it was determined that some of the evaporation data (from both sources) may have been estimated and not entirely accurate. However, this was still the best and only evaporation data source available for use.

There was a significant change in how evaporation data were measured between 1966 and 1967. Due to the significant disparity in evaporation rates from the different methodology, only DRM evaporation data following 1966 were used for ResSim modeling. It was decided to use post-1966 daily evaporation rates directly. To determine evaporation rates prior to 1966, a cyclic analysis from 1967-2008 was performed to estimate average daily evaporation for any given year. This calculated average evaporation was then repeated for the years 1898-1966 to complete the POR evaporation data set. All evaporation data are net evaporation, which is total evaporation minus precipitation. The next few paragraphs provide more detailed information on the evaporation rates from the DRM.

Prior to 1967, evaporation was computed in the DRM using input data from the Long Range Study (LRS). Evaporation for each dam was computed by multiplying the annual evaporation times the monthly distribution, and then dividing by the number of days in that month. The monthly distribution used in the DRM is shown in Table 5-6 below.

Table 5-6: Monthly Distribution of DRM Evaporation Prior to 1967.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0	0	0	0.07	0.05	0.19	0.2	0.19	0.13	0.12	0.05

Prior to 1967, additional calculations were performed in the DRM to adjust for evaporation on the channel surface area. Channel areas were subtracted from the reservoir areas using one of the input files because evaporation from the portion of the reservoir occupied by the original channel area was assumed to be accounted for already in the depletion calculations.

From 1967 to the present, the DRM used historic pan evaporation values to determine evaporation from the 6 mainstem reservoirs. Historic pan evaporation values were adjusted by the ratio of the computed reservoir area to the area determined from historic elevations. Channel area is not considered in evaporation calculations after 1966 once the reservoirs were in full operation. Historic pan evaporation values were obtained for the DRM from the MRADS database, and appear to be daily values.

Daily and monthly evaporation outputs from the DRM for 1898-2012 were obtained in text format and input into HEC-DSS. The DRM output was converted to inches per day or month using the DRM output elevations to determine the corresponding area from the DRM input elevation-area file. The following figures show a sample daily and monthly evaporation plot for Lake Oahe using DRM data. Figure 5-4 provides a plot of annual evaporation based on the DRM data.

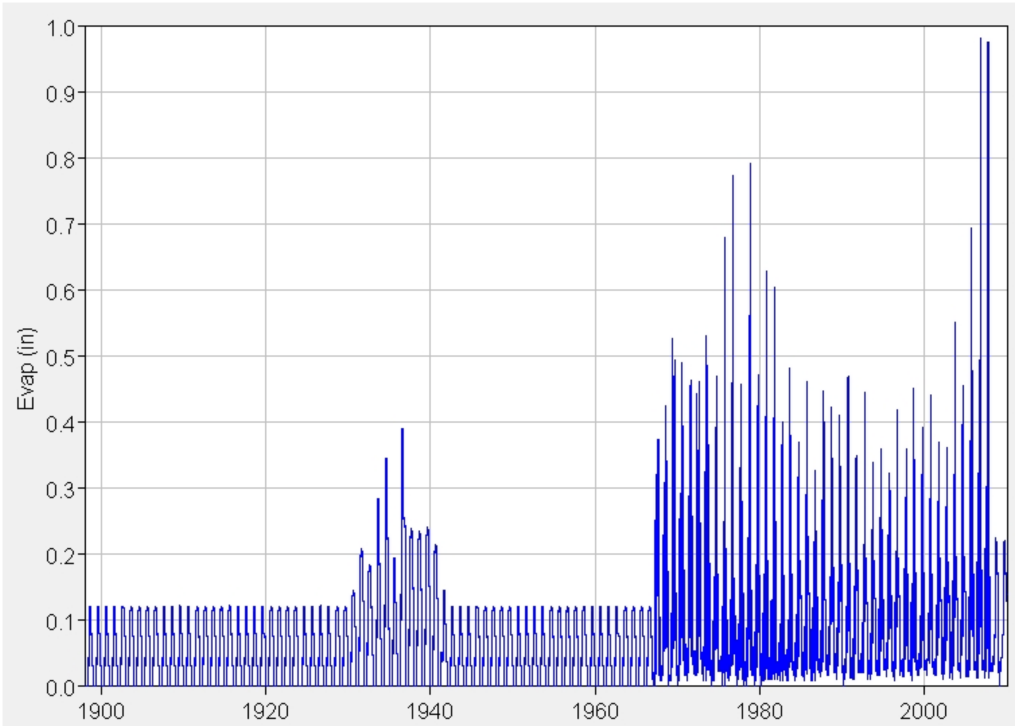


Figure 5-2: Oahe DRM Daily Evaporation.

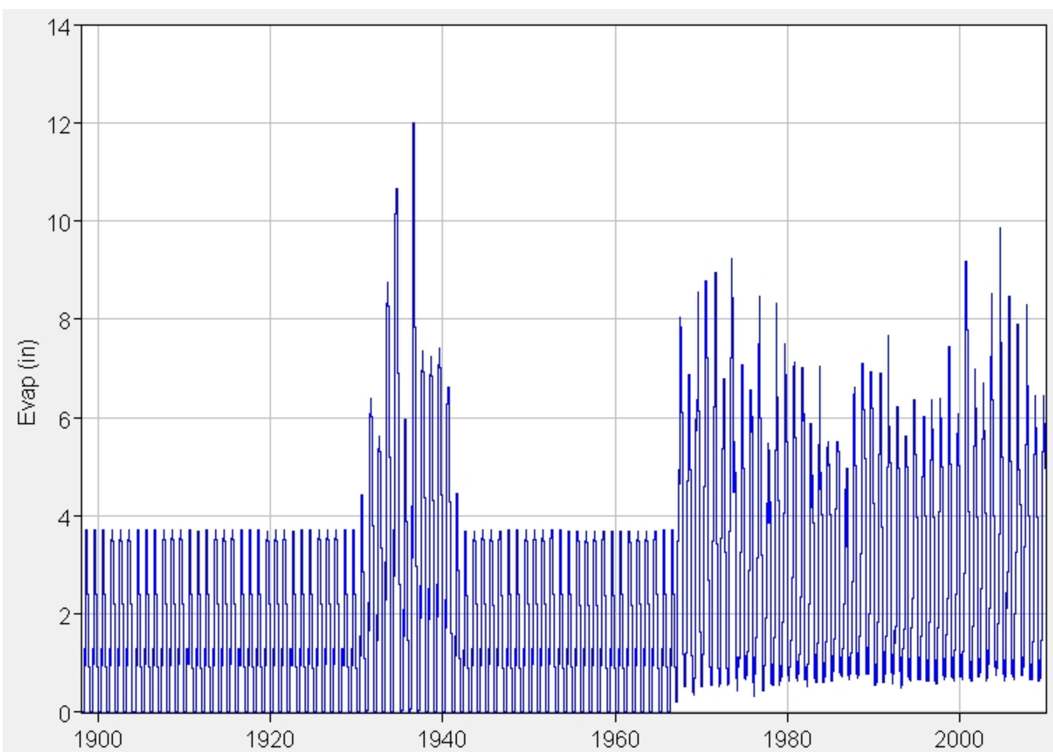


Figure 5-3: Oahe DRM Monthly Evaporation.

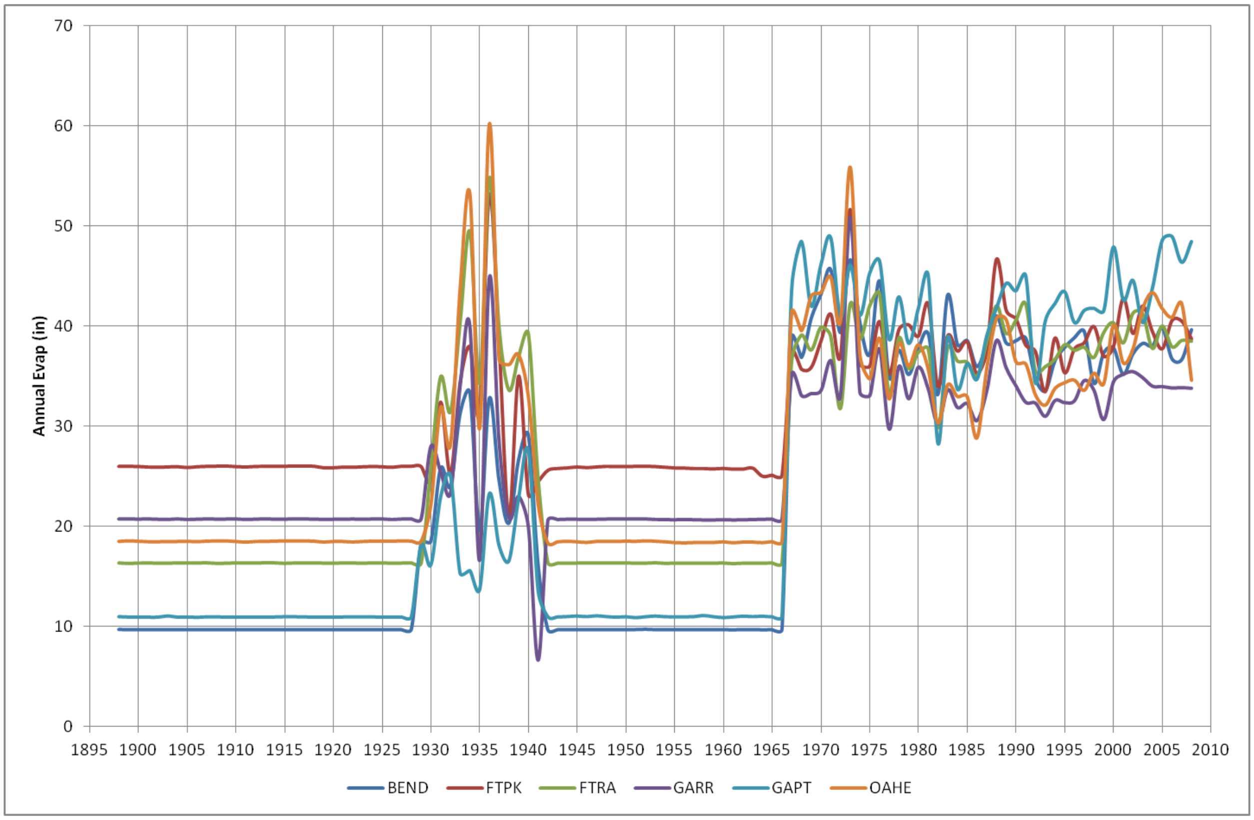


Figure 5-4: Annual DRM Evaporation at the Mainstem Projects.

Prior to 1967, annual evaporation from the DRM is consistent except for the 1930s decade. No information was found to determine how these data were scaled. The difference in magnitude of evaporation prior to and after 1967 is significant. As described earlier, it was decided to use post-1967 DRM data directly. Cyclic average evaporation at each project was calculated and repeated each year for the years 1898-1966. The final evaporation dataset is more consistent than using all DRM data and is expected to be sufficient for the ResSim model. The following figures show a sample daily, monthly and annual evaporation plot for Lake Oahe using combined final data.

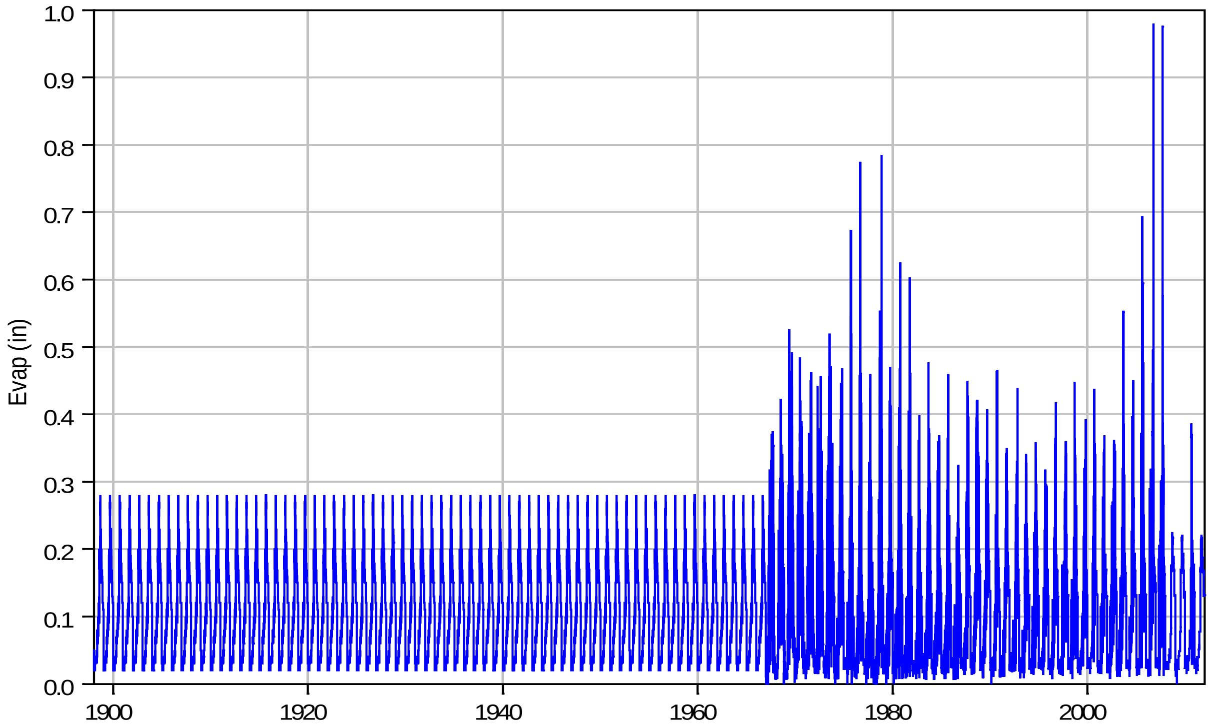


Figure 5-5: Oahe Final Daily Evaporation.

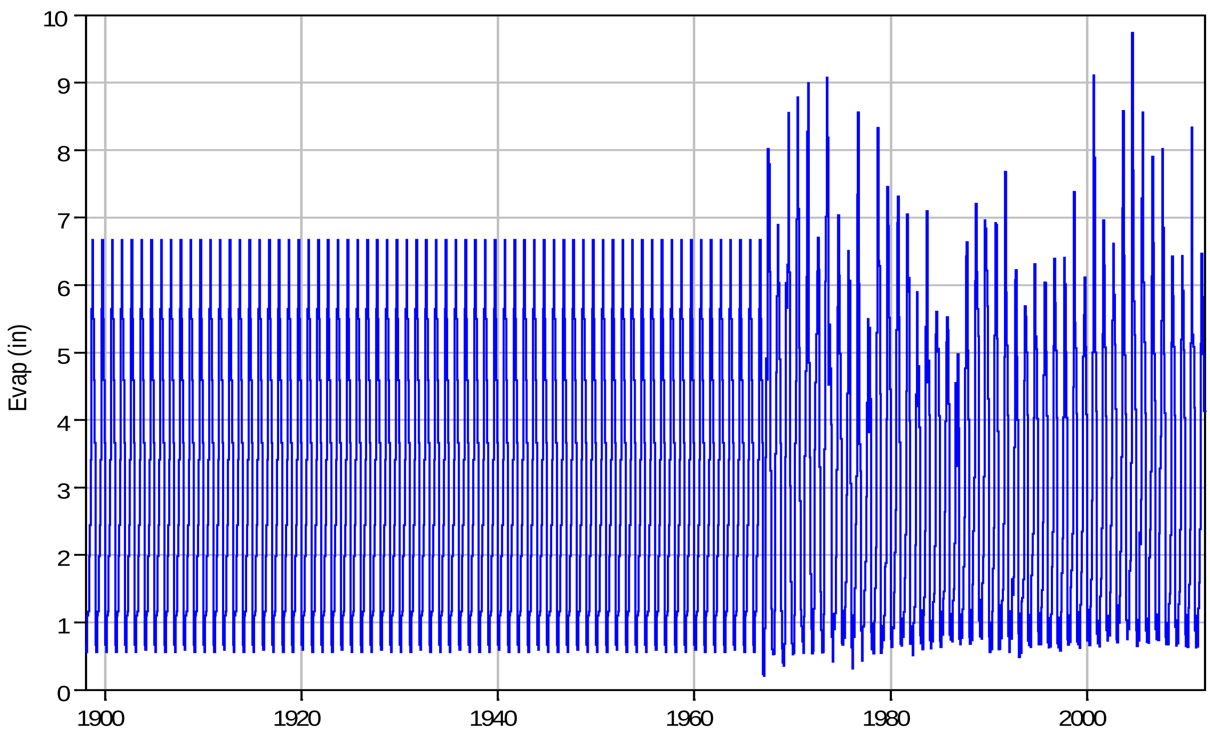


Figure 5-6: Oahe Final Monthly Evaporation.

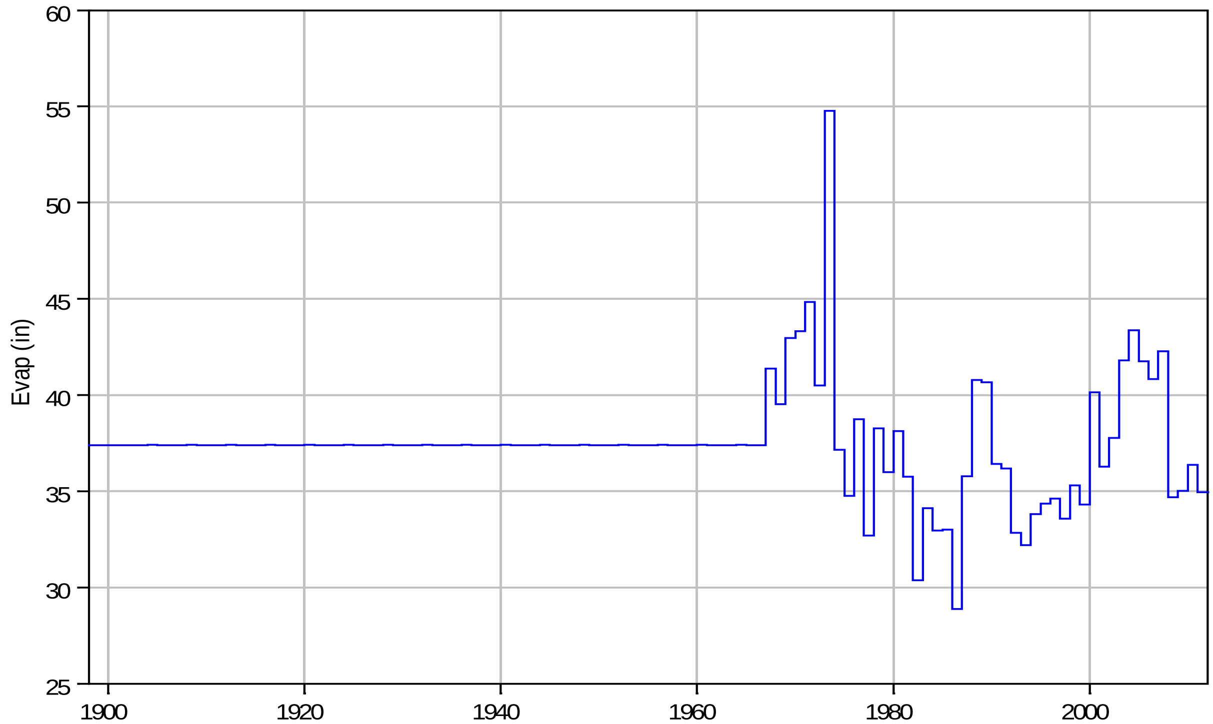


Figure 5-7: Oahe Final Annual Evaporation.

5.3 KANSAS CITY DISTRICT DATA SET DEVELOPMENT

5.3.1 Data Extension

This section discusses the observed gage flow and reservoir data development needed for the period of record datasets along the three major NWK regulated tributaries (Kansas, Osage, and Chariton Rivers) and the lower river gages on the Missouri River uncontrolled or minimally regulated tributaries downstream of Gavins Point Dam. The development of the datasets for the upper Missouri basin and the mainstem reservoirs are described in Sections 5.1 and 5.2. The Missouri River Recovery Program models were run for both observed conditions and current level depleted conditions. This section describes the development of the observed flow datasets. The depleted flow datasets are described in Section 6.

The daily USGS river gage data was generally available as 2400 data, as was some of the reservoir data. For the Kansas ResSim model all reservoir data was converted to 0600 data prior to calibration to be consistent with the current condition. For the Chariton River model, all the Rathbun Lake data was already in 0600 or 0800 format and was time stamped to 0600 for this data set. For the Osage River model, all the Melvern, Pomona, Hillsdale, and Pomme de Terre lake data was converted to 0600 data, while the Stockton, Truman, and Bagnell (hydropower projects) reservoir data was converted to 2400 data. The ResSim routing coefficients shown in

Table 5-10, Table 5-11, and Table 5-12 were computed assuming the above time stamps for reservoir releases and downstream gage data.

Few tributary river gages within NWK have observed flow data records for the entire 1930-2012 period of record. Most gages required some record extension back to 1930 or extensions to fill in missing value periods. Where possible, NWK used standard correlation techniques with other regional gages to extend or fill in missing value records. The specific technique was an extension of correlation procedures developed for the Kansas and Osage River analyses in the UMRSFFS study. Because of the number of NWK gages requiring extensions, NWK developed a specialized spreadsheet to optimize the gage data extension process. A description of the specialized spreadsheet methodology is included in Appendix C. The spreadsheet was first used to screen regional gage records to determine possible correlation candidates, then it tested single and multiple correlations to identify likely choices for each missing record period. Then a complete extended flow record was computed using the chosen correlation options. Different correlation gages may have been used depending on data availability for various required missing value periods. In most cases, separate correlations were also tested and sometimes used for extreme value zones.

NWK then screened the extended records with various techniques depending on the gage to ensure reasonableness and consistency in each extended record. In general the statistics (standard deviations, period volumes, flood peak flow frequency, minimum flow values) of the extended period were compared to the values for the observed period and any known values at sites upstream or downstream or at similar regional gages. Problems were most often noticed when the correlations to the known gages were weak, or when correlation gages having much larger or smaller drainage areas were used to extend records at the unknown gage. This was particularly true when the unknown record was for a gage with a relatively small drainage area. When concerns were noted, it was sometimes necessary to test other correlation candidates, apply volume correction factors to the extended records, and/or make various adjustments to the extreme values. Releases computed by the reservoir ResSim models are more affected by the total volume of the inflows than any other factor. Similarly, it is important that the volume of inflows passed downstream to the mainstem models are consistent throughout both the observed and extended records. Therefore, one of the statistics checked in extended gage records and reservoir inflow records was the annual flow volumes. If the volumes were within a reasonable range expected with due allowance for wet and dry periods and nearby gage records, then the extended flow record was accepted. If the volumes were unreasonable (determined somewhat subjectively) then a correction ratio was applied to bring it more in line with the observed record. This was primarily a problem with gages having relatively small drainage areas and more influenced by uncertain extreme values than for gages with large drainage areas. It was also a simple technique applicable when lagging a known upstream gage record to the downstream gage unknown record to account for additional drainage area inflow. A volume correction factor adjustment may not be applicable when attempting to define an accurate daily gage record, but since the long term inflow volumes are more important to a ResSim model than the individual daily values it seemed to be appropriate in this case.

In a couple cases, it was found that better correlations could be obtained by lagging records at the known correlation gages one or two days. In a couple other cases, upstream stations on the same tributary had longer records that could be lagged and expanded using volume correction or drainage area ratios to fill in portions of the missing record. Unless there was reason to believe otherwise, primary considerations for the extended record were consistency in the period runoff volumes and in the peak flow frequency as compared to the observed record and any supplemental studies completed for other projects. The Maintenance Of Variance Extension, type 1 (MOVE.1) (Hirsch, 1982) regression technique is a record extension refinement that David Goldman at HEC adapted for the UMRSFFS study and was used for many data extensions in this study by NWK. It attempts to retain the level of variability (standard deviation) in the extended flow record that one finds in the sample (observed) flow record. Although MOVE.1 correlation techniques were often applied, there was still an unavoidable loss of daily flow variability (standard deviation) in the extended record compared to the observed record. The variability in the data is less important to the reservoir modeling in this study than consistency and reasonable flow volumes and extreme values.

It was found that traditional extension techniques using single, multiple, and MOVE.1 correlations with known gages worked well at most unregulated gage sites. These techniques were also initially attempted for the river gages and for the headwater reservoir inflow nodes needed for the three major tributary ResSim models (Kansas, Osage, Chariton). At many sites in the Kansas and Osage River basins, portions of the extended records developed for the UMRSFSS study were also tested and found to be useful for extending the reservoir and gage records in this study.

But at many sites along the Kansas, Osage, and Chariton rivers, NWK generally found that large portions of the missing records could more reasonably be filled in by lagging known records at upstream or downstream sites on the same tributary with an additional application of a volume correction factor or drainage area ratio. The lagging factors used for the extended records were the lag coefficients derived in the calibration of the observed portion of the ResSim models. Given that these sites were used in the ResSim modeling, it was useful to have extended records at upstream sites which were statistically consistent with the observed portions of the record and with flood peaks derived in detailed historic reservoir design studies or observed in point discharge measurements. These sites were also desired to have a progressively increasing volume from upstream to downstream, and both flood peaks and low flow periods which lagged consistently from upstream to downstream in patterns typical of the observed period. The ResSim models can operate properly with long periods of negative local inflows, but when the computed local inflows have large and erratic daily variations from positive to negative flows, it can result in inconsistent and erratic modeled reservoir operations.

At NWK reservoirs included in the ResSim models, three parameters were necessary to calibrate and run the ResSim models: observed reservoir inflows, observed net reservoir evaporation minus reservoir precipitation, and observed reservoir releases. In all three cases, the observed (actual) records were used whenever possible. Daily inflows (cfs), releases (cfs), and reservoir evaporation (cfs) were available in the CWMS database back to 1980. However, the daily data in the CWMS database prior to 1997 and for short periods since then, particularly 2007-08, had a number of corrupted values. The corrupted values prior to 1997 appeared to be primarily due to errors in the annual archiving of the data, when the corrected values reflective of the monthly R0168 reports were overwritten by the raw values. In other cases, the corrected values were simply not read into the database or the R0168 monthly reports were not correctly balanced. In the 2007-08 period, the correct values for some NWK lakes were apparently lost in a conversion from an older database to the current oracle CWMS database.

Over the years, NWK has read the available CWMS reservoir data into spreadsheets, corrected erroneous values in the spreadsheet data as time was available, added useful portions of the data extensions from the UMRSFFS study, and added digitized data from historic paper R0168 monthly reports in NWK files. NWK has paper R0168 reports for most projects back to the date of dam closure. The earliest paper files for NWK USACE and USBR lakes date back to 1946, and 1931 for the private Lake of the Ozarks. The spreadsheet data records for the modeled reservoirs were extended to the study period of record 1930-2012 for this study and then read into DSS files for use in the ResSim models. As NWK completes its conversion from a legacy data entry system to a fully compatible CWMS data review and entry system, the NWK spreadsheet data will be used to correct and extend the current CWMS database entries.

For many lakes in the Kansas and Osage River basins, the available data in the spreadsheets through 1997 received a quick but general screening as part of the UMRSFFS study to correct large significant errors in the high flow periods, and then the pre-1980 daily pool elevations, reservoir inflows, and reservoir releases were digitized to the data spreadsheets from the R0168 monthly reports for some of the reservoirs. As part of a recent manual revision study, the available Rathbun Reservoir data was screened and all the pre-1980 data from the R0168 reports was added to the spreadsheets. As part of this study, the pre-1980 R0168 data for the remaining reservoirs in the Kansas and Osage river basins was digitized to the spreadsheets. As time was available, NWK also completed a more thorough comparison of all the spreadsheet data to the monthly R0168 reports than had been accomplished previously.

The lake inflow value (cfs) is a direct input to the ResSim models. Most of the reservoirs in the Kansas, Osage, and Chariton tributary river ResSim schematics are modeled as headwater nodes. The upstream inflow gages are not included in the models, although some of the inflow gage records were extended using the unregulated gage techniques. The observed inflows to the lakes for their operational periods were first taken from the screened and filled in data spreadsheets. NWK computes lake inflows as the change in storage plus net lake evaporation (cfs) plus releases (cfs). This is shown in Equation 1 where I is inflow, S is storage, E_{net} is net evaporation, and O is outflow.

$$I = \Delta S + E_{net} + O \qquad \text{Equation 1}$$

The computed inflows account not only for natural river surface water inflows to the lake but also errors in the lake elevation, infiltration, seepage, and precipitation on the lake. The ResSim lake inflow value is intended to be more of a natural inflow as inflow from precipitation is accounted for in the net evaporation component. For various reasons and for consistency with the extended unregulated period of reservoir inflows, NWK chose to deduct the portion of the lake precipitation included in the net evaporation value. The portion of the precipitation included in the net evaporation value was converted to an inflow (cfs) component by the lake area multiplication and deducted from the database computed inflow to derive the ResSim "natural" observed inflow. For the pre-reservoir period, the natural inflow at the dam was computed using the same regression, lagging, or other applicable techniques as used in extending the river gage records. Truman Reservoir and Lake of the Ozarks are the only downstream lakes not modeled as headwater locations. The observed inflows to those two lakes were first computed normally, but the ResSim model inflows to the two lakes are local inflows computed from the upstream model node to the downstream dam location.

The lake release value (cfs) value is not directly used in the ResSim model runs, but it was necessary in order to compute the local inflows between the dam and the next downstream river gage node in the model schematic, as well as some other intermediate computations. Daily average lake releases to the river are carried in the CWMS database and the NWK data spreadsheets, whether from direct entries or digitized from the paper monthly R0168 reports. All of the lake release values in the data spreadsheets were screened for this study. Lake releases for water supply are recorded in the database for some lakes, but not all of them. For those lakes that do have separate water supply intakes, the record can be incomplete and often was not recorded until recent years. Given that water supply withdrawals are generally much smaller than even lake evaporation and are not included in the local inflow computation from the dam to the downstream node, the water supply withdrawal component was not considered for this study or in the ResSim modeling. Since water supply withdrawals are not accounted for in the ResSim modeling input data, the withdrawals effectively reduce the computed inflow values. For the extended pre-reservoir period back to 1930, the observed lake releases were assumed to be equal to lake inflows. NWK reservoirs are mostly small enough that the travel time through the pre-reservoir length of the river during high flow periods is less than one day. This is probably not a good assumption for Milford, Tuttle Creek, Stockton, Truman and Lake of the Ozarks, but given the dynamic and often poorly defined nature of pre-reservoir routing, it was acceptable for this study. Errors in both routing and in the local inflow from upstream to the dam node are carried down to the local inflow computation between the dam and the next downstream model node with other unidentified gains and losses. The Missouri River Recovery Program ResSim model runs will result in different releases from the actual releases due to the application of standardized current condition reservoir operating rules.

Ideally, when the ResSim model data entries for inflows and net evaporation for the actual period of lake operations are run with specified actual releases, the results should exactly duplicate the observed daily lake elevations. Although the observed inflow dataset as discussed in previous paragraphs would generally result in satisfactory results, for this study the observed ResSim inflows for the actual reservoir operation period were recomputed using the ResSim input reservoir net evaporation and actual releases used in the local inflow computations for the downstream gage. This was done for a number of reasons. The current condition ResSim models use only the current area-capacity elevation tables, but the actual observed inflows were computed using tables that were in effect at the time. Inflows computed using current tables will result in sometimes significant differences from the recorded inflow, especially for lower pool elevations or when a lot of sedimentation has filled in the upper end of the reservoir as at Tuttle Creek. The recomputation of reservoir inflows will also account for water supply releases not accounted for in the ResSim model entries and errors in the computation of the R0168 monthly report values.

The data sources and techniques used to extend the observed gage data and reservoir parameters for the Kansas River model nodes are summarized in Table 5-7, for the Chariton River in Table 5-8, and for the Osage River in Table 5-9. As noted earlier, Appendix C contains a technical memorandum describing the specialized spreadsheets used to extend the observed records for unregulated gages. In the following tables, DA is drainage area and VCF is volume correction factor.

Table 5-7. Sources for Kansas River ResSim POR Data Set Construction

Location	Data Time Period	Source
Reservoir Inflows (See Text, Section 5.3.1, for Adjustments to Base Inflows, as well as Evap, Precip)		
Kanopolis Lake	1928-1940 1940-1948 1948-2013	At Ellsworth Gage (USGS, lagged 0.5 day) Nr Langley Gage (USGS) Observed (CWMS database with R0168 additions, corrections)
Wilson Lake	1929-1963 1963-1964 1964-2013	Nr Wilson Gage (USGS, lagged 1 day) UMRSFFS Observed (CWMS database with R0168 additions, corrections)
Waconda Lake	1929-1964 1964-1967 1967-2013	At Beloit Gage (USGS, with Drainage Area DA ratio factor) Nr Glen Elder Gage (USGS, with DA ratio factor) Observed (CWMS database with R0168 additions, corrections)
Milford Lake	1917-1950 1950-1964 1964 (Partial) 1964-2013	At Clay Center (USGS, lagged 1 day * DA ratio factor) At Milford Gage (USGS) At Junction City Gage (USGS) Observed (CWMS database with R0168 additions, corrections)
Tuttle Creek Lake	1918-1950 1950-1959 1959-2013	At Randolph Gage (linear regression on USGS lagged 0.25 day, VCF) Nr Manhattan Gage (USGS, overlaps with Randoph gage 1950-1959) Observed (CWMS database with R0168 additions, corrections)
Perry Lake	1922-1966 1966-2013	At Valley Falls (USGS, lagged 0.5 day * VCF to approximately duplicate preresv flood hydrographs generated for water control manual) Observed (CWMS database with R0168 additions, corrections)
Clinton Lake	1929-1977 1977-2013	Nr Lawrence Gage (USGS with DA ratio factor) Observed (CWMS database with R0168 additions, corrections)
Stream Gages		
Smoky Hill River at Mentor	1923-1932 Missing days 1932-1947 1947-2013	Observed (USGS) At Lindsborg Gage (As below, to fill in many missing values prior to 1933) At Lindsborg Gage (USGS, lagged 0.5 day+volume correction factor VCF) Observed (USGS)
Saline River at Tescott	1927-2013	Observed (USGS)

Smoky Hill River at New Cambria	1919-1948 1948-1952 1952-1962 1962-2013	UMRSFFS (better than test with routed Mentor+Tescott*DA ratio) Nr New Cambria Gage (USGS, with FFS for missing periods as below) UMRSFFS (better than test with routed Mentor+Tescott*DA ratio) Observed (USGS, with CWMS for some missing periods 2007-2013)
Solomon River at Niles	1897-2013	Observed (USGS)
Smoky Hill River at Enterprise	1922-1934 1934-2013	At Solomon Gage (USGS, lagged 0.25 day) Observed (USGS)
Kansas River at Fort Riley	1927-1951 1951-1963 1963-2013	At Ogden Gage (USGS) UMRSFFS Observed (USGS)
Kansas River at Wamego	1919-2013	Observed (USGS)
Kansas River at Topeka	1918-2013	Observed (USGS)
Kansas River at Lecompton	1919-1936 1936-2013	UMRSFFS (tried regressions against other gages, but not as good) Observed (USGS)
Kansas River at Desoto	1917-1973 1973-2013	At Bonner Springs Gage (USGS includes this with DeSoto record) Observed (USGS)
Missouri River at St Joseph	Refer to Table 5-2	
Missouri River at Kansas City	Refer to Table 5-2	
Missouri River at Waverly	Refer to Table 5-2	

Table 5-8. Sources for Chariton River ResSim POR Data Set Construction

Location	Data Time Period	Source
Reservoir Inflows (See Text, Section 5.3.1, for Adjustments to Base Inflows, as well as Evap, Precip)		
Rathbun Lake	1929-1938 1938-1956 1956-1967 1967-2013	At Novinger Gage (regression with USGS, lagged back 0.5 day, * VCF) Note: Also tested extending Promise City and Chariton upstream gages and routing extended values to Rathbun Dam with DA ratio or VCF correction, but results were not satisfactory. Also, Novinger record has short missing periods 1952-1954 and prior to 1930. These were filled in with separate regressions and monthly Volume Correction Factors (VCF) to the Prairie Hill gage. See below for Novinger. Nr Centerville Gage (regression with USGS, no lag, times VCF) Nr Rathbun Gage (USGS) Observed (CWMS database with R0168 additions, corrections)
Stream Gages		
Chariton River at Moulton	1929-1938 1938-1959	At Novinger Gage (regression with USGS, lagged back 0.5 day, * VCF) Nr Centerville Gage (USGS times small DA ratio, no lag)

	1959-1967 1967-1979 1979-2013	At Novinger Gage, pre-Dam (regr with USGS lagged back 0.5 day, * VCF) At Novinger Gage, post-Dam (regression with USGS, no lag, times VCF) Observed (USGS)
Chariton River at Livonia	1929-1974 1974-2013	At Novinger Gage (regression with USGS, no lag, times VCF) Note: Tested regressions with pre-dam and post-dam periods, but differences were not significant enough to use Observed (USGS)
Chariton River at Novinger	1929-1930 1930-1952 1952-1954 1954-2013	Nr Prairie Hill Gage (regression with USGS, lagged back 0.25 day, * VCF) Observed (USGS) Nr Prairie Hill Gage (regression with USGS, lagged back 0.25 day, * VCF) Observed (USGS)
Chariton River at Prairie Hill	1921-1929 1929-2013	At Elmer Gage (USGS lagged 1 day times small VCF) Observed (USGS)
Missouri River at Waverly	Refer to Table 5-2	
Missouri River at Boonville	Refer to Table 5-2	

Table 5-9. Sources for Osage River ResSim POR Data Set Construction

Location	Data Time Period	Source
Reservoir Inflows (See Text, Section 5.3.1, for Adjustments to Base Inflows, as well as Evap, Precip)		
Melvern Lake	1922-1938 1938-1939 1939-1970 1970-2013	Nr Pomona Gage (USGS, lagged back to Melvern Dam by ResSim coefficients times a volume correction factor (VCF) Extended Nr Pomona Gage, lagged back to Melvern Dam by ResSim coefficients times a VCF. See notes on the Pomona Gage extension below. Also tried regression spreadsheet with Soldier Ck nr Topeka, Stranger Ck nr Tonganoxie, Solomon nr Niles, but results were not consistent with downstream flows. Adopted method is weak, but inflows above Ottawa reasonably distributed, and actual inflows are captured and regulated by Truman Reservoir. UMRSFFS study ignored Melvern, Pomona, and Hillsdale Lakes altogether. This study tried to distribute flows upstream of Truman Dam for a better system regulation and for the benefit of future studies. At Melvern Gage (USGS) Observed (CWMS database with R0168 additions, corrections)
Pomona Lake	1918-1939 1938-1939 1939-1962 1962-2013	Nr Pomona Gage (USGS, lagged back to Pomona Dam by ResSim coefficients times a volume correction factor (VCF) Extended Nr Pomona Gage lagged back to Pomona Dam with ResSim coefficients times VCF to match the regression spreadsheet volumes for Pomona Dam inflow extension and consistent with Melvern portion 110-Mile Ck nr Quenemo (USGS) Observed (CWMS database with R0168 additions, corrections)

Hillsdale Lake	1921-1958 1958-1981 1981-2013	Regression spreadsheet with Soldier Ck nr Topeka, Stranger Ck nr Tonganoxie. Also used Grand River nr Gallatin for a few missing days. Computed results times a volume correction factor. Nr Hillsdale Gage (USGS) Observed (CWMS database with R0168 additions, corrections)
Stockton Lake	1921-1968 1968-2013	At Stockton Gage (USGS) Observed (CWMS database with R0168 additions, corrections)
Pomme de Terre Lake	1921-1960 1960-2013	At Hermitage Gage(USGS, lagged upstream 0.25 day times VCF for an overlapping period 1960-1965) Observed (CWMS database with R0168 additions, corrections)
Harry S. Truman Reservoir	1921-1977 1977-2013	Total of Osage at Osceola, South Grand at Brownington, Pomme at Hermitage, Pomme Dam releases, as data was available, times a DA expansion ratio for ungaged area to Truman Dam varying by data availability periods, * a small VCF based on an overlapping obsv period Observed (CWMS database with R0168 additions, corrections)
Lake of the Ozarks Bagnell Dam	1880-1931 1931-2013	Nr Bagnell Gage (USGS with Ameren adjustments to pre1925 NWS record which appeared reasonable. The Ameren adjustments to the NWS streamflow records were part of the design studies for Bagnell Dam. USGS added the NWS records to their database without adjustment. Observed data. Started with CWMS data entries reported to NWK Water Management. Obtained historic records from Ameren (owners) and checked and extended CWMS data accordingly. Historic inflows were computed with varying formulas with or without rain on pool, evap, etc. Values were standardized for ResSim.
Stream Gages		
Marais des Cygnes River nr Pomona	1922-1938 1938-1968 1968-2013	Observed (USGS) Regression to Nr Ottawa Gage lagged upstream with ResSim model routing coefficients times volume correction factor (VCF) Observed (USGS)
Marais des Cygnes River nr Ottawa	1918-2013	Observed (USGS)
Marais des Cygnes River at State Line	1928-1929 1929-1958 1958-2013	At Trading Post Gage (USGS with DA ratio factor) At Trading Post plus At Farlinville Gages (USGS, analysis showed Farlinville accounted for almost all of ungagged between Trading Post And State Line gage. Note that many reports equate Trading Post and State Line gage records, but there are definite volume differences) Observed (USGS)
Sac River at Highway J	1921-1973 1973-2013	Nr Stockton Gage (USGS values lagged downstream with ResSim lag coefficients, then times monthly volume correction factors Observed (USGS)
Sac River nr Caplinger Mills	1922-1934 1948-1974 1974-2013	Regression to extended Hwy J gage lagged to Caplinger Mills with ResSim coefficients, then times volume correction factor (no Pleasant View gage) Separate regression to observed, extended Hwy J gage lagged to Cap Mills with ResSim coefficients, added to Pleasant View gage, times VCF Observed (USGS)
Osage River below St. Thomas	1898-1931	Nr Bagnell Gage (USGS, with Ameren adjustments to the pre-1925 record, see Lake of the Ozarks notes above, then lagged 0.5 day downstream and expanded with a monthly volume correction factor)

	1931-1996 1996-2013	Nr St. Thomas Gage (USGS, times small VCF based on an overlapping period with the blw St. Thomas gage. Note that the USGS considers the records equivalent, but the VCF is also about the same as the DA ratio) Observed (USGS)
Gasconade River nr Rich Fountain	1921-1959 1959-1986 1986-2013	Observed (USGS) At Jerome Gage (USGS, lagged 0.75 day, then regression against lagged values. VCF not needed.) Observed (USGS)
Missouri River at Boonville	Refer to Table 5-2	
Missouri River at Hermann	Refer to Table 5-2	

5.3.2 Local Inflows

NWK computed the observed local inflows used for the three tributary ResSim models and used the local inflows computed by NWO for the Missouri River mainstem. Computed local inflows can be positive or negative on a day-by-day basis depending on simplifying assumptions used in the routing. The NWK tributary ResSim models all use Coefficient Routing. In general, the presence of negative inflow values was not a problem for the NWK ResSim models as long as the longer term summation volumes were positive and computed local inflows were not highly erratic. The following tables list the routing coefficients used in the NWK ResSim models and the computation of the local inflows.

Table 5-10: Kansas River Routing Parameters

Kansas River Basin			
Reach Name			
Start	**End**	**Routing Method**	**Coefficients**
Waconda Lake	Gage: USGS Niles, NLSK	Coefficient Routing	0.2, 0.1, 0.1, 0.3, 0.3
Gage: USGS Niles, NLSK	Solomon Confluence	Coefficient Routing	0.2, 0.7, 0.1
Wilson Lake	Gage: USGS Tescott, TSTK	Coefficient Routing	0.1, 0.2, 0.3, 0.4
Gage: USGS Tescott, TSTK	Saline Confluence	Coefficient Routing	0.2, 0.3, 0.5
Kanopolis Lake	Gage: USGS Mentor, MEKS	Coefficient Routing	0, 0.4, 0.6
Gage: USGS Mentor, MEKS	Saline Confluence	Coefficient Routing	0.4, 0.6
Saline Confluence	Gage: USGS New Cambria, NWCK	Null	-
Gage: USGS New Cambria, NWCK	Solomon Confluence	Coefficient Routing	0.0, 0.7, 0.3
Solomon Confluence	Gage: USGS Enterprise, EPKS	Null	-
Gage: USGS Enterprise, EPKS	Republican Confluence	Coefficient Routing	0.3, 0.7
Milford Lake	Republican Confluence	Coefficient Routing	0.7, 0.3
Republican Confluence	Gage: USGS Fort Riley, FRI	Null	-
Gage: USGS Fort Riley, FRI	Big Blue River Confluence	Coefficient Routing	0.4, 0.6
Tuttle Creek Lake	Big Blue River Confluence	Coefficient Routing	0.8, 0.2
Big Blue River Confluence	Gage: USGS Wamego, WGKS	Null	-

Gage: USGS Wamego, WGKS	Gage: USGS Topeka, TPAK	Coefficient Routing	0.4, 0.6
Gage: USGS Topeka, TPAK	Delaware Confluence	Coefficient Routing	0.8, 0.2
Perry Lake	Delaware Confluence	Coefficient Routing	0.8, 0.2
Delaware Confluence	Gage: USGS LeCompton, LEKS	Null	-
Gage: USGS LeCompton, LEKS	Wakarusa Confluence	Coefficient Routing	0.5, 0.5
Clinton Lake	Wakarusa Confluence	Coefficient Routing	0.5, 0.5
Wakarusa Confluence	Gage: USGS DeSoto, DESO	Null	-
Gage: USGS DeSoto, DESO	Kansas – MR JCT	Coefficient Routing	0.8, 0.2
Gage: USGS St. Joseph, STJ	Platte MO – MR JCT	Coefficient Routing	0.426, 0.449, 0.125
Platte MO – MR JCT	Kansas – MR JCT	Null	-
Kansas – MR JCT	Gage: USGS Kansas City, MKC	Null	-
Gage: USGS Kansas City, MKC	Gage: USGS Waverly, WVMO	Coefficient Routing	0.476, 0.524

Table 5-11: Chariton Routing Parameters.

Chariton River Basin			
Reach			
Start	**End**	**Routing Type**	**Coefficients**
Rathbun Lake	Fish water return, u/s of Rathbun Regional Water Association Diversion	Null	-
Fish water return, u/s of Rathbun Regional Water Association Diversion	Rathbun Regional Water Association Diversion	Null	-
Rathbun Regional Water Association Diversion	Outflow of Fish Hatchery Diversion	Null	-
Outflow of Fish Hatchery Diversion	Moulton	Coefficient Routing	0.25, 0.75
Moulton	Livonia	Coefficient Routing	0.17, 0.83
Livonia	Novinger	Coefficient Routing	0.56, 0.44
Novinger	Prairie Hill	Coefficient Routing	0.0, 0.50, 0.50
Prairie Hill	Confluence: Chariton River at Missouri River	Coefficient Routing	0.0, 1.0
Waverly	Confluence: Chariton River at Missouri River	Coefficient Routing	0.50, 0.50
Boonville	Confluence: Chariton River at Missouri River	Coefficient Routing	0.50, 0.50

Table 5-12: Osage Routing Parameters.

Osage Basin			
Reach			
Start	**End**	**Routing Type**	**Coefficients**
Melvern Lake	Confluence: Hundred Ten Mile Creek	Coefficient Routing	0.40, 0.60
Pomona Lake	Confluence: Hundred Ten Mile Creek	Coefficient Routing	0.30, 0.70
Confluence: Hundred Ten Mile Creek	Gage: USGS Pomona, PMNK	Null	-
Gage: USGS Pomona, PMNK	Gage: USGS Ottawa, OTTK	Coefficient Routing	0.70, 0.30
Gage: USGS Ottawa, OTTK	Confluence: Big Bull Creek	Coefficient Routing	0.10, 0.90
Hillsdale Lake	Confluence: Big Bull Creek	Coefficient Routing	0.40, 0.60
Confluence: Big Bull Creek	Gage: USGS Stateline, MKSL	Coefficient Routing	0.20, 0.20, 0.20, 0.20, 0.20
Gage: USGS Stateline, MKSL	Confluence: Little Osage	Coefficient Routing	0.10, 0.90
Confluence: Little Osage	Confluence: Sac River at Osage	Coefficient Routing	0.10, 0.90
Stockton Lake	Gage: USGS Highway J, SHJM	Coefficient Routing	0.10, 0.90
Gage: USGS Highway J, SHJM	Gage: USGS Caplinger Mills, CPMO	Coefficient Routing	0.70, 0.30
Gage: USGS Caplinger Mills, CPMO	Confluence: Sac River at Osage	Coefficient Routing	0.70, 0.30
Confluence: Sac River at Osage	Inflow into Truman Lake from Osage River	Null	-
Pomme de Terre Lake	Gage: USGS Pomme de Terre, PDT1	Coefficient Routing	1.0

Gage: USGS Pomme de Terre, PDT1	Inflow into Truman Lake from PDT River	Null	-
Truman Lake	Inflow for Lake of the Ozarks	Coefficient Routing	1.0
Lake of the Ozarks / Bagnell Dam	Gage: USGS Bagnell, BAGB	Coefficient Routing	1.0
Gage: USGS Bagnell, BAGB	Gage: St. Thomas, STTM	Coefficient Routing	0.0, 0.10, 0.20, 0.20, 0.20, 0.20, 0.10
Gage: St. Thomas, STTM	Confluence: Osage River with Missouri River	Coefficient Routing	0.80, 0.20
Gage: USGS Boonville, BVMO	Confluence: Osage River with Missouri River	Coefficient Routing	0.30, 0.30, 0.30, 0.10
Confluence: Osage River with Missouri River	Confluence: Gasconade with Missouri River	Coefficient Routing	0.20, 0.30, 0.30, 0.20
Gage: USGS Rich Fountain, RIFM	Confluence: Gasconade with Missouri River	Coefficient Routing	0.80, 0.20
Confluence: Gasconade with Missouri River	Gage: USGS Hermann, HEMO	Coefficient Routing	0.80, 0.20

5.3.3 Evaporation

The observed lake evaporation in cfs was obtained from the filled in and screened data spreadsheets and converted to lake evaporation in inches by dividing out the lake area in acres with unit conversions. Lake area is not carried in the databases or monthly R0168 reports. All of the early area-capacity tables were therefore digitized into spreadsheets and daily reservoir areas were interpolated from the tables for the daily observed reservoir elevation. Reservoir storage cannot be found on the pre-1981 R0168 reports and daily reservoir storage was also interpolated to the data spreadsheets. For periods of time both before and after the reservoir was constructed when the observed lake evaporation (inches) could not be computed directly, average daily lake evaporation (inches) values were computed for each month for the period 1990-2012, and the average daily equivalents for the monthly values were used. The 1990-2012 period used current pan evaporation measuring equipment and conversion factors in computing lake evaporation.

Although NWK records the daily total precipitation measured at the project office in the CWMS database, it was determined that a more reliable value reflective of the entire lake could be developed relatively easily. Most precipitation at NWK lakes, particularly from storms producing the larger flood inflow volumes, is convective and localized in nature, and the project office precipitation record is sometimes poorly reflective of storms over the lake. Project office precipitation was only recorded in the CWMS database back to the early 1980's and is not found on the monthly R0168 reports. In addition, the daily precipitation values entered into the electronic database are often values accumulated over many days, particularly for weekend and holiday periods, earlier years, and for certain lakes like the USBR Waconda Lake. These large anomalous values can distort the evaporation component in the ResSim modeling. Other lakes have extended missing value periods, due to staffing and equipment shortages.

The NCDC maintains an excellent and easily accessible daily precipitation database for regional climatic sites. Their database also includes the project office recorded daily precipitation values digitized from the project office monthly E19 climatic reports (more recently entries through a web-based NWS interface). The NCDC values are often more reliable than the daily values routinely reported to the NWK Water Management Office. For this study, all of the available NWS electronic daily precipitation data for the lake project offices and for regional reporting sites was downloaded from the NCDC website. The NCDC precipitation record for the project office and for regional sites was then compared to the Corps spreadsheet records to correct and complete the USACE record for the project office since dam closure. The project office record and the available data from regional sites were then averaged to develop a daily precipitation record in inches for the entire lake area for the extended observed period back to 1930. For the pre-reservoir period, the average of only the regional gages was used. Given that there is a definite west to east pattern of increasing precipitation in NWK, the average annual regional averages were compared to the average annual values for the more reliable portions of the observed project office records to ensure that the derived pattern of rainfall across the lake did not deviate significantly from what would have been expected at the project office.

As noted above, the ResSim lake evaporation value is actually a net value of the lake evaporation minus the effective lake precipitation. The effective lake precipitation included in the ResSim net evaporation value is actually only a portion of the total observed lake precipitation. Analysis has shown that only a portion of the actual precipitation, varying by lake and storm from an average of 30% to 70% of the total precipitation, can be detected in the computed lake inflow value. Various techniques were used to separate out the effective portion of the precipitation on the lake that could be detected in the observed inflows. The effective precipitation was then deducted from the lake evaporation to determine the net evaporation. As described earlier, the portion of the observed inflows that could be attributed to the effective precipitation was then deducted from the observed total inflows to derive a value more representative of the ResSim natural inflows. For the extended pre-reservoir period, the average percentage of actual precipitation that was accounted for in the effective precipitation during the actual reservoir operation period was applied to the total lake precipitation. It is assumed that the remaining portion of the precipitation is accounted for in the lake inflow value.

Net evaporation along NWK tributary rivers was only needed in developing the reservoir datasets. Although at times free-flowing river evaporation is obviously significant, particularly along the Kansas River, in general evaporation along the tributary rivers is minimal compared to rainfall and snowmelt inflows. Given the many other uncertainties in the extension of the river gage records, NWK decided that it was reasonable to assume that evaporation is accounted for in the observed gage flows and the computation of local inflows between model nodes.

6 DEPLETION CALCULATIONS

The observed datasets compiled from various sources and described previously were then corrected with the net current level (2011) depletions minus historic depletions obtained from the USBR. USBR provided the depletions by 8-digit HUC's. NWK combined the HUC data to develop net depletions above each headwater gage location and between model nodes used in the models, for the entire Missouri River basin. The net depletions above each gage were then subtracted from the historic or observed gaged record resulting in depleted flow datasets used in the final MRRP alternative analyses. The depleted flow datasets represent flows as if all current basin development including reservoirs, agriculture irrigation, water supply withdrawals, and other sources of surface water depletions were in place for the entire period of record. Net depletions are used to adjust the historic flows because the historic depletions are already included in the historic flows. If the entire current level depletion was removed from the historic gage flow, the historic depletions would be double counted.

Unfortunately, to date it appears that the current level depletions were overestimated for earlier years in the record, resulting in negative flows at many tributary sites during dry years when the net depletions are removed from the historic flows. Negative flows at tributary sites were deemed unreasonable because it is likely that irrigation depletions would be limited under current conditions to maintain a viable stream, similar to historic minimum flows during recent droughts. Therefore, after adding the net depletions to the observed flows, the depletions were reduced during periods of negative depleted flows. The same depletion volume that was added back to the depleted flows at the tributary sites was also added back to the depleted flows at the mainstem locations to ensure the volume remained consistend between differernt locations in the basin. To date, the study is using the USBR net depletions corrected to what appears to be more reasonable levels based on known conditions from other studies. Attempts to revise the USBR depletion data continue at the time of this documentation (October 2015).

The datasets provided by NWK for depletions were adjusted further by NWO to remove large negative local flows at Mainstem locations that MRBWM personnel felt were unreasonable. A minimum of -2,000 cfs was used for all Mainstem flow input datasets. Discharge volumes below the minimum were redistributed throughout the corresponding month. This resulted in final discharges after redistribution that were still less than the specified minimum of -2,000 cfs in some areas, but were considered more reasonable than the previous datasets.

7 RAS MODEL DATA SET DEVELOPMENT

In the RAS models, a complete POR dataset from 1930 to 2012 was needed for the tributary inflows and ungaged computations, both of which were applied to each of the six alternative runs. Data sources include USGS gages, output from Baseline ResSim models, and stage and flow estimates made using a variety of methods.

7.1 GAGE DATA EXTENSION

A complete POR dataset from 1930 to 2012 was necessary for the RAS models. Gage record extensions were necessary due to tributary gages coming online at different times in the POR. Two methods were used to extend the gage records. For the upper three RAS models, ResSim calculated local inflows were used along with a cyclic analysis in HEC-DSS. For the lower Missouri River RAS models, the inputs were Gavins Point releases, the extended unregulated tributary gage records, and the tributary ResSim model results for the Kansas, Chariton, and Osage River models.

7.1.1 Upper Models (Above Gavins)

For the three HEC-RAS models above Gavins Point Dam, the tributary gage records were extended using ResSim computed local inflows and a cyclic analysis in HEC-DSS to obtain a complete POR dataset (1930 to 2012). Tributaries that were located well into the reservoir pools were not used as input into the HEC-RAS models and therefore gage records were not extended.

The observed tributary flows were lagged by an estimated lag time determined by calculating the travel time from the gage to the nearest downstream Missouri River local inflow location. A daily ratio was then computed by dividing the lagged tributary flows by the local inflows. Next, a cyclic analysis using HEC-DSS was performed on the ratio data set to obtain the median (P50) representative daily ratio for each day of the year.

The daily ratio values computed through the cyclic analysis were then multiplied by the local inflows to obtain an estimated lagged (routed) tributary flow. These flows were then back routed to reflect the proper timing at the tributary gage location. These estimated flows were used to fill any missing gaps in the observed tributary POR data sets.

Main stem gage locations used in the ungaged computations also needed a complete POR of both flow and stage. Missing flow data was filled in with the Baseline run from ResSim while missing stage data was computed from flow using a reverse rating curve.

Upstream flow and downstream stage boundary conditions for HEC-RAS for the POR were compiled using the best data available for the time period. This included USGS gage data, data from the Corps CWMS database, or ResSim output. The data sources for the POR for each location (tributary, main stem flow gage, and boundary conditions) are listed in Table 7-1, Table 7-2, and Table 7-3.

Table 7-1: Fort Peck Dam to Garrison Dam POR Data Sources

Location	Data Source	Data Time Period
Fort Peck Dam to Wolf Point, MT		
Fort Peck Dam Outflow	ResSim Data (Observed Flows.dss)	1930-1934
	USGS Gage - Blw Fort Peck (06132000)	1934-1939
	CWMS Database	1939-2012
Milk River	ResSim Flow Estimation	1930-1939
	USGS Gage - Nashua, MT (06174500)	1939-2012
Prairie Elk Creek	ResSim Flow Estimation	1930-1975

	USGS Gage - Oswego, MT (06175540) ResSim Flow Estimation	1975-1985 1985-2012
Wolf Creek	ResSim Flow Estimation USGS Gage - Wolf Point, MT (06176500) ResSim Flow Estimation USGS Gage - Wolf Point, MT (06176500) ResSim Flow Estimation	1930-1950 1950-1953 1953-1981 1981-1992 1992-2012
Wolf Point, MT to Culbertson, MT		
Missouri River (Wolf Point, MT)	USGS Gage Flow - Wolf Point, MT (06177000) Reverse Rating Curve from Obs Flow USGS Gage Stage - Wolf Point, MT (06177000)	1930-2012 1930-1989 1989-2012
Redwater River	ResSim Flow Estimation USGS Gage - Vida, MT (06177825) ResSim Flow Estimation USGS Gage - Vida, MT (06177825)	1930-1975 1975-1985 1985-2012 2012
Poplar River	ResSim Flow Estimation USGS Gage - Poplar, MT (06181000) ResSim Flow Estimation USGS Gage - Poplar, MT (06181000) ResSim Flow Estimation USGS Gage - Poplar, MT (06181000)	1930-1947 1947-1969 1969-1975 1975-1979 1979-1981 1981-2012
Big Muddy Creek	ResSim Flow Estimation USGS Gage - Culbertson, MT (06185110) ResSim Flow Estimation USGS Gage - Culbertson, MT (06185110)	1930-1981 1981-1992 1992-2012 2012
Culbertson, MT to Garrison Dam		
Missouri River (Culbertson, MT)	ResSim (Observed Flows.dss) USGS Gage Flow - Culbertson, MT (06185500) ResSim (Observed Flows.dss) USGS Gage Flow - Culbertson, MT (06185500) Reverse Rating Curve from Obs Flow USGS Gage Stage - Culbertson, MT (06185500)	1930-1941 1941-1951 1952-1958 1958-2012 1930-1989 1989-2012
Yellowstone River	USGS Gage - Sidney, MT (06329500) ResSim Flow Estimation USGS Gage - Sidney, MT (06329500)	1930-1931 1931-1933 1933-2012
Little Muddy River	ResSim Flow Estimation USGS Gage - Williston, ND (06331000)	1930-1954 1954-2012
Little Missouri River	ResSim Flow Estimation USGS Gage - Watford City, ND (06337000)	1930-1934 1934-2012
Garrison Pool (Lake Sakakawea)	ResSim Data (Elev) CWMS Database	1930-1966 1967-2012

Table 7-2: Garrison Dam to Oahe Dam POR Data Sources

Location	Data Source	Data Time Period
Garrison Dam to Bismarck, ND		
Garrison Dam Outflow	ResSim Data USGS Gage - blw Garrison (06339000) CWMS Database	1930-1948 1948-1953 1953-2012
Knife River	USGS Gage - Hazen, ND (06340500) ResSim Flow Estimation USGS Gage - Hazen, ND (06340500)	1930-1933 1933-1937 1937-2012

Alderin Creek	ResSim Flow Estimation USGS Gage - Fort Clark, ND (06340780) ResSim Flow Estimation	1930-1977 1977-1983 1983-2012
Coal Lake Coulee	ResSim Flow Estimation USGS Gage - Hensler, ND (06340905) ResSim Flow Estimation	1930-1977 1977-1989 1989-2012
Buffalo Creek	ResSim Flow Estimation USGS Gage - Washburn, ND (06340930) ResSim Flow Estimation	1930-1978 1978-1983 1983-2012
Turtle Creek	ResSim Flow Estimation USGS Gage - Washburn, ND (06341410) ResSim Flow Estimation	1930-1986 1986-2003 2003-2012
Painted Woods Creek	ResSim Flow Estimation USGS Gage - Wilton, ND (06341800) ResSim Flow Estimation	1930-1957 1957-2003 2003-2012
Square Butte Creek	ResSim Flow Estimation USGS Gage - Center, ND (06342260)	1930-1965 1965-2012
Burnt Creek	ResSim Flow Estimation USGS Gage - Bismarck, ND (06342450)	1930-1967 1967-2012
Bismarck, ND to Oahe Dam		
Missouri River (Bismarck, ND)	USGS Gage Flow - Bismarck, ND (06342500) USGS Gage Stage - Bismarck, ND (06342500) Reverse Rating Curve from Obs Flow USGS Gage Stage - Bismarck, ND (06342500)	1930-2012 1930-1957 1957-1984 1984-2012
Heart River	USGS Gage - Mandan, ND (06349000) ResSim Flow Estimation USGS Gage - Mandan, ND (06349000)	1930-1933 1933-1937 1937-2012
Apple Creek	ResSim Flow Estimation USGS Gage - Menoken, ND (06349500)	1930-1945 1945-2012
Cannonball River	ResSim Flow Estimation USGS Gage - Breien, ND (06354000)	1930-1934 1934-2012
Oahe Pool (Lake Oahe)	ResSim Data (Elev) CWMS Database	1930-1966 1967-2012

Table 7-3: Fort Randall Dam to Gavins Point Dam POR Data Sources

Location	Data Source	Data Time Period
Fort Randall Dam to Gavins Point Dam		
Fort Randall Dam Outflow	ResSim Data (Observed Flows.dss) USGS Gage - At Fort Randall (06453000) CWMS Database	1930-1947 1947-1953 1953-2012
Choteau Creek	ResSim Flow Estimation USGS Gage - Avon, SD (06453255) ResSim Flow Estimation	1930-1982 1982-2003 2003-2012
Ponca Creek	ResSim Flow Estimation USGS Gage - Verdel, NE (06453600)	1930-1957 1957-2012
Niobrara River	ResSim Flow Estimation UGSG Gage - Verdel, NE (06465500) ResSim Flow Estimation UGSG Gage - Verdel, NE (06465500)	1930-1938 1938-1940 1940-1958 1958-2012
Verdigre Creek	ResSim Flow Estimation USGS Gage - Verdigre, NE (06465700)	1930-2002 2002-2012

Bazile Creek	ResSim Flow Estimation	1930-1952
	USGS Gage - Niobrara, NE (06466500)	1952-1995
	ResSim Flow Estimation	1995-2002
	USGS Gage - Niobrara, NE (06466500)	2002-2012
Gavins Point Pool (L&C Lake)	ResSim Data (Elev)	1930-1966
	CWMS Database	1967-2012

7.1.2 Gavins to Rulo

For the Gavins Point Dam to Rulo HEC-RAS model, the POR data set was extended using linear regression and MOVE.1 analyses. Appendix C – Technical Memorandum for NWK Unregulated Gage Extensions, explains the calculation methods in more detail. The data sources for the POR for each location are listed in Table 7-4.

Main stem gage locations used in the ungaged computations also needed a complete POR of both flow and stage. Missing flow and stage data for these locations were filled in with data from the UMRSFFS (USACE, 2003). Data sources for these locations are also listed in Table 7-4.

Table 7-4: Gavins to Rulo POR Data Sources

Location	Data Source	Data Time Period
Gavins Point to Sioux City		
Gavins Point Dam Outflow	UMRSFFS Flow	1930-1955
	CWMS Database	1955-2013
James River	USGS Gage - Scotland (06478500)	1928-2013
Vermillion River	Big Sioux River MOVE.1 Run2	1928-1983
	USGS Gage - Vermillion (06479010)	1983-2013
Big Sioux River	USGS Gage - Akron (06485500)	1928-2013
Sioux City to Omaha		
Missouri River (Sioux City)	USGS Gage Flow - Sioux City (06486000)	1928-1931
	UMRSFFS Flow	1931-1938
	USGS Gage Flow - Sioux City (06486000)	1938-2013
	UMRSFFS Stage	1930-1988
	USGS Gage Stage - Sioux City (06486000)	1988-2013
Floyd River	CDM Extension	1930-1934
	USGS Gage - James (06600500)	1934-2013
Omaha Creek	CDM Extension	1930-1945
	USGS Gage - Homer (06601000)	1945-2013
Monona Harrison Ditch	CDM Extension	1930-1942
	USGS Gage - Turin (06602400)	1942-2013
Little Sioux River	Lagged Correctionville MOVE.1 * Volume Correction Factor	1928-1932
	Elkhorn River Regression * Volume Correction Factor	1932-1934
	Floyd River Regression * Volume Correction Factor	1934-1936
	Lagged Correctionville + Lagged Mapleton * Volume Correction Factor	1936-1958
	USGS Gage - Turin (06607500)	1958-2013
Soldier River	CDM Extension	1930-1940
	USGS Gage - Pisgah (06608500)	1940-2013
Boyer River	Little Sioux MOVE.1 with Monthly Volume Correction Factor	1928-1932
	Big Sioux MOVE.1 with Monthly Volume Correction Factor	1932-1934
	Floyd MOVE.1 with Monthly Volume Correction Factor	1934-1936
	E. Nishnabotna-Floyd MOVE.1 Run 4 with Monthly Volume Correction Factor	1936-1937
	USGS Gage - Logan (06609500)	1937-2013
Omaha to Nebraska City		
Missouri River (Omaha)	USGS Gage Flow - Omaha (06610000)	1928-2013

	UMRSFFS Stage	1930-1987
	USGS Gage Stage - Omaha (06610000)	1987-2013
Platte River	Ashland MOVE.1	1928-1953
	USGS Gage - Louisville (06805500)	1953-2013
Weeping Water Creek	Tarkio MOVE.1 with Monthly Volume Correction Factor	1924-1936
	Tarkio-Nodaway Run 3 with Monthly Volume Correction Factor	1936-1950
	USGS Gage - Union (06806500)	1950-2013
Nebraska City to Rulo		
Missouri River (Nebraska City)	USGS Gage Flow - Nebraska City (06807000)	1929-2013
	UMRSFFS Stage	1930-1988
	USGS Gage Stage - Nebraska City (06807000)	1988-2013
Nishnabotna River	USGS Gage - Hamburg (06810000)	1928-2013
Little Nemaha River	Tarkio MOVE.1 with Monthly Volume Correction Factor	1925-1936
	Tarkio-Nodaway Run 2 with Monthly Volume Correction Factor	1936-1949
	USGS Gage - Auburn (06811500)	1949-2013
Tarkio River	USGS Gage - Fairfax (06811500)	1922-1990
	Nodaway Reg w/ Vol Corr Factor	1991-2007
	USGS Gage - Fairfax (06811500)	2007-2013
Missouri River (Rulo)	UMRSFFS Flow	1930-1949
	USGS Gage Flow - Rulo (06813500)	1949-2013
	UMRSFFS Stage	1930-1988
	USGS Gage Stage - Rulo (06813500)	1988-2013

7.1.3 Rulo to the Mouth

For the Rulo to the Mouth HEC-RAS model, the POR data set was extended using linear regression and MOVE.1 analyses. Appendix C – Technical Memorandum for NWK Unregulated Gage Extensions, explains the calculation methods in more detail. The data sources for the POR for each location are listed in Table 7-5. Only flow extensions were necessary as the simplified methodology used for estimating ungaged inflows for this reach did not require stages.

Table 7-5: Rulo to the Mouth POR Data Sources

Location	Data Source	Data Time Period
Big Nemaha River at Falls City, Nebr.	Tarkio MOVE.1 with Monthly Volume Correction Factor	1925-1936
	Tarkio - Nodaway MOVE.1 Run 4 with Monthly Volume Correction Factor	1936-1944
	USGS Gage - Falls City (06815000)	1944-2013
Nodaway River near Graham, MO	Tarkio MOVE.1	1925-1936
	Nodaway Clarinda w/12-hr lag Regression	1936-1982
	USGS Gage - Graham (06817700)	1982-2013
Platte River at Sharps Station, MO (input to RAS)	Lagged Observed Platte Agency MOVE.1 Run 4	1924-1930
	Extended Lagged Platte Agency MOVE.1 Run 4	1930-1932
	Lagged Observed Platte Agency MOVE.1 Run 4	1932-1978
	USGS Gage - Sharps Station (06821190)	1978-2013
Platte River at Agency (extended for Sharps Station extension)	Extended Boyer River MOVE.1	1925-1934
	Floyd River MOVE.1	1934-1936
	E. Nishnabotna River MOVE.1	1936-1937
	Boyer River MOVE.1 Run 2	1937-1940
	USGS Gage - Agency (06820500)	1940-2013
Kansas River at Desoto	Refer to Table 5-7	
Blue River at Stadium Drive	Stranger-Marmaton MOVE.1 Run 3	1929-1934
	Marmaton MOVE.1	1934-1938
	Stranger-Marmaton MOVE.1 Run 3	1938-1939
	Kansas City lagged MOVE.1 with Monthly Vol Corr Factor	1939-2002
	USGS Gage - Stadium Drive KC (06893578)	2002-2013
Little Blue River near Lake City, MO	Stranger Tonganoxie MOVE.1 with Monthly Volume Correction Factor	1929-1939
	Blue-Stranger MOVE.1 Run 2 with Monthly Volume Correction Factor	1939-1948

	USGS Gage - Lake City (06894000)	1948-2013
Crooked River near Richmond, MO	Gallatin-Linneus MOVE.1 with Monthly Volume Correction Factor	1929-1934
	Grand Gallatin MOVE.1 with Monthly Volume Correction Factor	1934-1948
	USGS Gage - Richmond (06895000)	1948-1970
	Gallatin-Linneus MOVE.1 with Monthly Volume Correction Factor	1970-1972
	Grand Gallatin MOVE.1 with Monthly Volume Correction Factor	1972-2000
	Gallatin-Linneus MOVE.1 with Monthly Volume Correction Factor	2000-2007
	USGS Gage - Richmond (06895000)	2007-2013
Wakenda Creek at Carrollton, MO	Blackwater-Locust Run 3 with Monthly Volume Correction Factor	1929-1933
	Locust MOVE.1 with Monthly Volume Correction Factor	1933-1938
	Blackwater-Locust Run 3 with Monthly Volume Correction Factor	1938-1948
	Observed	1948-1970
	Blackwater-Locust Run 3 with Monthly Volume Correction Factor	1970-1972
	Blackwater MOVE.1 with Monthly Volume Correction Factor	1972-2000
	Blackwater-Locust Run 3 with Monthly Volume Correction Factor	2000-2008
	Observed	2008-2013
Grand River near Sumner, MO	Refer to Table 5-8	
Chariton River near Prairie Hill, MO	Refer to Table 5-8	
Blackwater River at Blue Lick, MO	Locust Creek MOVE.1 Run 4	1926-1930
	USGS Gage - Blue Lick (06908000)	1930-1933
	Lamine at Clifton City MOVE.1 Run 4 with Monthly Volume Correction Factor	1933-1938
	USGS Gage - Blue Lick (06908000)	1938-2013
Lamine River near Otterville, MO	Factored Clifton City	1922-1987
	USGS Gage - Otterville (06906800)	1987-2013
Moniteau Creek near Fayette, MO	Lamine Locust MOVE.1 Run 4 with monthly volume correction factor	1929-1948
	USGS Gage - Fayette (06909500)	1948-1960
	Lamine Locust MOVE.1 Run 4 with monthly volume correction factor	1960-1961
	USGS Gage - Fayette (06909500)	1961-1969
	Lamine Locust MOVE.1 Run 4 with monthly volume correction factor	1969-1971
	Locust MOVE.1 with monthly volume correction factor	1971-1972
	Sumner MOVE.1 with monthly volume correction factor	1972-2000
	Locust MOVE.1 with monthly volume correction factor	2000-2002
	USGS Gage - Fayette (06909500) ??? - time per was missing in prev table	2002-2013
Petite Saline Creek at Hwy U nr Boonville, MO	Little Piney-Grand-Sumner Run 4	1928-1948
	Booneville Gage Drainage Area Ratio	1948-1967
	Little Piney-Grand-Sumner Run 4	1967-2007
	USGS Gage - Hwy U (06909950)	2007-2013
Hinkson Creek at Columbia, MO	Rich Fountain Regression With Annual Vol Correction Factor	1921-1934
	Bourbeuse Regression With Annual Vol Correction Factor	1934-1966
	USGS Gage - Columbia (06910230)	1966-1981
	Rich Fountain Regression With Annual Vol Correction Factor	1981-1986
	USGS Gage - Columbia (06910230)	1986-1991
	Rich Fountain Regression With Annual Vol Correction Factor	1991-2000
	Locust Borbeuse MOVE.1 with Annual Volume Correction Factor	2000-2007
	USGS Gage - Columbia (06910230)	2007-2013
Moreau River near Jefferson City, MO	Gasconade-Rich Fountain--Big Piney MOVE.1 Run 4	1921-1947
	USGS Gage - Jefferson City (06910750)	1947-1956
	Gasconade-Rich Fountain--Big Piney MOVE.1 Run 4	1956-1957
	USGS Gage - Jefferson City (06910750)	1957-1974
	Gasconade-Rich Fountain--Big Piney MOVE.1 Run 4	1974-1982
	Gasconade-Rich Fountain Regression	1982-1988
	Gasconade-Rich Fountain--Big Piney MOVE.1 Run 4	1988-1996
	Gasconade-Rich Fountain Regression	1996-1999
	Gasconade-Rich Fountain--Big Piney MOVE.1 Run 4	1999-2000
	USGS Gage - Jefferson City (06910750)	2000-2013
Osage River below St Thomas, MO	Refer to Table 5-12	
Maries River	Meramec-Bourbeuse MOVE.1 Run 4 with monthly vol corr factor	1922-1947
	USGS Gage - Westphalia (06927000)	1947-1970
	Meramec-Bourbeuse MOVE.1 Run 4 with monthly vol corr factor	1970-2002
	USGS Gage - Westphalia (06927000)	2002-2013

Gasconade River	Refer to Table 5-12	1921-1959

7.2 UNGAGED INFLOWS

For the NWO district models, ungaged inflows for tributaries with no gage records were calculated using the ungaged option within RAS unsteady flow. Ungaged calculations are made between two gages on the main-stem which have a continuous record of both stage and flow. The ungaged flow calculation is made by running the unsteady model with internal stage and flow boundaries at the downstream end of ungaged reaches. At the endpoint, the calculated flow hydrograph is compared to the observed hydrograph, and the difference is calculated. The difference is put back into the model between the two gages at user specified locations with a backwards lag in time and the model is run again. This process is repeated until the flow at the endpoint either matches the flow convergence desired or meets the maximum number of iterations specified. Simultaneous was selected as the optimization mode. The Simultaneous option makes ungaged calculations for each reach independent of the others, whereas the sequential option runs calculations for each reach in order of upstream to downstream taking into account any lack in flow convergence that may have occurred in the upstream reach.

For the NWK model (Rulo to Mouth), ungaged inflows were calculated using a simplified methodology described in Section 7.2.3 below. The ungaged option within HEC-RAS was explored with a short time window, but run times were so long (8 hours of run time for 2 months of simulation) it was not considered feasible to apply this methodology to the entire period of record.

7.2.1 Upper Models (Above Gavins)

Ungaged inflows were calculated for the Fort Peck to Garrison and Garrison to Oahe RAS models using the RAS computation method. Ungaged computations were not performed for the Fort Randall to Gavins Point model due to the lack of flow gages in the reach. Input parameters for each of the ungaged routing reaches are shown in Figure 7-1, Figure 7-2, and Figure 7-3.

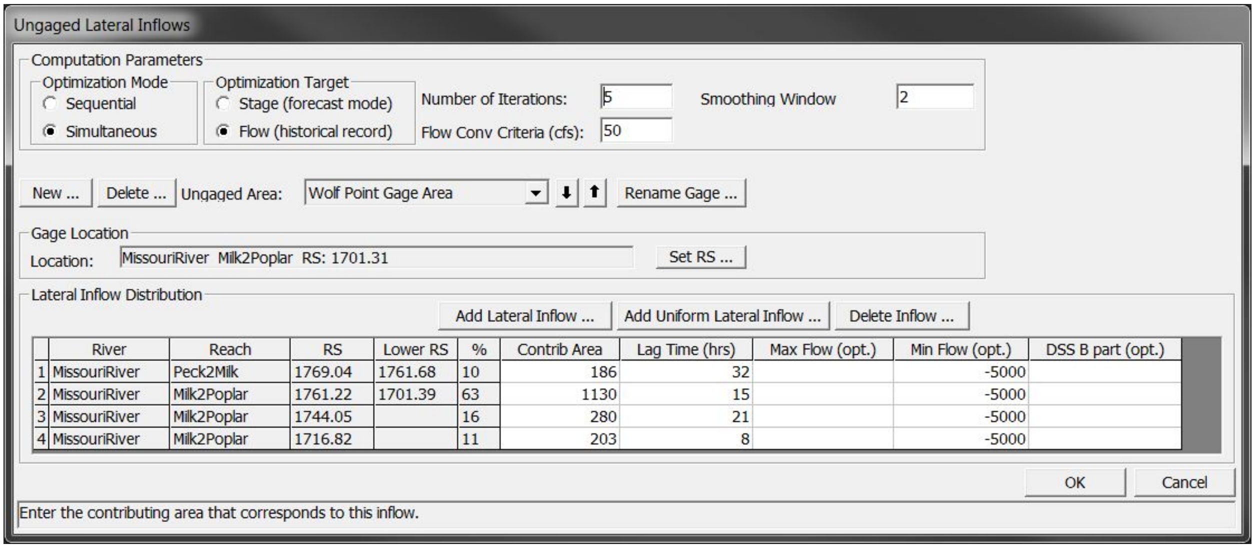


Figure 7-1: Ungaged Inflow Fort Peck to Wolf Point

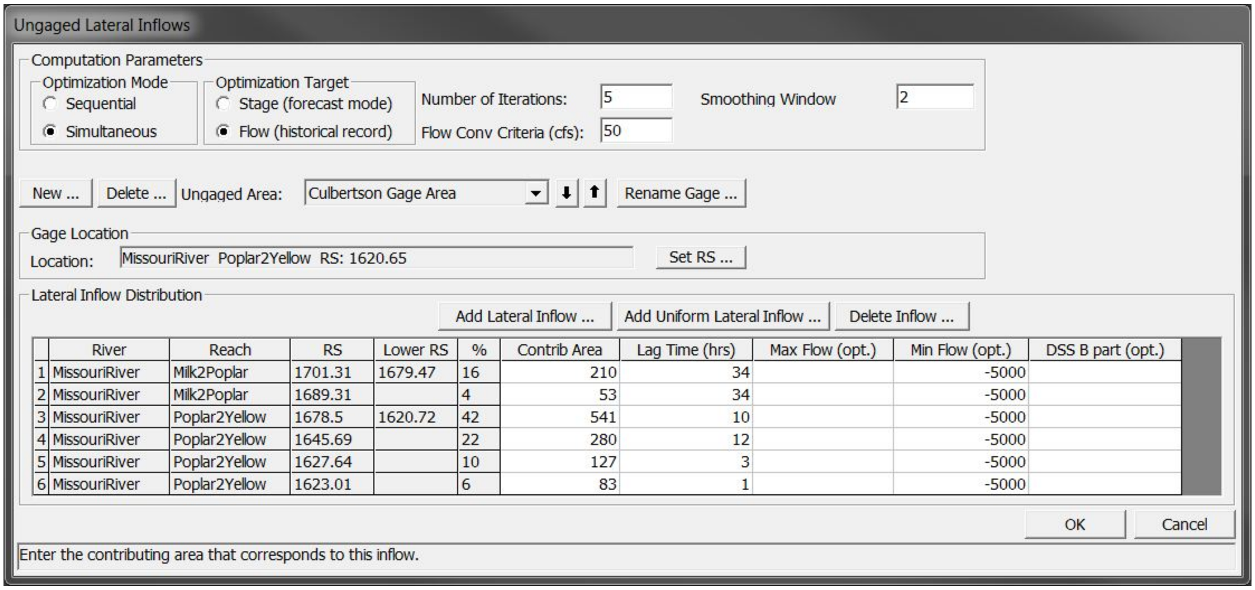
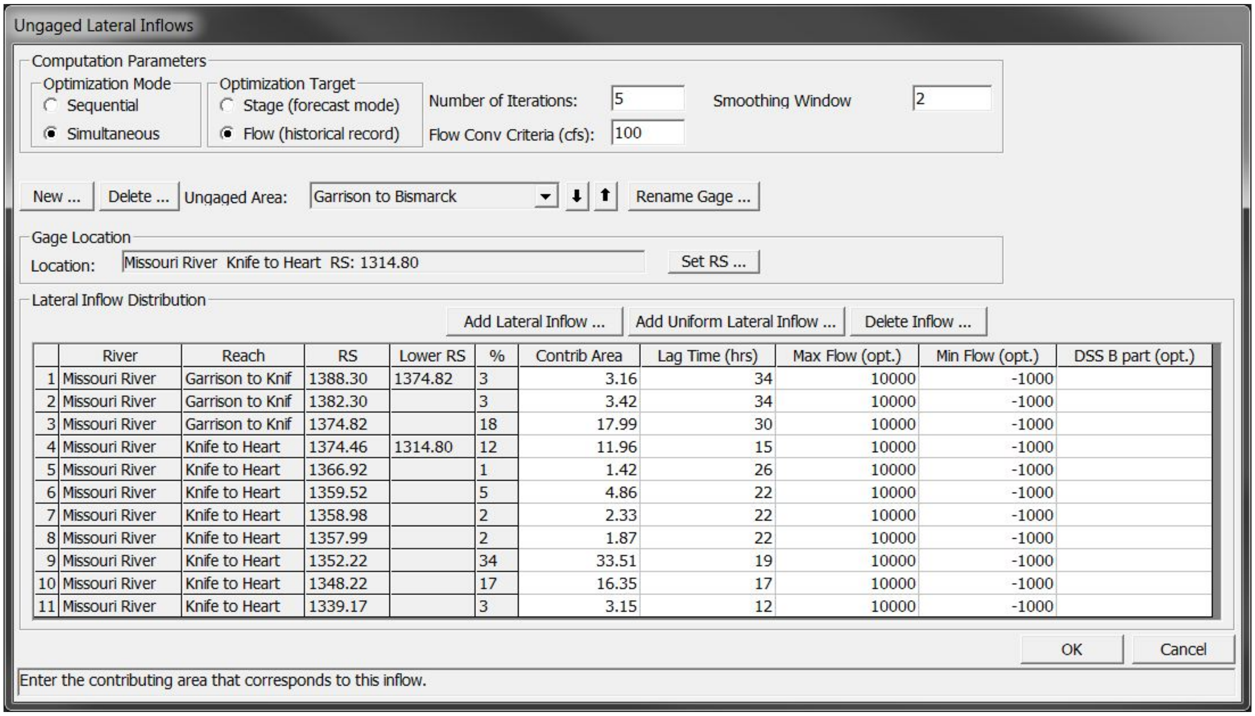


Figure 7-2: Ungaged Inflow Wolf Point to Culbertson

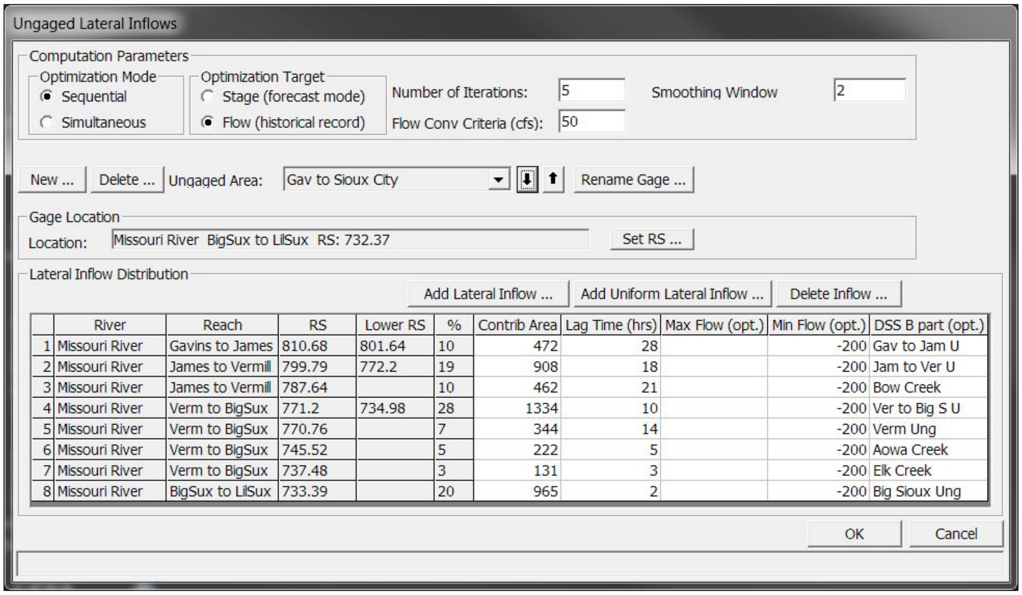


	River	Reach	RS	Lower RS	%	Contrib Area	Lag Time (hrs)	Max Flow (opt.)	Min Flow (opt.)	DSS B part (opt.)
1	Missouri River	Garrison to Knif	1388.30	1374.82	3	3.16	34	10000	-1000	
2	Missouri River	Garrison to Knif	1382.30		3	3.42	34	10000	-1000	
3	Missouri River	Garrison to Knif	1374.82		18	17.99	30	10000	-1000	
4	Missouri River	Knife to Heart	1374.46	1314.80	12	11.96	15	10000	-1000	
5	Missouri River	Knife to Heart	1366.92		1	1.42	26	10000	-1000	
6	Missouri River	Knife to Heart	1359.52		5	4.86	22	10000	-1000	
7	Missouri River	Knife to Heart	1358.98		2	2.33	22	10000	-1000	
8	Missouri River	Knife to Heart	1357.99		2	1.87	22	10000	-1000	
9	Missouri River	Knife to Heart	1352.22		34	33.51	19	10000	-1000	
10	Missouri River	Knife to Heart	1348.22		17	16.35	17	10000	-1000	
11	Missouri River	Knife to Heart	1339.17		3	3.15	12	10000	-1000	

Figure 7-3: Ungaged Inflow Garrison to Bismarck

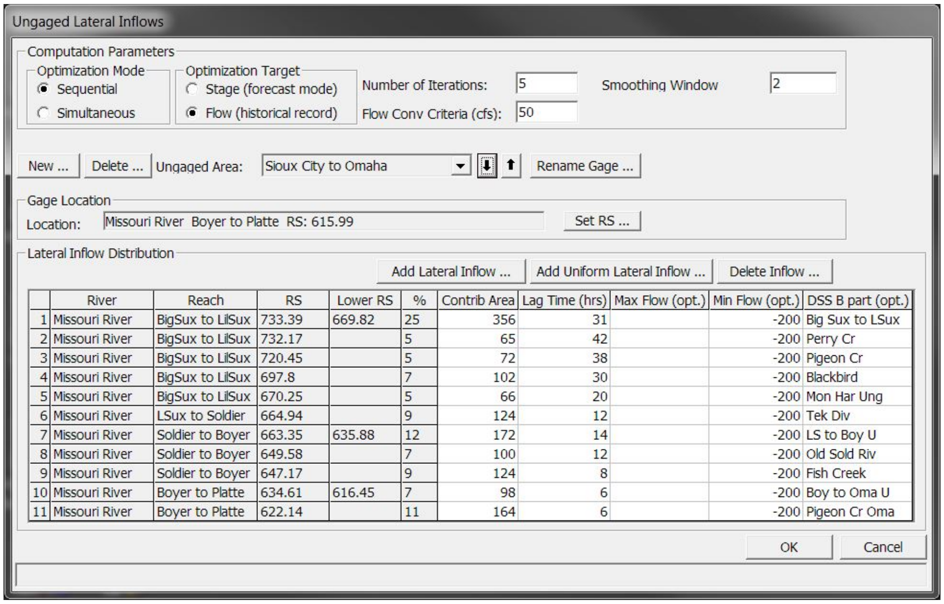
7.2.2 Gavins to Rulo

Ungaged inflows were calculated for the Gavins Point to Rulo RAS model using the RAS computation method. Input parameters for each of the ungaged routing reaches are shown in Figure 7-4 through Figure 7-7.



	River	Reach	RS	Lower RS	%	Contrib Area	Lag Time (hrs)	Max Flow (opt.)	Min Flow (opt.)	DSS B part (opt.)
1	Missouri River	Gavins to James	810.68	801.64	10	472	28		-200	Gav to Jam U
2	Missouri River	James to Vermil	799.79	772.2	19	908	18		-200	Jam to Ver U
3	Missouri River	James to Vermil	787.64		10	462	21		-200	Bow Creek
4	Missouri River	Verm to BigSux	771.2	734.98	28	1334	10		-200	Ver to Big S U
5	Missouri River	Verm to BigSux	770.76		7	344	14		-200	Verm Ung
6	Missouri River	Verm to BigSux	745.52		5	222	5		-200	Aowa Creek
7	Missouri River	Verm to BigSux	737.48		3	131	3		-200	Elk Creek
8	Missouri River	BigSux to LilSux	733.39		20	965	2		-200	Big Sioux Ung

Figure 7-4: Ungaged Inflow Gavins Point to Sioux City



Ungaged Lateral Inflows

Computation Parameters

Optimization Mode: (•) Sequential ( ) Simultaneous

Optimization Target: ( ) Stage (forecast mode) (•) Flow (historical record)

Number of Iterations: 5

Flow Conv Criteria (cfs): 50

Smoothing Window: 2

New ... | Delete ... | Ungaged Area: Sioux City to Omaha | Rename Gage ...

Gage Location

Location: Missouri River Boyer to Platte RS: 615.99 | Set RS ...

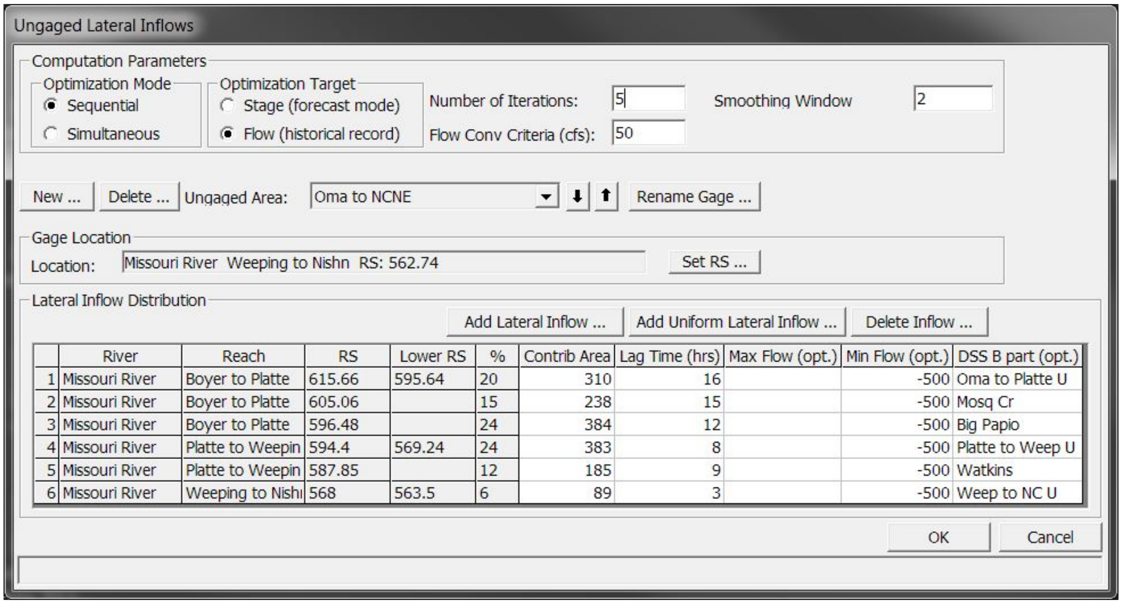
Lateral Inflow Distribution

Add Lateral Inflow ... | Add Uniform Lateral Inflow ... | Delete Inflow ...

	River	Reach	RS	Lower RS	%	Contrib Area	Lag Time (hrs)	Max Flow (opt.)	Min Flow (opt.)	DSS B part (opt.)
1	Missouri River	BigSux to LilSux	733.39	669.82	25	356	31		-200	Big Sux to LSux
2	Missouri River	BigSux to LilSux	732.17		5	65	42		-200	Perry Cr
3	Missouri River	BigSux to LilSux	720.45		5	72	38		-200	Pigeon Cr
4	Missouri River	BigSux to LilSux	697.8		7	102	30		-200	Blackbird
5	Missouri River	BigSux to LilSux	670.25		5	66	20		-200	Mon Har Ung
6	Missouri River	LSux to Soldier	664.94		9	124	12		-200	Tek Div
7	Missouri River	Soldier to Boyer	663.35	635.88	12	172	14		-200	LS to Boy U
8	Missouri River	Soldier to Boyer	649.58		7	100	12		-200	Old Sold Riv
9	Missouri River	Soldier to Boyer	647.17		9	124	8		-200	Fish Creek
10	Missouri River	Boyer to Platte	634.61	616.45	7	98	6		-200	Boy to Oma U
11	Missouri River	Boyer to Platte	622.14		11	164	6		-200	Pigeon Cr Oma

OK | Cancel

Figure 7-5: Ungaged Inflow Sioux City to Omaha



Ungaged Lateral Inflows

Computation Parameters

Optimization Mode: (•) Sequential ( ) Simultaneous

Optimization Target: ( ) Stage (forecast mode) (•) Flow (historical record)

Number of Iterations: 5

Flow Conv Criteria (cfs): 50

Smoothing Window: 2

New ... | Delete ... | Ungaged Area: Oma to NCNE | Rename Gage ...

Gage Location

Location: Missouri River Weeping to Nishn RS: 562.74 | Set RS ...

Lateral Inflow Distribution

Add Lateral Inflow ... | Add Uniform Lateral Inflow ... | Delete Inflow ...

	River	Reach	RS	Lower RS	%	Contrib Area	Lag Time (hrs)	Max Flow (opt.)	Min Flow (opt.)	DSS B part (opt.)
1	Missouri River	Boyer to Platte	615.66	595.64	20	310	16		-500	Oma to Platte U
2	Missouri River	Boyer to Platte	605.06		15	238	15		-500	Mosq Cr
3	Missouri River	Boyer to Platte	596.48		24	384	12		-500	Big Papio
4	Missouri River	Platte to Weepin	594.4	569.24	24	383	8		-500	Platte to Weep U
5	Missouri River	Platte to Weepin	587.85		12	185	9		-500	Watkins
6	Missouri River	Weeping to Nishi	568	563.5	6	89	3		-500	Weep to NC U

OK | Cancel

Figure 7-6: Ungaged Inflow Omaha to Nebraska City

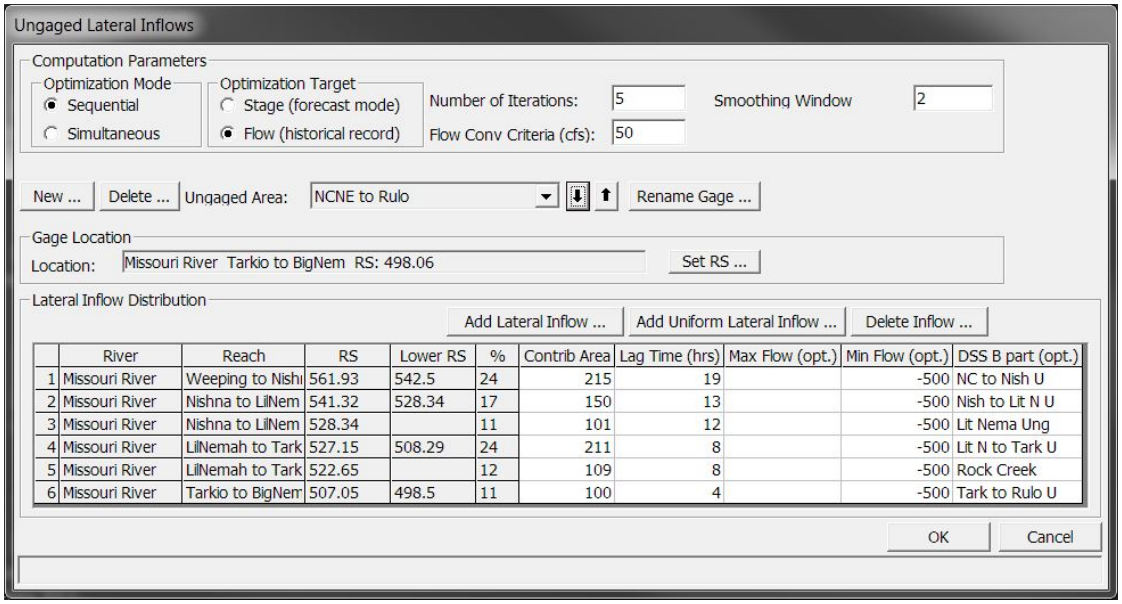


Figure 7-7: Ungaged Inflow Nebraska City to Rulo

7.2.3 Rulo to the Mouth

A simplified ungaged methodology was developed during model calibration, prior to period of record simulations. Several different approaches were explored, and the selected methodology was the best overall match to four parameters: 1) total flow volume, 2) winter low flows, 3) annual peak flows at USGS gages, and 4) observed flow duration curves. The selected methodology was applied to the calibration time window, and then duplicated using the POR dataset. There are two components to the ungaged estimation. First, in RAS, the tributary flow inputs were scaled by the ratio of the area of the drainage basin at the tributary gage to the area of the drainage basin at the confluence of the Missouri. This could be thought of as a way to account for ungaged inflow that enters tributary downstream of the gaging station. Second, a monthly uniform lateral inflow was added on a reach by reach basis. This could be thought of as a way to account for the contribution from groundwater of base flow as it was higher during wet months and zero or negative during dry months or drought years. The uniform lateral inflow dataset was created by calculating monthly average flow for all mainstem and tributary gages used in the model. The model extents were broken into reaches, bounded by two mainstem Missouri River USGS flow gages. In HEC-DSS, time series math functions were used to find the difference between the downstream gage and the upstream gage plus tributaries, essentially the monthly average missing flow in that reach. The resulting dataset was added into the model as a uniform lateral inflow. Overall, this method tended to overestimate total flow volume when compared to observed flows during the calibration period. To compensate, uniform lateral inflows were scaled down with a multiplier in RAS to calibrate better to flow volume at the mainstem gages. Table 7-6 summarizes the selected ungaged reaches bounded by mainstem USGS gages, uniform lateral inflow locations in RAS, the applied multiplier, and major tributaries in that reach.

Table 7-6. Ungaged Inflow Rulo to Mouth

Name of Reach (Part F in DSS)	Evenly Distributed Uniform Lateral Inflow Location	Multiplier	Tributaries
NECITY - RULO	527.55 - 507.90 (Little Nemaha - Tarkio)	0.25	Nishnabotna - Little Nemaha - Tarkio
RULO - STJOE	494.19 - 463.98 (Big Nemaha - Nodaway)	0.75	Big Nemaha - Nodaway
STJOE - KC	448.15 - 391.92 (St. Joseph - Platte)	0.5	Platte - Kansas
KC - WAV	366.06 - 293.22 (Kansas City - Waverly)	0.85	Blue - Little Blue - Crooked
WAV - BOON	238.52 - 202.97 (Chariton - Lamine)	0.4	Wakenda - Grand - Charition - Blackwater - Lamine
BOON - HERM	129.29 - 105.21 (Osage - Gasconade)	0.1	Moniteau - Petite Saline - Hinkson - Moreau - Osage - Maries - Gasconade

8 POR ADJUSTMENT

Input data from 1898-2012 were initially developed for modeling at sites within NWO and along the Missouri River mainstem. After inspection of the data, it was clear that flow records prior to 1960 were not as reliable, and the period prior to 1930 was almost unusable at some locations. For a more reliable data set throughout the entire basin, it was determined that the POR used for alternative analysis simulation modeling be limited to the period from January 1, 1930 to December 31, 2012. Prior to January 1930, the only data sources available in many locations throughout the basin were the DRM or UMRSFFS. The accuracy of these two data sources is somewhat questionable prior to 1930 (when USGS discharge gages were online in most locations). Most locations were stage gages maintained by the US Weather Bureau prior to 1930 and the data had to be converted using approximate stage-discharge rating curves, which could explain the vast difference in discharges between the pre- and post-1930 records. Calculated local flows prior to 1930 often included large and persistent negative flows, which caused problems for making release decisions using the ResSim software and scripts. Even applying smoothing techniques described in previous sections proved insufficient. An example of the problematic (unsmoothed) negative flows is shown in the following figure.

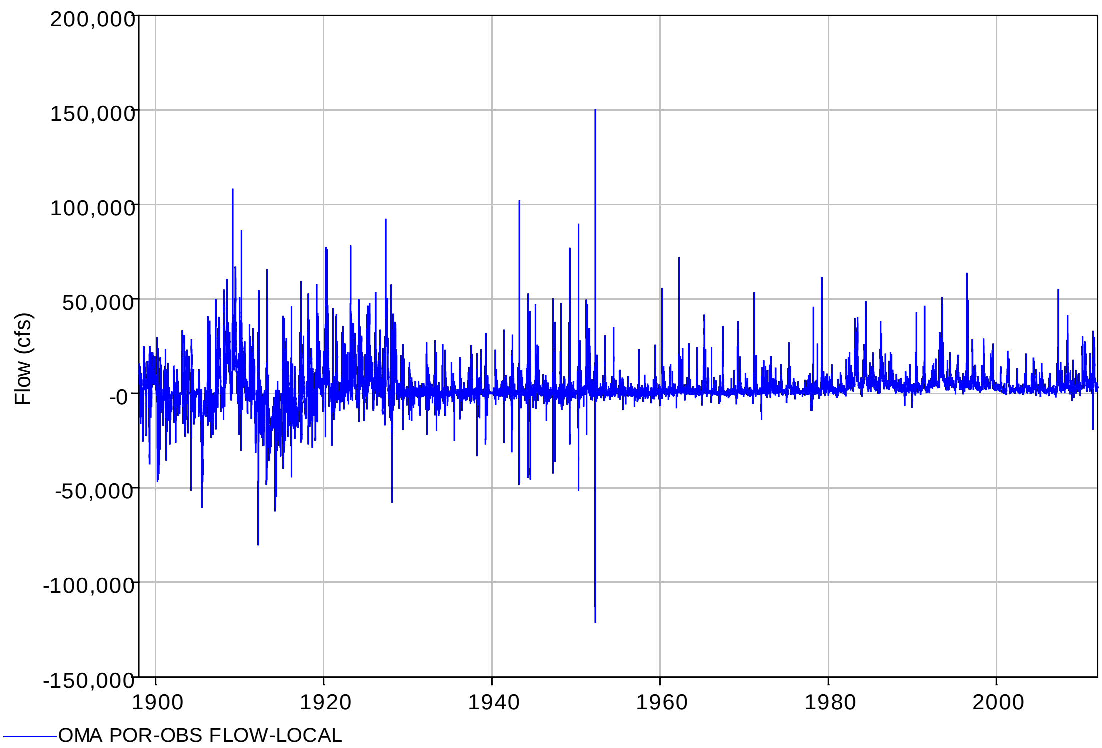


Figure 8-1: Local Flows at OMA (Omaha, unsmoothed).

The larger the negative local flow discharges are, the more difficult it is for the Mainstem Missouri ResSim scripts to handle and accurately model historic conditions. If the ResSim scripts cannot adequately model the pre-1930 conditions, the inaccurate results would impact subsequent years in the model and could compound the error of the model. Because the data prior to 1930 was erratic, it was excluded from extended POR modeling for the Mainstem Missouri ResSim model.

Obtaining reliable data on tributary gages prior to 1930 also proved challenging. The NWO data was compiled using synthetic methods and is available, but is not recommended for use. A review of the UMRSFFS mainstem and tributary gage extensions and the historic data available for new tributary gage extensions showed that uncertainty in the gage extensions significantly increases for records prior to 1927-30, particularly in the NWK tributary basins. As part of the UMRSFFS study, attempts were made to extend gage data along the Kansas and Osage tributaries back to 1898, but the lack of reliable data resulted in a decision at that time to limit the extended datasets to 1930-34, depending on the location. As part of this study, NWK attempted to develop flow data along the Kansas, Osage, and Chariton rivers prior to 1930 using rainfall-runoff relationships, but again the effort did not result in usable results. The additional value of including these earlier gage extensions in the H&H analysis did not appear to be sufficient to counterbalance the increased uncertainty that would be added to the results. Although the gage records for many sites were extended back further where the historical gage records for correlation sites were available, only the values for January 1930 through December 2012 are included in the current MRRMP-EIS ResSim and RAS analyses. If a longer POR including the data prior to 1930 is absolutely necessary, the NWO data is available and could be used. When comparing the effects of different alternatives, useful information could possibly be gained by using the longer POR, regardless of how historically accurate the pre-1930 results are.

9 REFERENCES

Hirsch, R.M. (1982). *A Comparison of Four Streamflow Record Extension Techniques.* Water Resources Research.

Hydrologic Engineering Center. (2007). *HEC-ResSim Reservoir System Simulation User's Manual.* Davis, CA: U.S. Army Corps of Engineers.

National Weather Service. (1982). *NOAA Technical Report NWS 34 - Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States.* Washington, D.C.: National Weather Service.

U.S. Army Corps of Engineers. (2004). *Upper Mississippi River System Flow Frequency Study.* Omaha, NE: U.S. Army Corps of Enginers.

U.S. Army Corps of Engineers. (2014). *Missouri River Recovery Modeling - Upper Missouri Reservoirs.* Omaha, NE: U.S. Army Corps of Engineers.

10 APPENDIX A – MAINSTEM MISSOURI RIVER ROUTING PARAMETER DETERMINATION SUMMARY

To determine routing parameters for use in the HEC-ResSim model more quickly, a HEC-HMS routing model was setup to test four different routing methods, and an HEC-ResSim model was used to test the Coefficient Routing Method. HEC-DSSVue has limited routing capabilities and was not used to route flows. All three HEC hydrologic modeling software programs have different available routing methods. Table 1 below is a summary of the routing methods available in each program.

Table A-1. Routing Methods in Hydrologic HEC Programs

HEC-ResSim	HEC-HMS	HEC-DSSVue
Coefficient Routing	N/A	N/A
N/A	Kinematic Wave	N/A
N/A	Lag	N/A
Modified Puls	Modified Puls	Modified Puls
Muskingum	Muskingum	Muskingum
Muskingum-Cunge 8-pt	Muskingum-Cunge 8-pt	N/A
SSARR	N/A	N/A
N/A	Straddle-Stagger	Straddle-Stagger
Working R&D	N/A	N/A
Variable Lag & K	N/A	N/A

The Coefficient routing parameters from the USACE Daily Routing Model (DRM) were used to help determine initial routing parameters for some of the methods. The Coefficient routing parameters in the DRM were based on statistical discharge correlations from 1/1/1967 to 12/31/1994. The routing parameters from the DRM are shown in Table 2 on the following page. The A0 value, or intercept, is zero for all reaches in the DRM because that model already included local flow and only translation was necessary. A1 through A4 are coefficients, and must add to 1 for each reach. A1 is the coefficient to be applied to today's (d) flow. A2 is the coefficient to be applied to yesterday's (d-1) flow, or the flow lagged by 1 day. A3 is the coefficient to be applied to the flow from 2 days ago (d-2), or the flow lagged by 2 days. Since HMS does not have Coefficient routing or any comparable method, the old DRM Coefficient routing parameters were tested using HEC-ResSim.

Table A-2. DRM Coefficient Routing Parameters

Reach	A0	A1 (d)	A2 (d-1)	A3 (d-2)	A4 (d-3)
FTPK_GARR	0	0.237	0.444	0.319	0
GARR_OAHE	0	0.057	0.503	0.44	0
OAHE_BEND	0	0.766	0.234	0	0
BEND_FTRA	0	0.647	0.353	0	0
FTRA_GAPT	0	0.005	0.637	0.358	0
GAPT_SUX	0	0.17532	0.53734	0.28734	0
SUX_OMA	0	0.16794	0.72176	0.1103	0
OMA_NCNE	0	0.5879	0.4121	0	0
NCNE_RUNE	0	0.58837	0.41163	0	0
RUNE_STJ	0	0.77547	0.22453	0	0
STJ_MKC	0	0.42647	0.44863	0.1249	0
MKC_WVMO	0	0.47605	0.52395	0	0
WVMO_BNMO	0	0.3542	0.61748	0.02832	0
BNMO_HEMO	0	0.38146	0.43382	0.18472	0
HEMO_STL	0	0.22208	0.77792	0	0
FTPK_WPMT	0	0.10283	0.65925	0.23792	0
WPMT_CLMT	0	0.18943	0.55198	0.25858	0
CLMT_WSN	0	0.0847	0.41119	0.50411	0
GARR_BIS	0	0.05704	0.50308	0.43988	0

The four routing methods tested in HMS were Straddle-Stagger, Muskingum, Muskingum-Cunge, and Modified Puls. Each method was calibrated based on major events during the period of record (POR). The POR was January 1, 1898 to October 1, 2011. For each reach during calibration, the two major event years of 1952 and 2011 were examined. At least two other major peak years noticed in each reach comparable to those events were also examined. After calibrating the routing parameters, the four methods were compared to each other and the observed POR. Priority was given to the more recent events during calibration and routing method comparison, since the final model will require routing parameters that are representative of current conditions.

Straddle-Stagger is a progressive average-lag routing method in which equal weight is applied to each day's flow for the straddle duration. For the Straddle-Stagger method, the initial lag (Stagger) was determined by the day with the highest coefficient from the DRM routing method for each reach. For example: The A1 (d) column for the RUNE-STJ reach had the highest coefficient for that reach, so a zero day lag was used initially for that reach. The initial duration (Straddle) was determined by the equation:

$$\text{Straddle} = \text{Stagger} + 1 \text{ day} \qquad (1)$$

The straddle value is the number of days that the flow is averaged over. For example, a 1-day stagger with a 1-day straddle would apply the total weight of 1.0 to the d-1 timestep. A 1-day stagger with a 2-day straddle applies equal weights of 0.5 to the d-1 and d-2 timesteps. A 1-day stagger with a 3-day straddle applies equal weights of 0.33 to the d, d-1, and d-2 timesteps. The lag and durations were varied for some reaches during calibration. The duration cannot be less than the lag. The Straddle-Stagger method in HMS has hourly input values. However, only whole day increments were used since the computation and data input time-step of the final ResSim model will be daily. The calibrated Straddle-Stagger routing parameters, along with the equivalent coefficient routing parameters, are shown in Table 3. The HMS basin schematic used for Straddle-Stagger routing is shown in Figure 1.

Table A-3. Calibrated Straddle-Stagger and Corresponding Coefficient Routing Parameters

Reach	Lag (day)	Duration (day)	A0	A1 (d)	A2 (d-1)	A3 (d-2)	A4 (d-3)
RBMT_FTPK	1	1	0	0	1	0	0
FTPK_WPMT	1	2	0	0	0.5	0.5	0
WPMT_CLMT	1	1	0	0	1	0	0
CLMT_GARR	1	2	0	0	0.5	0.5	0
GARR_BIS	1	2	0	0	0.5	0.5	0
BIS_OAHE	0	0	0	1	0	0	0
OAHE_BEND	0	0	0	1	0	0	0
BEND_FTRA	0	0	0	1	0	0	0
FTRA_GAPT	1	2	0	0	0.5	0.5	0
GAPT_SUX	1	2	0	0	0.5	0.5	0
SUX_OMA	1	2	0	0	0.5	0.5	0
OMA_NCNE	1	1	0	0	1	0	0
NCNE_RUNE	1	2	0	0	0.5	0.5	0
RUNE_STJ	0	0	0	1	0	0	0
STJ_MKC	1	2	0	0	0.5	0.5	0
MKC_WVMO	1	2	0	0	0.5	0.5	0
WVMO_BNMO	1	2	0	0	0.5	0.5	0
BNMO_HEMO	1	2	0	0	0.5	0.5	0
HEMO_MR-Mississippi	1	2	0	0	0.5	0.5	0

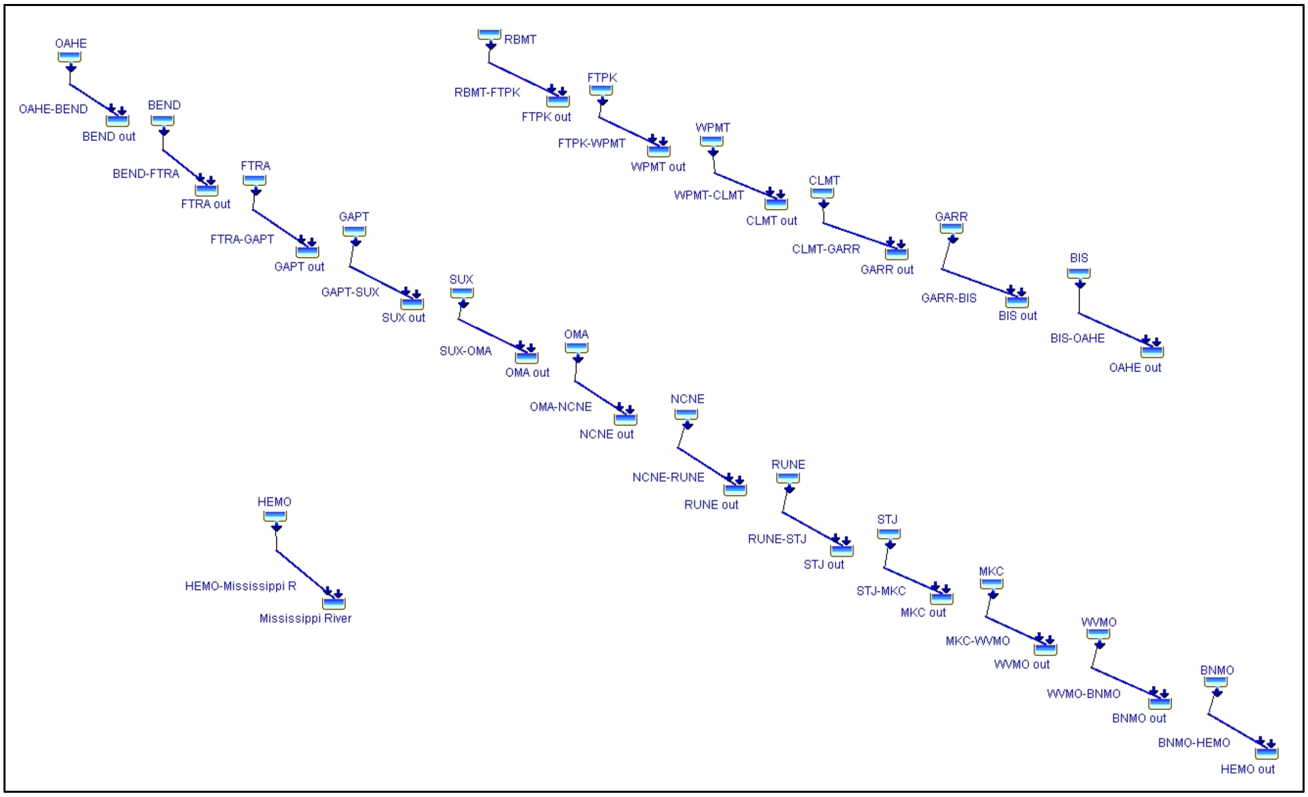


Figure A-1. Straddle-Stagger and Muskingum HMS Basin Schematic

For the Muskingum Routing method, the final calibrated lag values from the Straddle-Stagger method were used as the initial Lag (K) values. However, HMS does not allow Muskingum routing reaches with K values of zero. To force the model to compute, zeroes were replaced with lags of 1 day. With the exception of the zero lag routing reaches, the initial lag values used for the Muskingum routing reaches produced results that matched the timing of the observed events.

The number of steps, or subreaches, in the Muskingum Routing method is approximated by the equation:

$$\# \text{ Subreaches} = K/\Delta t \qquad (2)$$

Where K is the lag in days and Δt is the computation interval in days. Since the computation time-step that will be used in the final ResSim model is 1 day, and most reaches have a lag of 1 day, only 1 subreach is required.

The Muskingum Routing X parameter is a coefficient determined or verified during calibration. The value X can vary anywhere between zero and 0.5. According to the HMS Technical Manual, X is typically near zero for channels with mild slopes and lots of overbank flow. An X coefficient of zero produces hydrograph results that are considerably smoother and flatter than the Straddle-Stagger routing results. The X coefficient is typically near 0.5 for well-defined channels with steeper slopes and minimal out of bank flows. An X coefficient of 0.5 produces the most peaked hydrograph flows possible with the Muskingum routing method, and results similar to the Straddle-Stagger routing method. With these guidelines in mind, X values closer to 0.5 seem most logical for the Missouri River main channel. However, five different X values were tested on all reaches using the Muskingum routing method: 0.1, 0.2, 0.3, 0.4, and 0.5. These results were compared to the observed events during calibration. The final Muskingum Routing parameters selected are shown in Table 4. The HMS basin schematic for the Muskingum routing was the same as it was for the Straddle-Stagger routing (Figure 1). It should be noted that reaches most accurately modeled with a zero day lag cannot be modeled using Muskingum Routing, and are denoted in Table 4 with an "N/A." If Muskingum routing were selected as the final routing method, these reaches should be modeled in ResSim using null, or no, routing.

Table A-4. Calibrated Muskingum Routing Parameters

Reach	Muskingum Final		
	K (hr)	X	Subreaches
RBMT_FTPK	24	0.38	1
FTPK_WPMT	24	0.45	1
WPMT_CLMT	24	0.5	1
CLMT_GARR	24	0.28	1
GARR_BIS	24	0.3	1
BIS_OAHE	N/A	N/A	N/A
OAHE_BEND	N/A	N/A	N/A
BEND_FTRA	N/A	N/A	N/A
FTRA_GAPT	24	0.38	1
GAPT_SUX	24	0.38	1
SUX_OMA	24	0.3	1
OMA_NCNE	24	0.45	1
NCNE_RUNE	24	0.4	1
RUNE_STJ	N/A	N/A	N/A
STJ_MKC	24	0.4	1
MKC_WVMO	24	0.4	1
WVMO_BNMO	24	0.28	1
BNMO_HEMO	24	0.4	1
HEMO_MR-Mississippi	24	0.4	1

For the Muskingum-Cunge and Modified Puls Routing methods, only reaches downstream of Sioux City and upstream of Rulo were modeled. These routing methods require cross-sections, Manning's n values and storage-discharge curves, best obtained from existing calibrated HEC-RAS models. The Omaha District currently has RAS models for these reaches only.

For Muskingum-Cunge routing, the 8-point cross section was selected. Cross sections in the RAS model were much more complex and had to be reduced to 8-point cross sections while conserving the total flow area. Each hydraulic modeling reach in the RAS model also had many cross sections. One representative cross section had to be selected for each hydrologic modeling reach in the HMS model. This was done by calculating the average cross section flow area for each reach and selecting a cross section with the corresponding flow area that was not located in the immediate vicinity of a bridge/road. The average main channel, left overbank, and right overbank Manning's n values were determined from the cross-sections in each RAS reach. The lengths and slopes for each Muskingum-Cunge routing reach were also obtained from the RAS model. The Muskingum-Cunge routing parameters were not changed during calibration since the parameters from the RAS model had already been calibrated and the HMS results closely matched the observed events. The final Muskingum-Cunge routing parameters are shown in Table 5. The HMS basin schematic used for Muskingum-Cunge and Modified Puls routing is shown in Figure 2.

Table A-5. Muskingum-Cunge Routing Parameters

Reach	Length (ft)	Slope (ft/ft)	Manning's n	Left n	Right n
SUX_OMA	609363	0.000172	0.023	0.056	0.058
OMA_NCNE	276081	0.000171	0.025	0.065	0.059
NCNE_RUNE	339739	0.000206	0.025	0.055	0.058

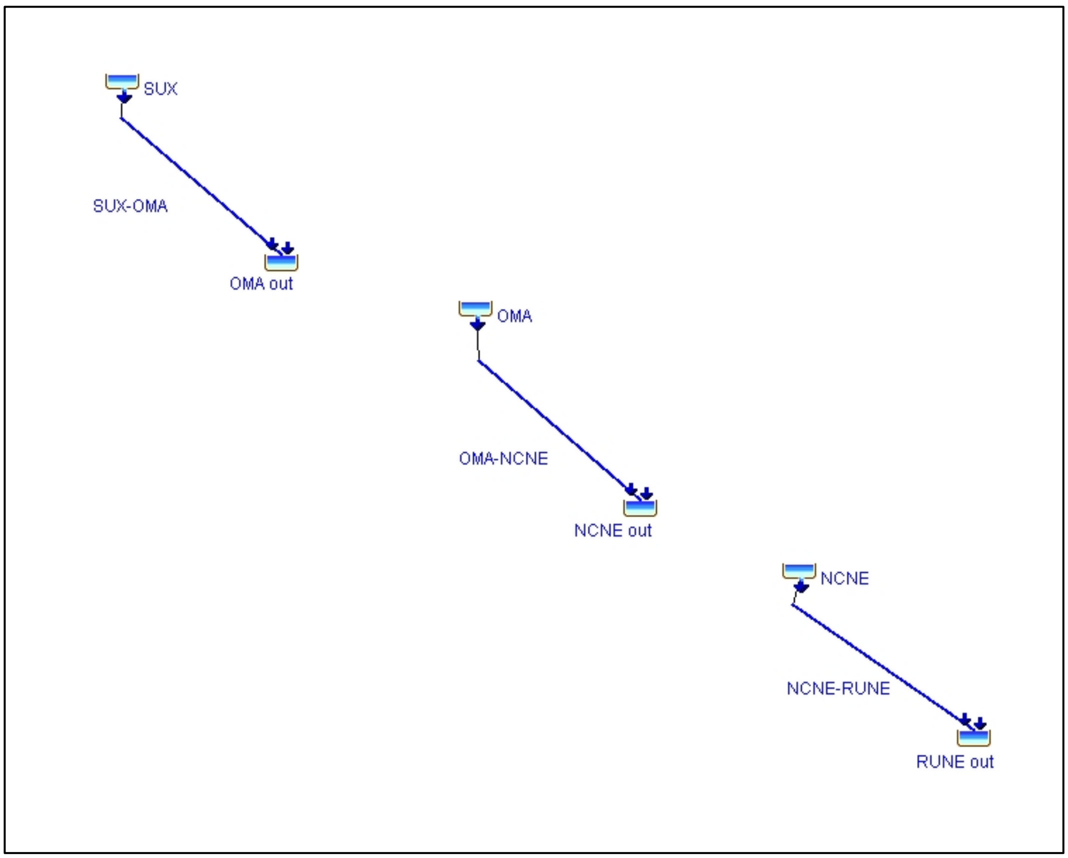


Figure A-2. Muskingum-Cunge and Modified Puls HMS Basin Schematic

The Modified Puls Routing method in HMS requires storage-discharge curves and the number of subreaches for each reach as input parameters. Storage-discharge curves from a calibrated RAS model had previously been used in an HMS model during 2011 flood forecasting. The reaches used in the 2011 flood forecasting HMS model were shorter and had to be combined for use in this HMS Routing model. The Sioux City to Decatur, Decatur to Blair, and Blair to Omaha storage-discharge curves were combined to create the SUX-OMA storage-discharge curve. The Omaha to Plattsmouth and Plattsmouth to Nebraska City storage-discharge curves were combined into the OMA-NCNE storage-discharge curve. The Nebraska City to Brownville and Brownville to Rulo storage-discharge curves were combined into the NCNE-RUNE storage-discharge curve. The number of subreaches in each reach was determined using the same procedure as the Muskingum Routing method, and had previously been determined to be one subreach for each of these three reaches. The storage-discharge curves were not modified during calibration, since the curves had been obtained from a calibrated RAS model. The storage-discharge curves are shown in Table 6.

Table A-6. Modified Puls Routing Storage-Discharge Curves

SUX-OMA		OMA-NCNE		NCNE-RUNE	
Storage (ac-ft)	Discharge (cfs)	Storage (ac-ft)	Discharge (cfs)	Storage (ac-ft)	Discharge (cfs)
0	0	0	0	0	0
167,208	50,000	70,843	50,000	121,963	50,000
211,082	60,000	80,652	60,000	182,006	60,000
276,447	70,000	92,197	70,000	272,336	70,000
368,533	80,000	107,949	80,000	362,845	80,000
490,166	90,000	128,270	90,000	450,979	90,000
647,438	100,000	151,478	100,000	535,653	100,000
843,532	110,000	176,494	110,000	617,771	110,000
1,061,784	120,000	198,216	120,000	662,627	120,000
1,289,901	130,000	218,697	130,000	706,682	130,000
1,544,669	140,000	237,981	140,000	758,253	140,000
1,806,854	150,000	258,650	150,000	800,555	150,000
2,091,718	160,000	278,438	160,000	838,997	160,000
2,382,440	170,000	300,742	170,000	887,171	170,000
2,696,430	180,000	319,279	180,000	924,584	180,000
2,995,799	190,000	337,718	190,000	965,073	190,000
3,277,063	200,000	354,551	200,000	1,002,559	200,000
3,491,316	210,000	372,652	210,000	1,037,098	210,000
3,675,907	220,000	388,961	220,000	1,069,014	220,000
3,823,026	230,000	404,992	230,000	1,101,622	230,000
3,966,847	240,000	420,696	240,000	1,135,661	240,000
4,094,193	250,000	436,594	250,000	1,168,479	250,000
4,214,866	260,000	452,352	260,000	1,202,194	260,000
4,322,512	270,000	467,764	270,000	1,236,466	270,000

Of the four routing methods tested using HMS, which did not include the coefficient method, the Straddle-Stagger Routing method was best. The Straddle-Stagger routing results closely approximated the timing of the observed events. The resulting peak flows did not always match the observed event peak flows, but this was mainly because the incremental local or ungaged flow between the upstream and downstream gages had not been factored into the model at this point. The Muskingum Routing results were very similar to the Straddle-Stagger Routing results, and also approximated the timing of the observed events fairly well. However, the Straddle-Stagger method produced better results in a couple locations. The Straddle-Stagger routing method is also less complicated and should be better understood by all users of the final model, since various sources and previous models have attempted to determine the lag or travel times between mainstem reservoirs and reaches. The Muskingum-Cunge Routing results approximated the observed events fairly well and were very similar to the Straddle-Stagger results also. However, the Straddle-Stagger results approximated some events more closely than the Muskingum-Cunge results. The Muskingum-Cunge results also had slightly delayed timing for some events compared to the observed data. The Modified Puls Routing results did not approximate the timing of the observed events as closely as the other routing methods. The hydrographs produced by this routing method were considerably flatter and delayed compared to the observed events. Comparison hydrograph results for the three reaches that tested all four routing methods are shown in the figures in Appendix B-1 for select events. The black dotted lines are the observed events (Flow-Observed), the blue lines are the Modified Puls routing (Mod Puls), the purple lines are the Muskingum-Cunge routing (Musk Cunge), the green lines are the Muskingum routing (Musk-Final), and the dashed red lines are the Straddle-Stagger routing (SS-Final).

A composite HMS routing model using the final Straddle-Stagger routing parameters was constructed to test the overall timing of the routing method. One continuous routing model could not be constructed due to the effect of reservoir routing at upstream locations. The timing of peaks for inflow hydrographs is often different than the timing of the peaks for outflow hydrographs at reservoirs. For this reason, the model was broken up at reservoir locations. The reach from GAPT to HEMO was also broken up at RUNE to better observe the timing effects of the routing parameters. When the GAPT outflow hydrograph is routed all the way to HEMO without any additional flow added between those locations, the difference in modeled and observed discharge is so great that it becomes difficult to locate and compare the timing of the peaks. For this reason, the observed RUNE flow was routed downstream to HEMO instead. After reviewing the results of the composite HMS routing model, none of the Straddle-Stagger Routing parameters were changed. The timing produced by the previously determined parameters was considered acceptable. The composite routing HMS basin schematic is shown in Figure 3. Appendix B-2 contains Straddle-Stagger routing result hydrographs versus observed hydrographs for the 2011 event for each reach. Results for the complete POR are stored in HEC-DSSVue and are best viewed there.

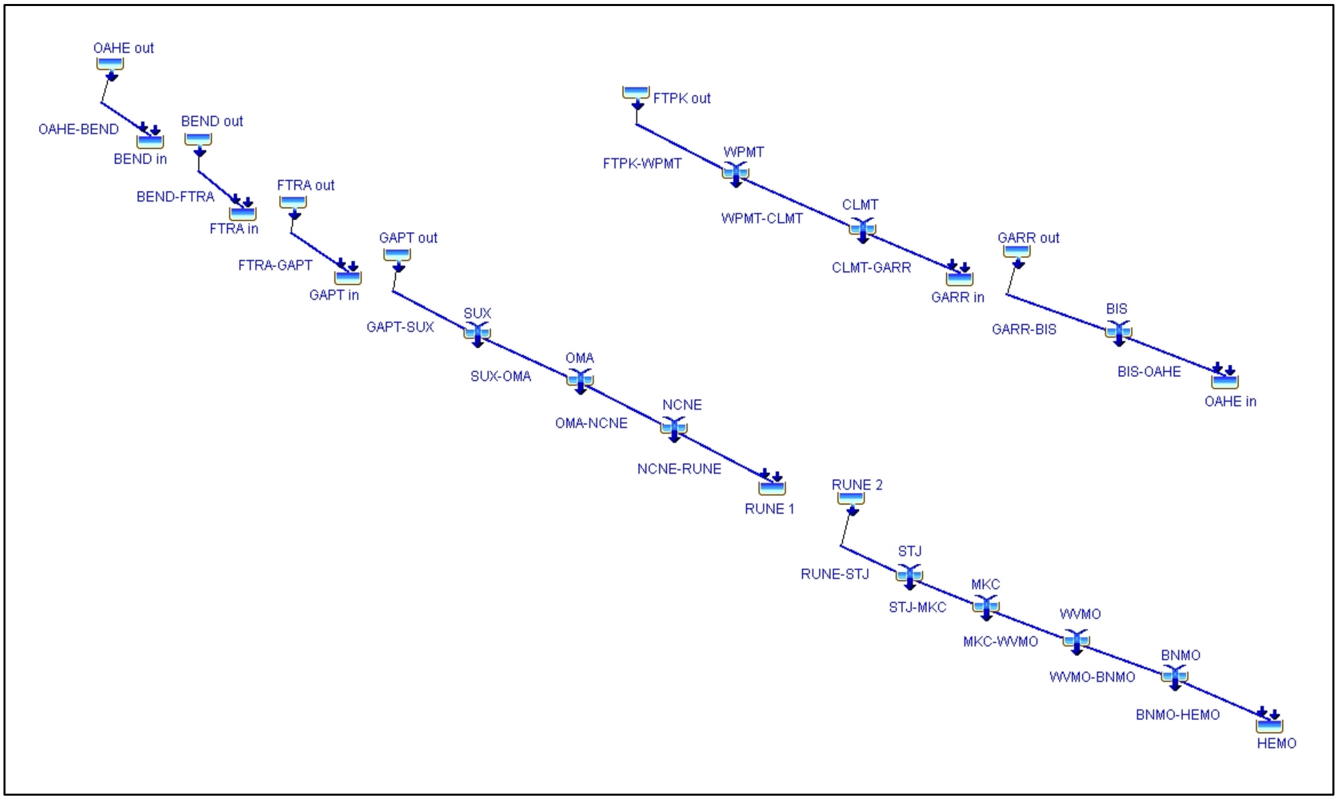


Figure A-3. Straddle-Stagger Composite Routing HMS Basin Schematic

A simplified routing model similar to the HMS model was constructed in ResSim to compare the DRM Coefficient routing parameters to the final Straddle-Stagger routing parameters. The structure of the ResSim model is identical to the structure of the HMS model shown in Figure 1. Four reaches that will be used in the final ResSim model do not have Coefficient routing parameters defined in the DRM: RBMT-FTPK, CLMT-GARR, and BIS-OAHE. These reaches use the final Straddle-Stagger routing parameters converted to the Coefficient routing method, and are identical to the Straddle-Stagger results in Appendix B-2. The Coefficient routing results compared to the Straddle-Stagger routing results and the observed discharges for all other reaches during the 2011 event are shown in Appendix B-3. Coefficient routing results are in blue, Straddle-Stagger routing results are in red, and the observed discharges are in black. After comparing the two methods, the Coefficient routing method was selected as the final method for use in the ResSim model. For the majority of the reaches, the Coefficient routing results and the Straddle-Stagger routing results are nearly identical. However, the timing of the Coefficient routing results is slightly better on a few reaches (NCNE-RUNE, STJ-MKC, and MKC-WVMO). The final routing parameters for use in the ResSim model are shown in Table 7.

Table A-7. Final Routing Parameters

Reach	A1 (d)	A2 (d-1)	A3 (d-2)
RBMT_FTPK	0	1	0
FTPK_WPMT	0.10283	0.65925	0.23792
WPMT_CLMT	0.18943	0.55198	0.25858
CLMT_GARR	0	0.5	0.5
GARR_BIS	0.05704	0.50308	0.43988
BIS_OAHE	1	0	0
OAHE_BEND	0.766	0.234	0
BEND_FTRA	0.647	0.353	0
FTRA_GAPT	0.005	0.637	0.358
GAPT_SUX	0.17532	0.53734	0.28734
SUX_OMA	0.16794	0.72176	0.1103
OMA_NCNE	0.5879	0.4121	0
NCNE_RUNE	0.58837	0.41163	0
RUNE_STJ	0.77547	0.22453	0
STJ_MKC	0.42647	0.44863	0.1249
MKC_WVMO	0.47605	0.52395	0
WVMO_BNMO	0.3542	0.61748	0.02832
BNMO_HEMO	0.38146	0.43382	0.18472
HEMO_MISL	0.22208	0.77792	0

Appendix B-1: Routing Method Comparisons

Figure B-1.1. SUX-OMA 2011 Event

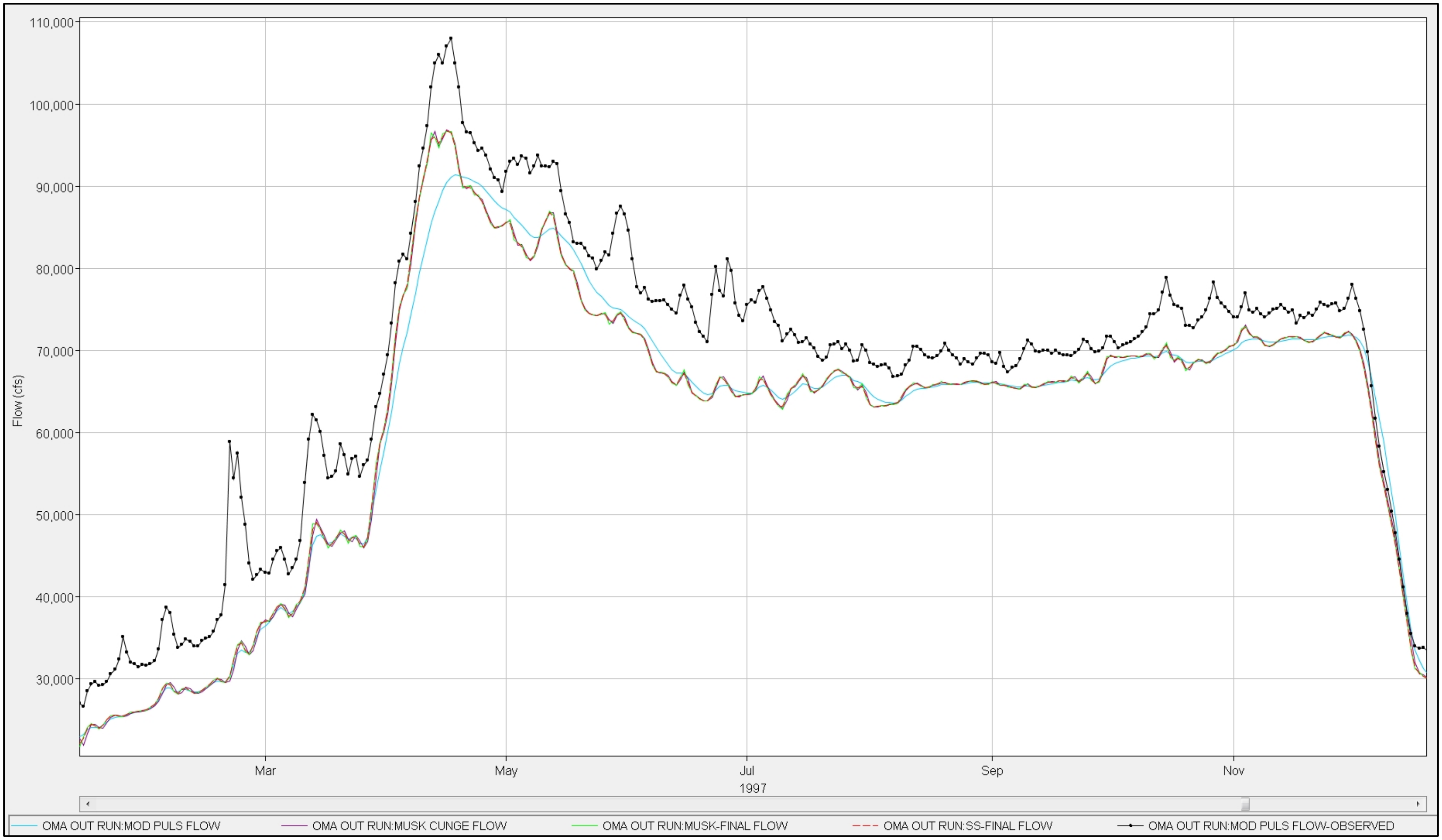


Figure B-1.2. SUX-OMA 1997 Event

Figure B-1.3. SUX-OMA 1993 Event

Figure B-1.4. OMA-NCNE 2011 Event

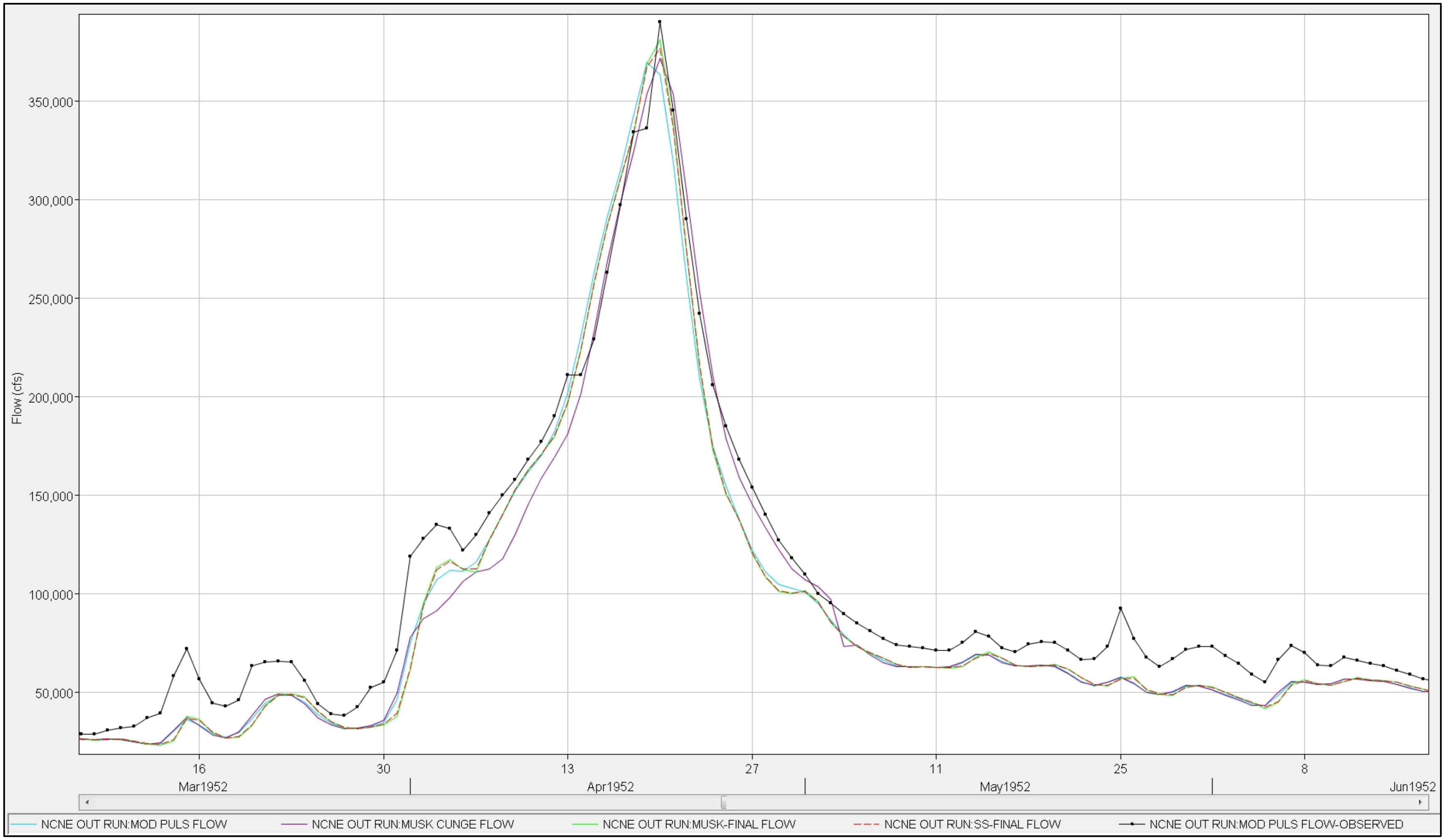


Figure B-1.5. OMA-NCNE 1952 Event

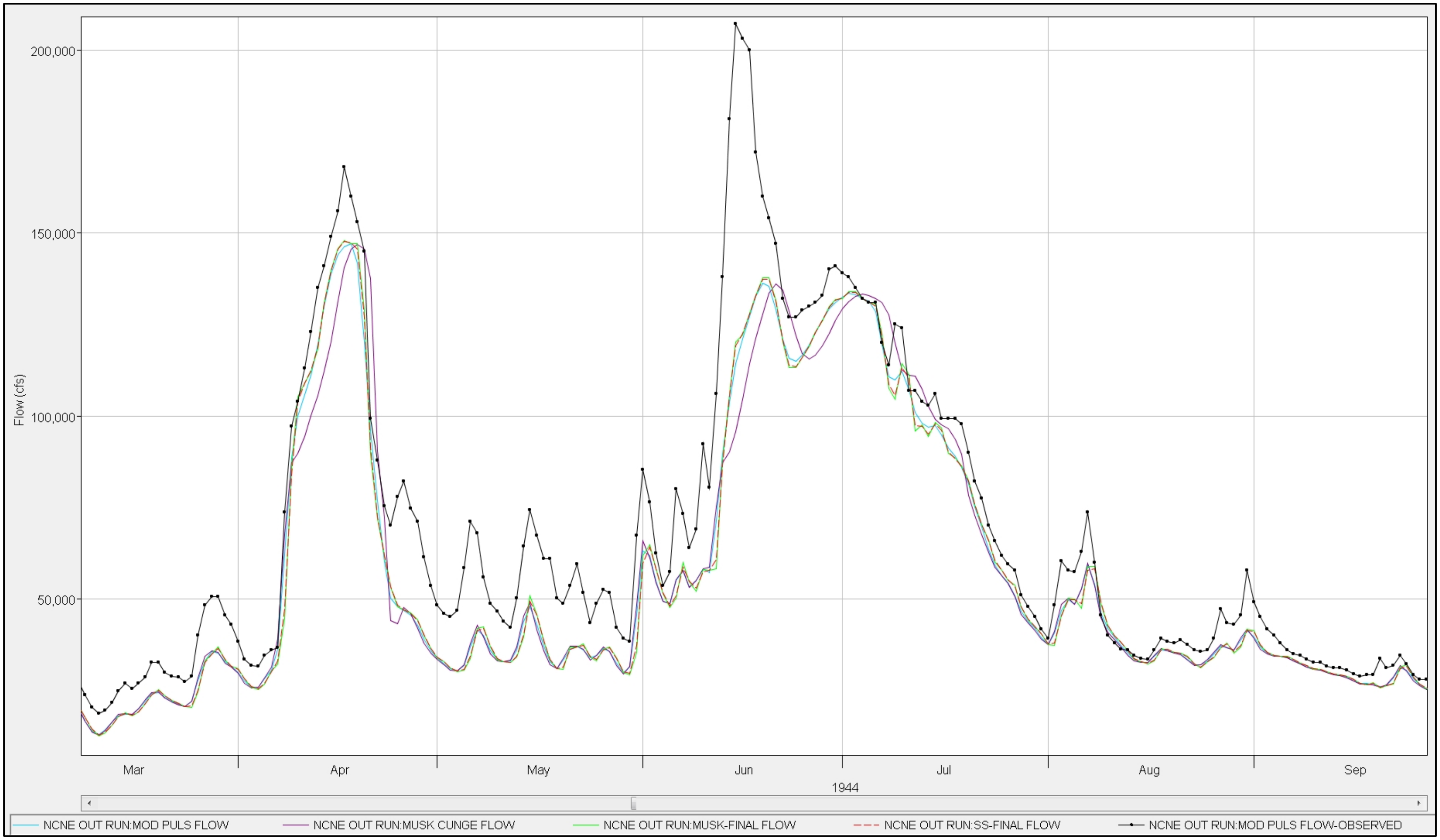


Figure B-1.6. OMA-NCNE 1944 Event

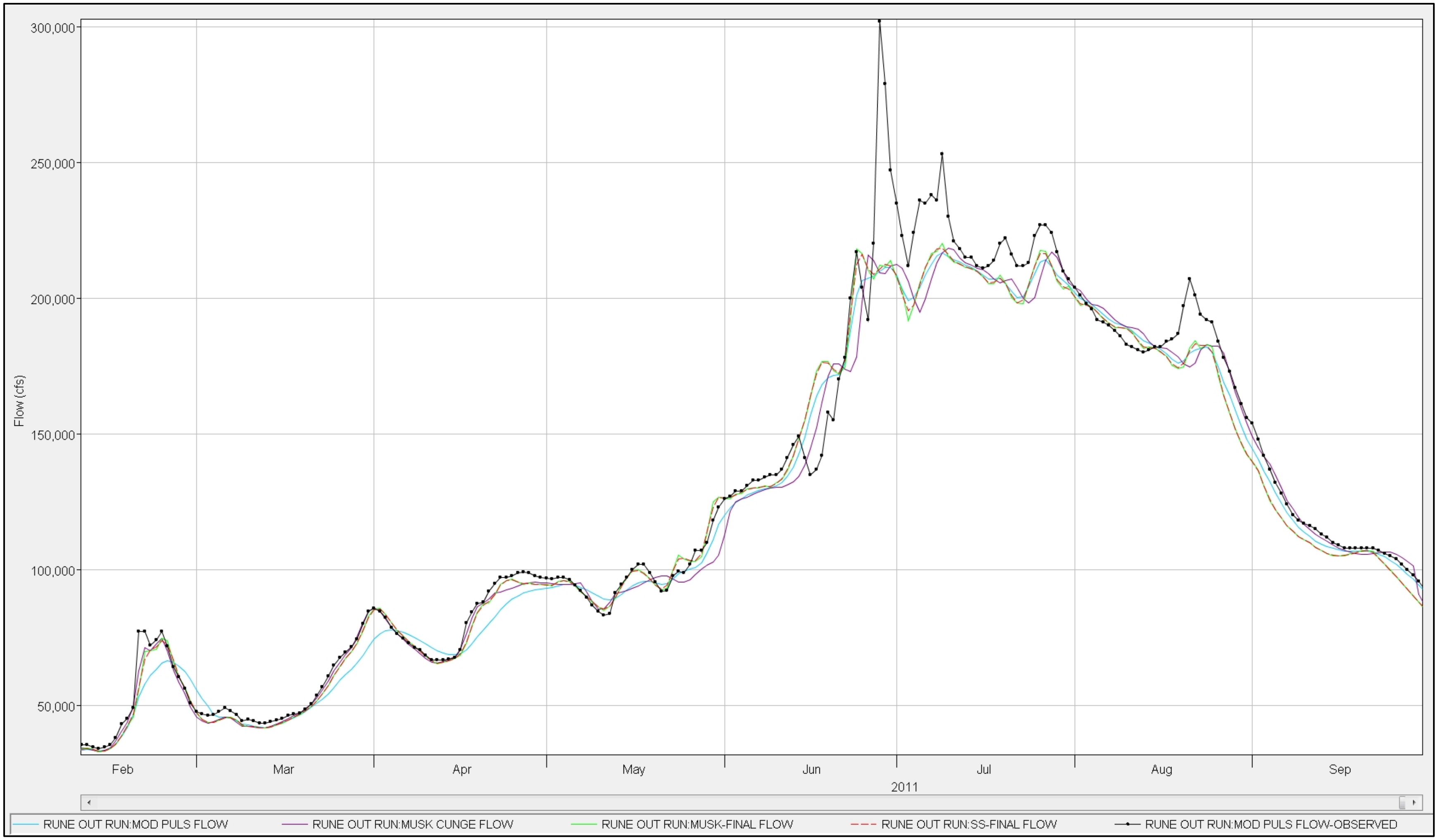


Figure B-1.7. NCNE-RUNE 2011 Event

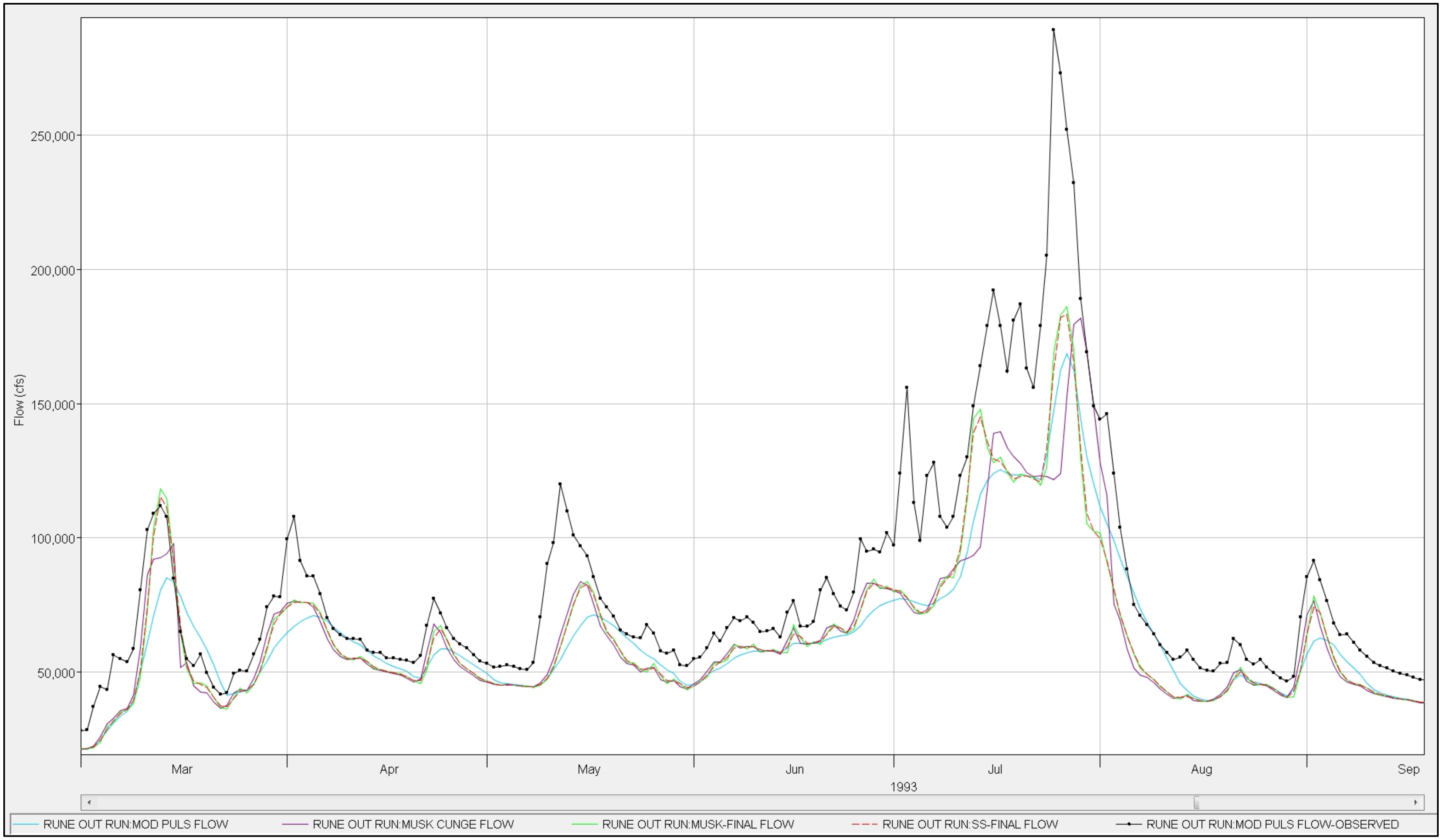


Figure B-1.8. NCNE-RUNE 1993

Figure B-1.9. NCNE-RUNE 1984 Event

Appendix B-2: Straddle-Stagger Routing Results

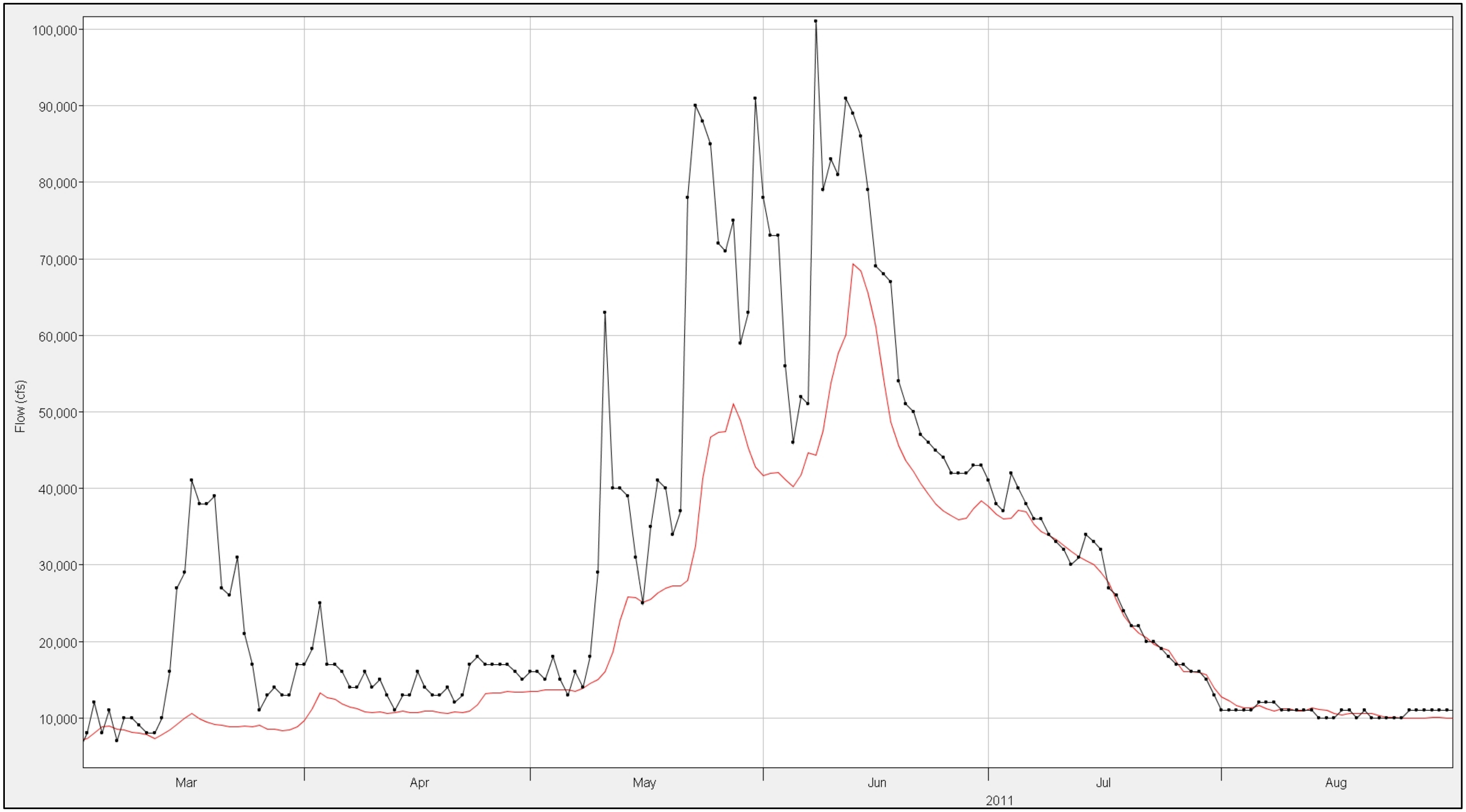


Figure B-2.1. RBMT-FTPK 2011

Figure B-2.2. FTPK-WPMT 2011

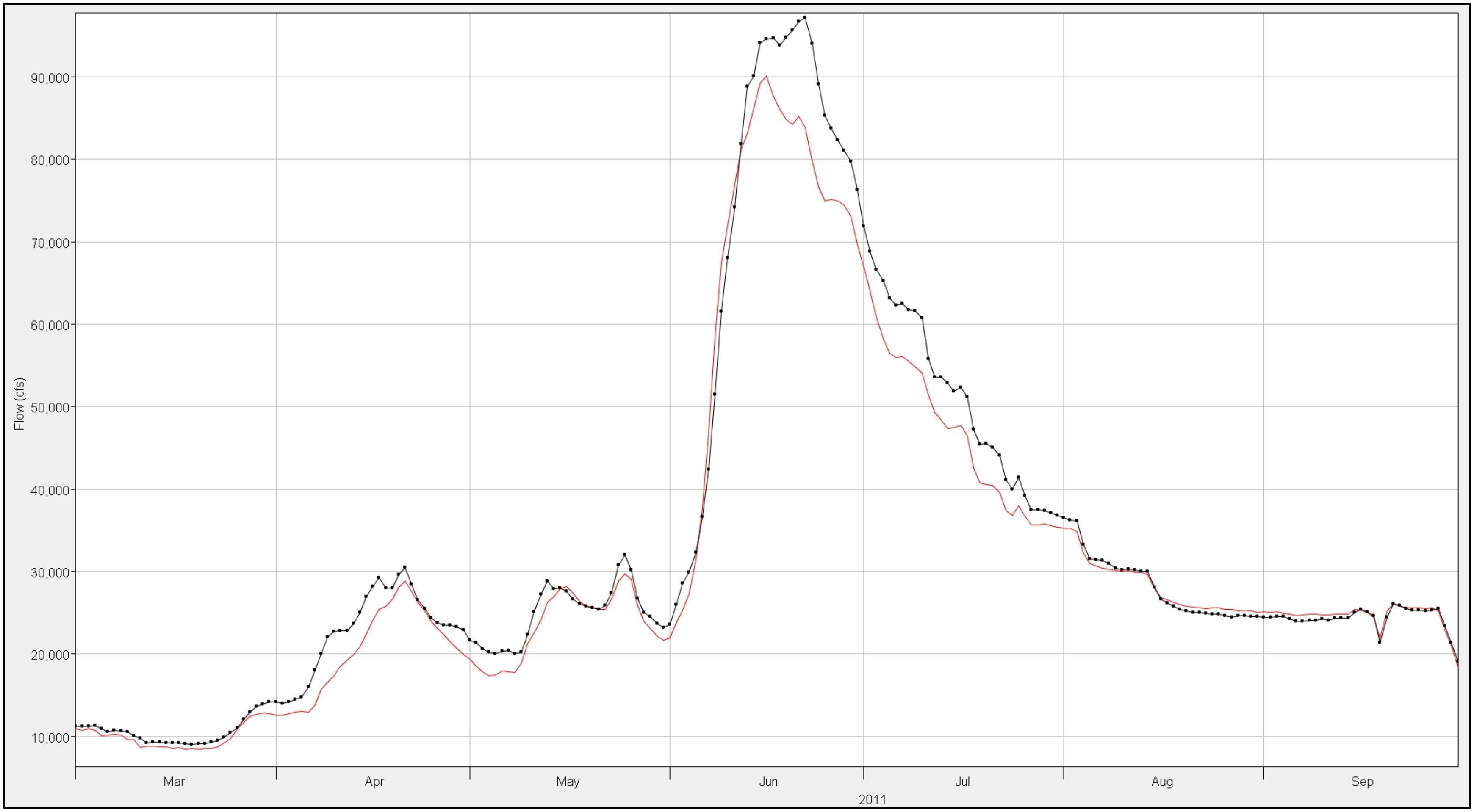


Figure B-2.3. WPMT-CLMT 2011

Figure B-2.4. CLMT-GARR 2011

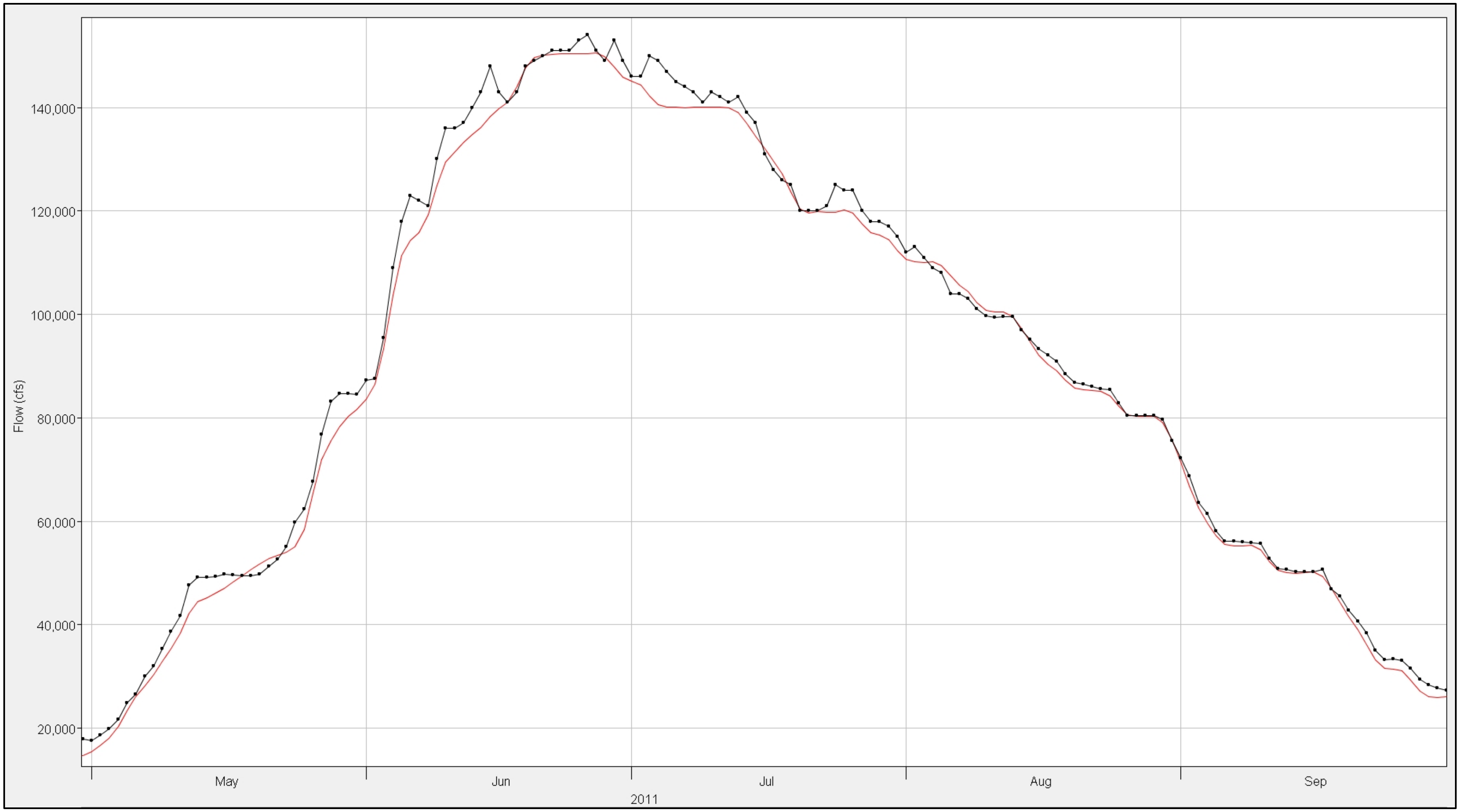


Figure B-2.5. GARR-BIS 2011

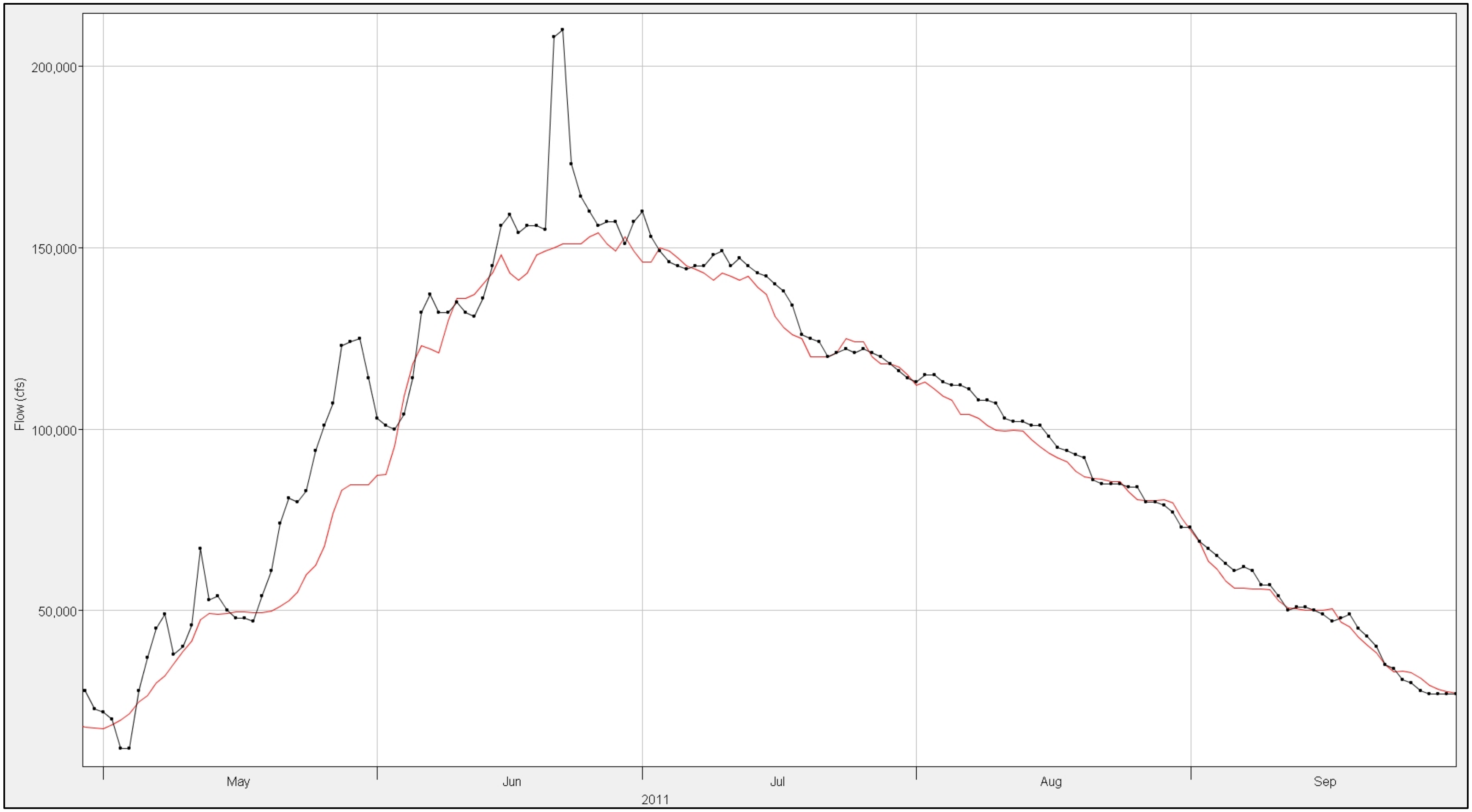


Figure B-2.6. BIS-OAHE 2011

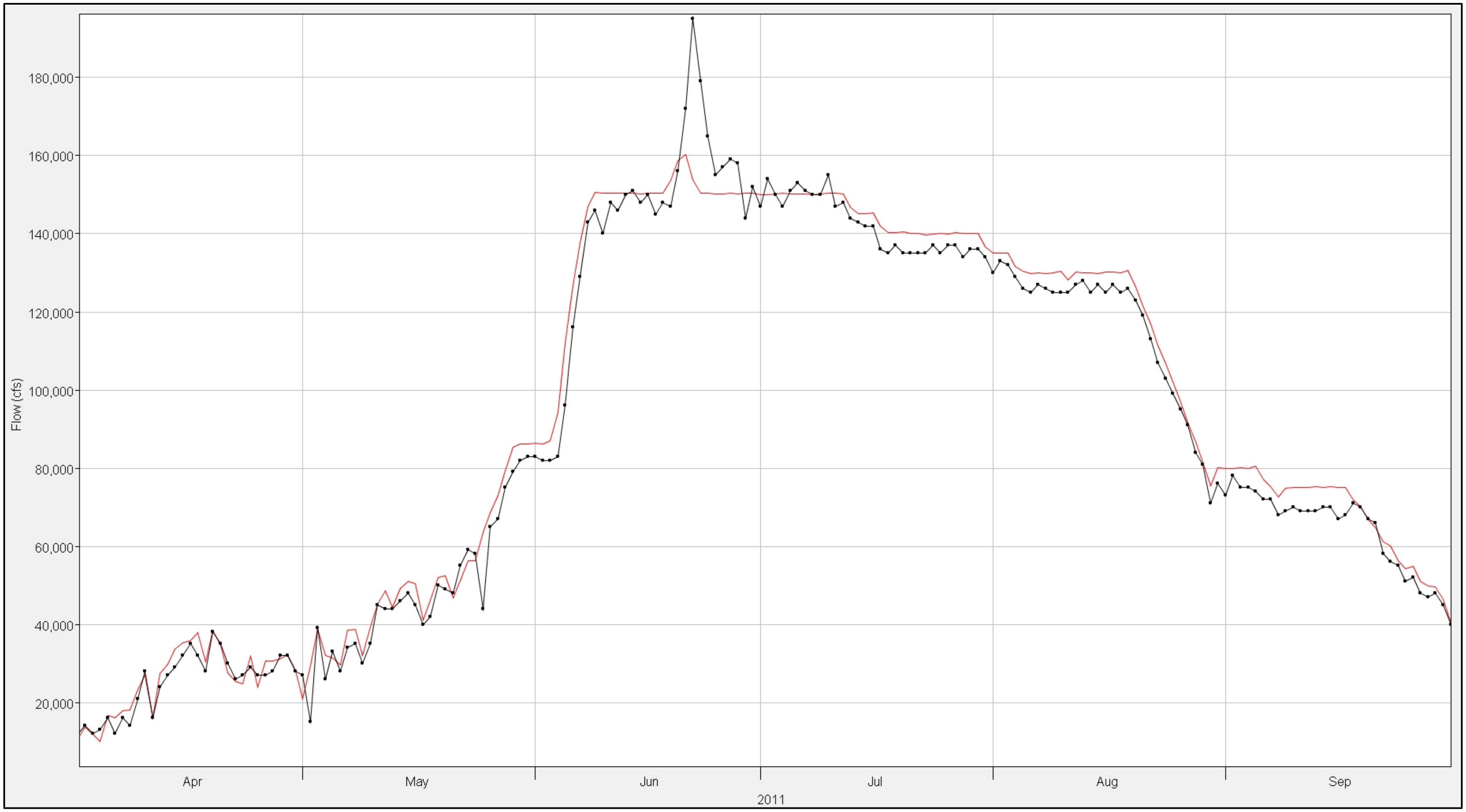


Figure B-2.7. OAHE-BEND 2011

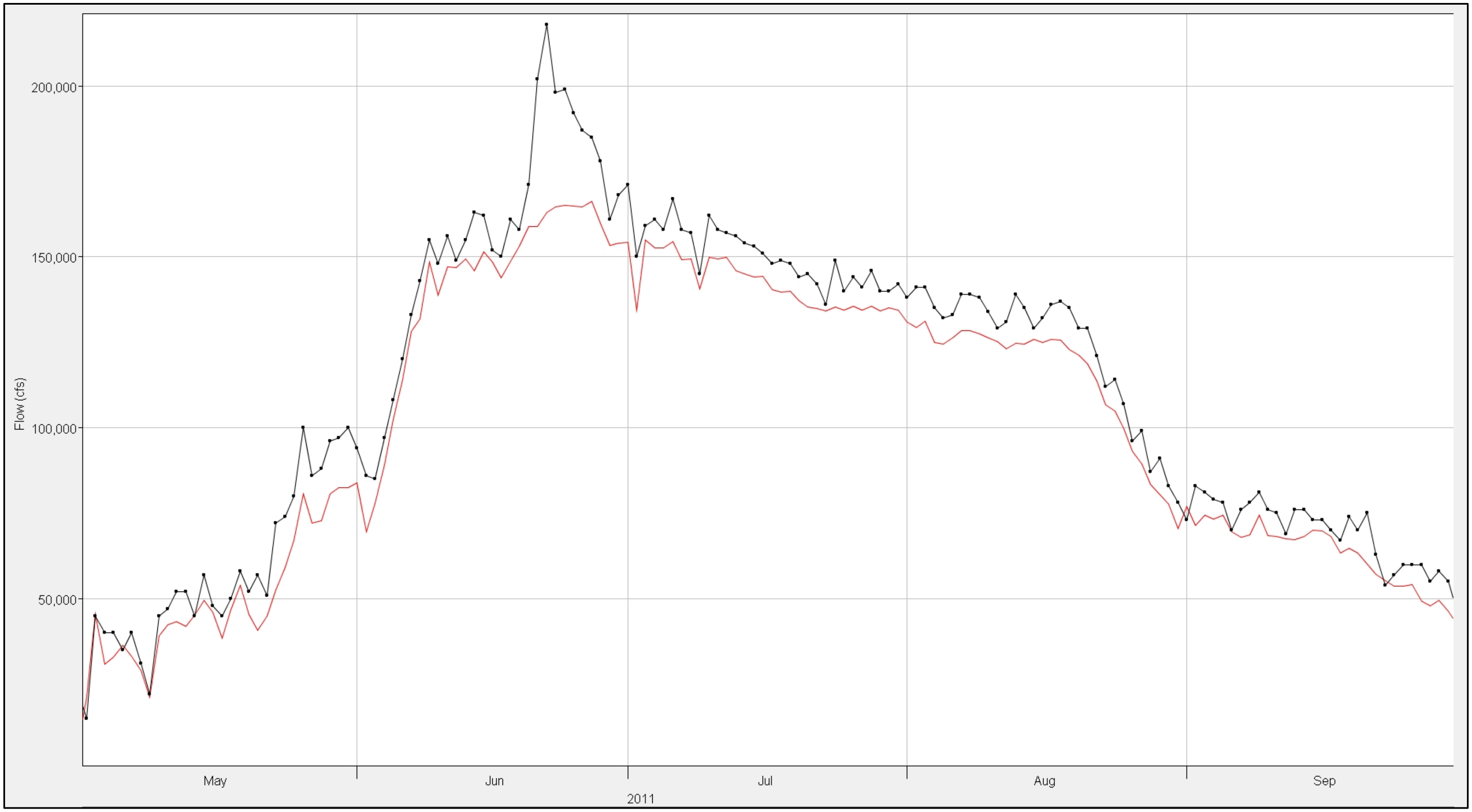


Figure B-2.8. BEND-FTRA 2011

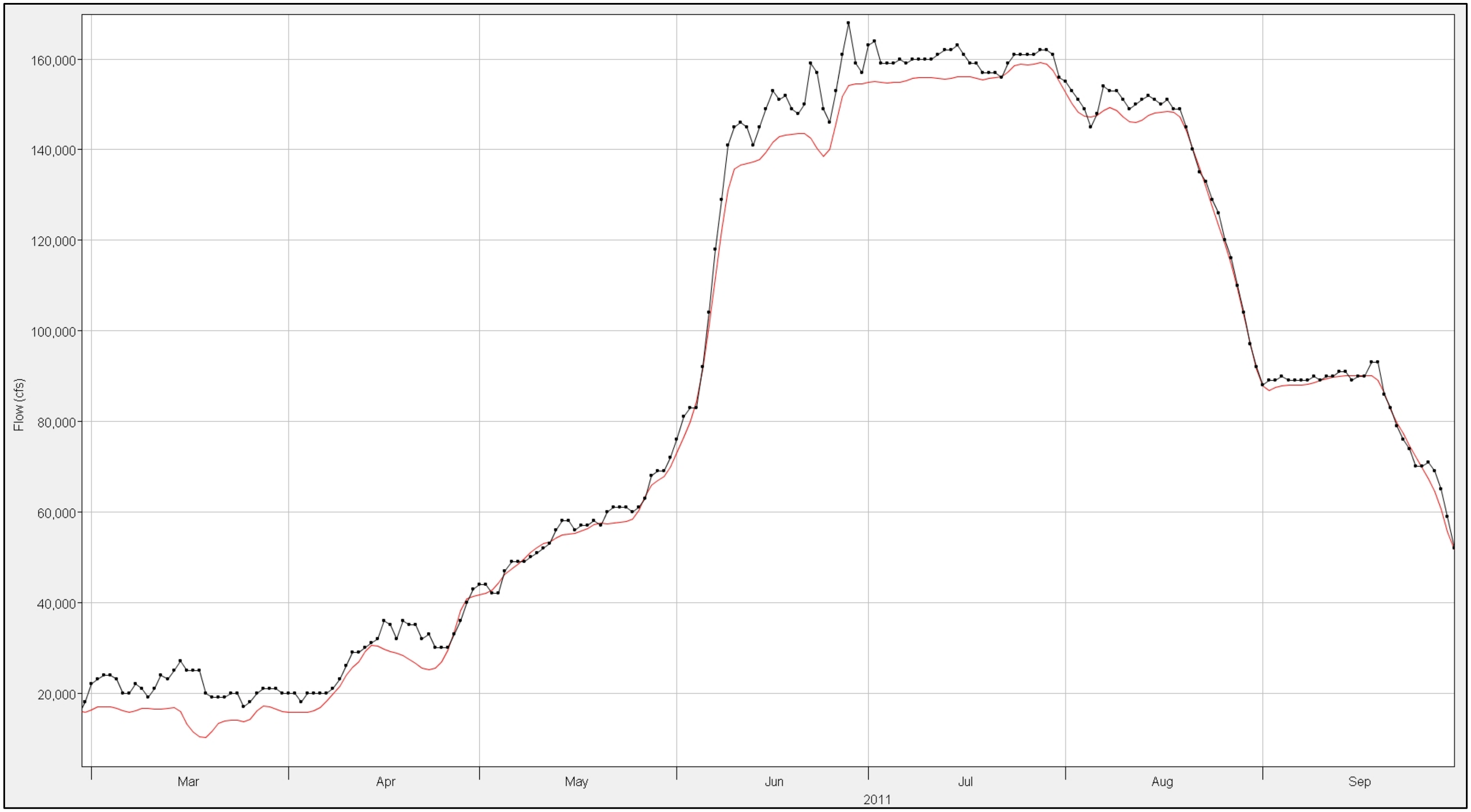


Figure B-2.9. FTRA-GAPT 2011

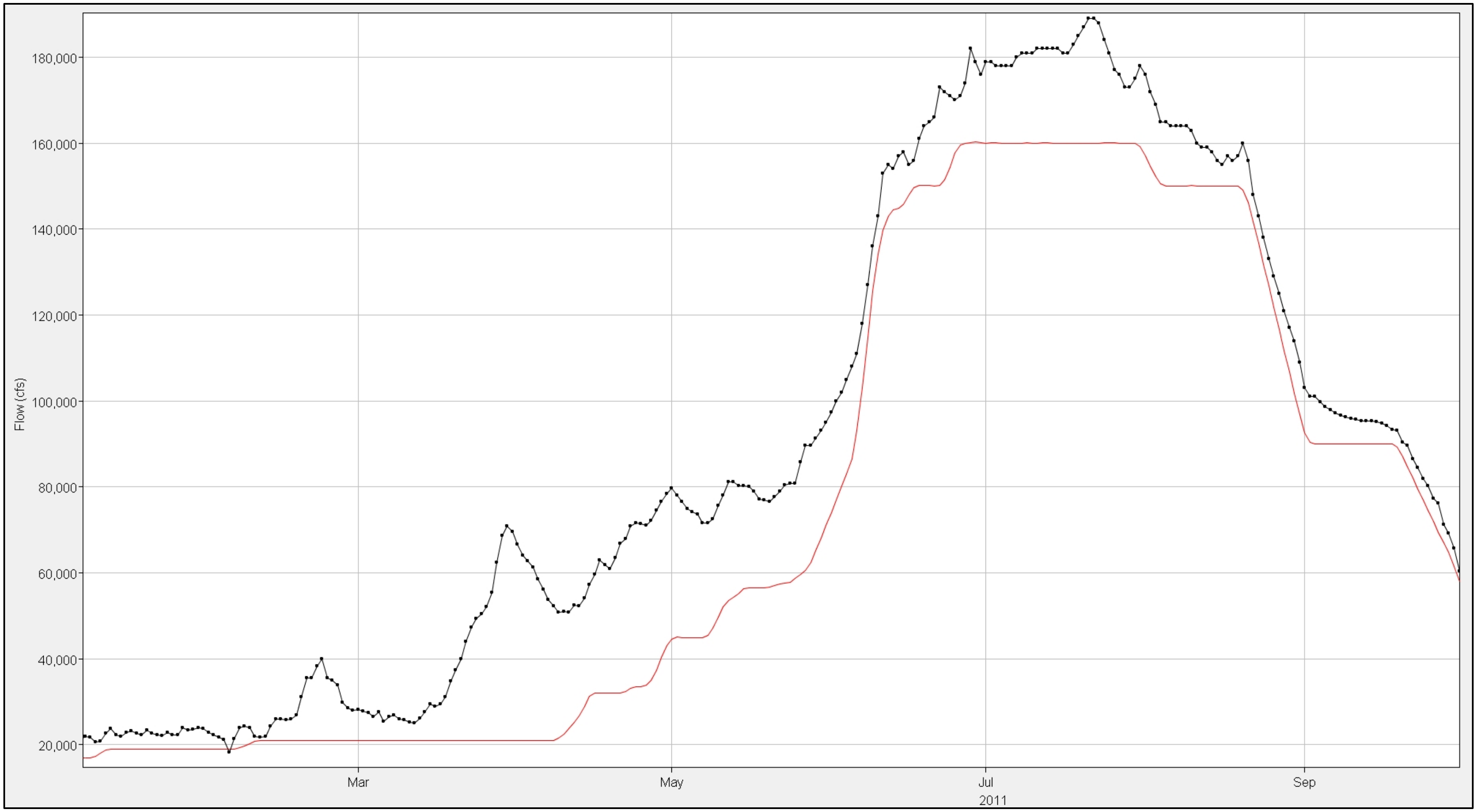


Figure B-2.10. GAPT-SUX 2011

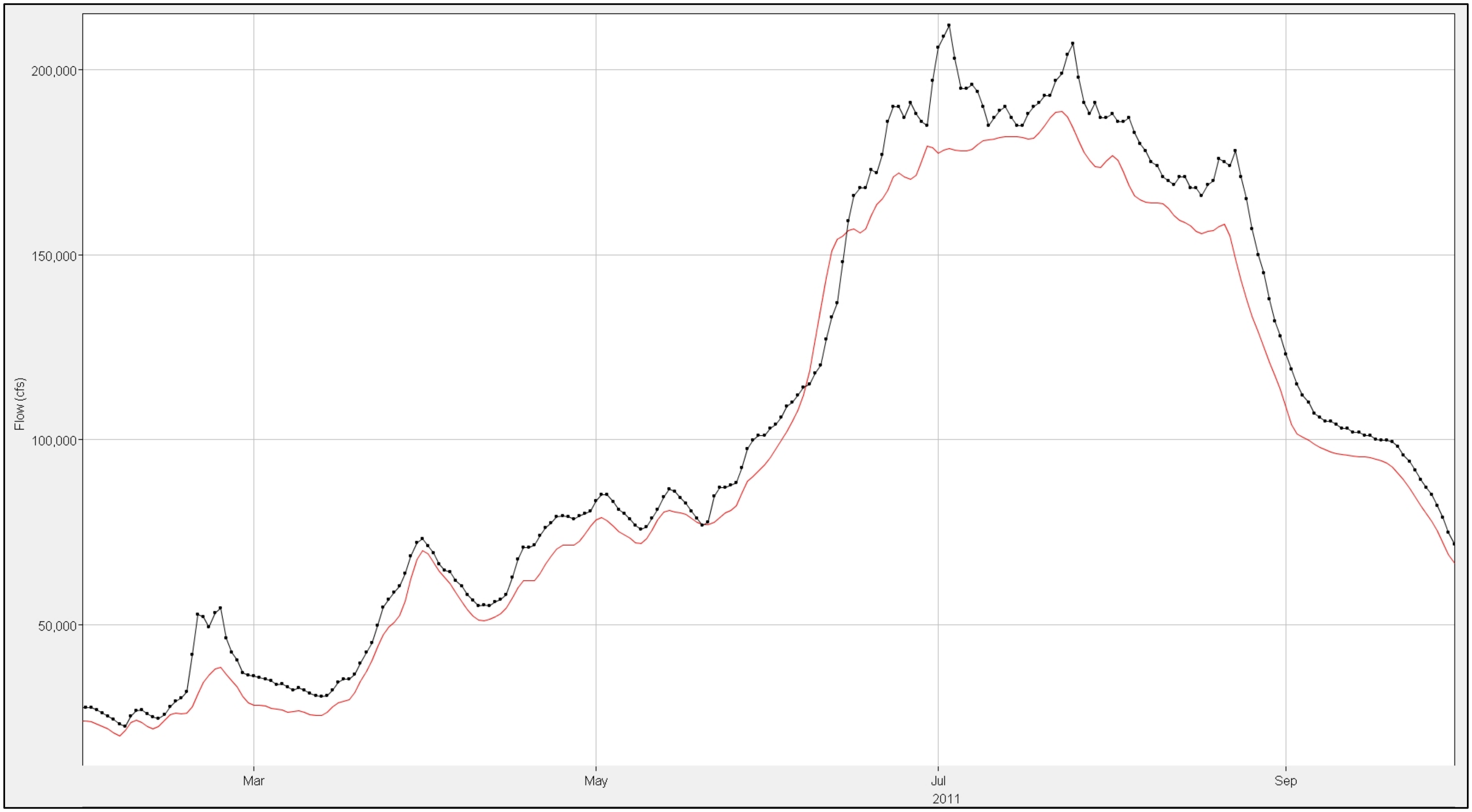


Figure B-2.11. SUX-OMA 2011

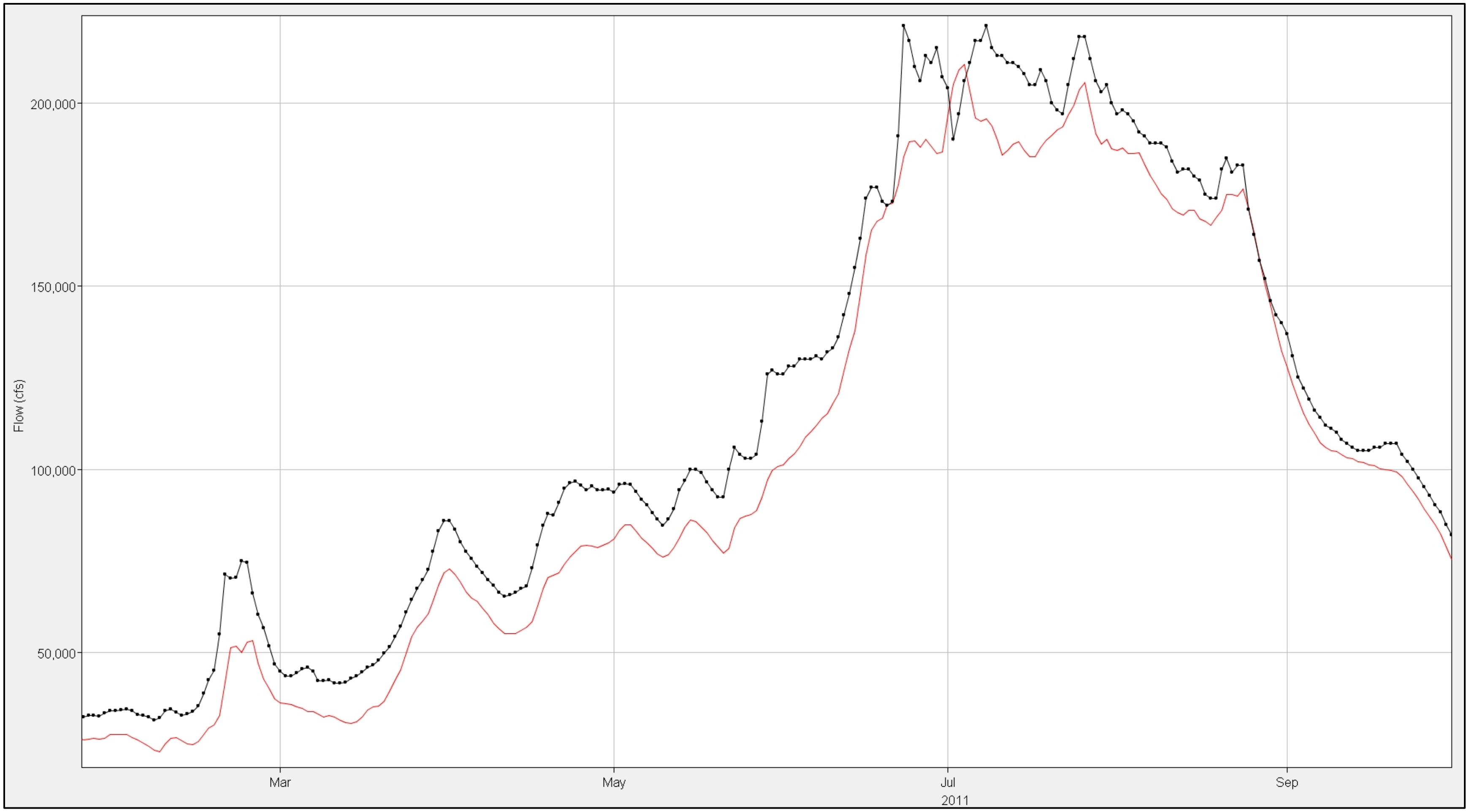


Figure B-2.12. OMA-NCNE 2011

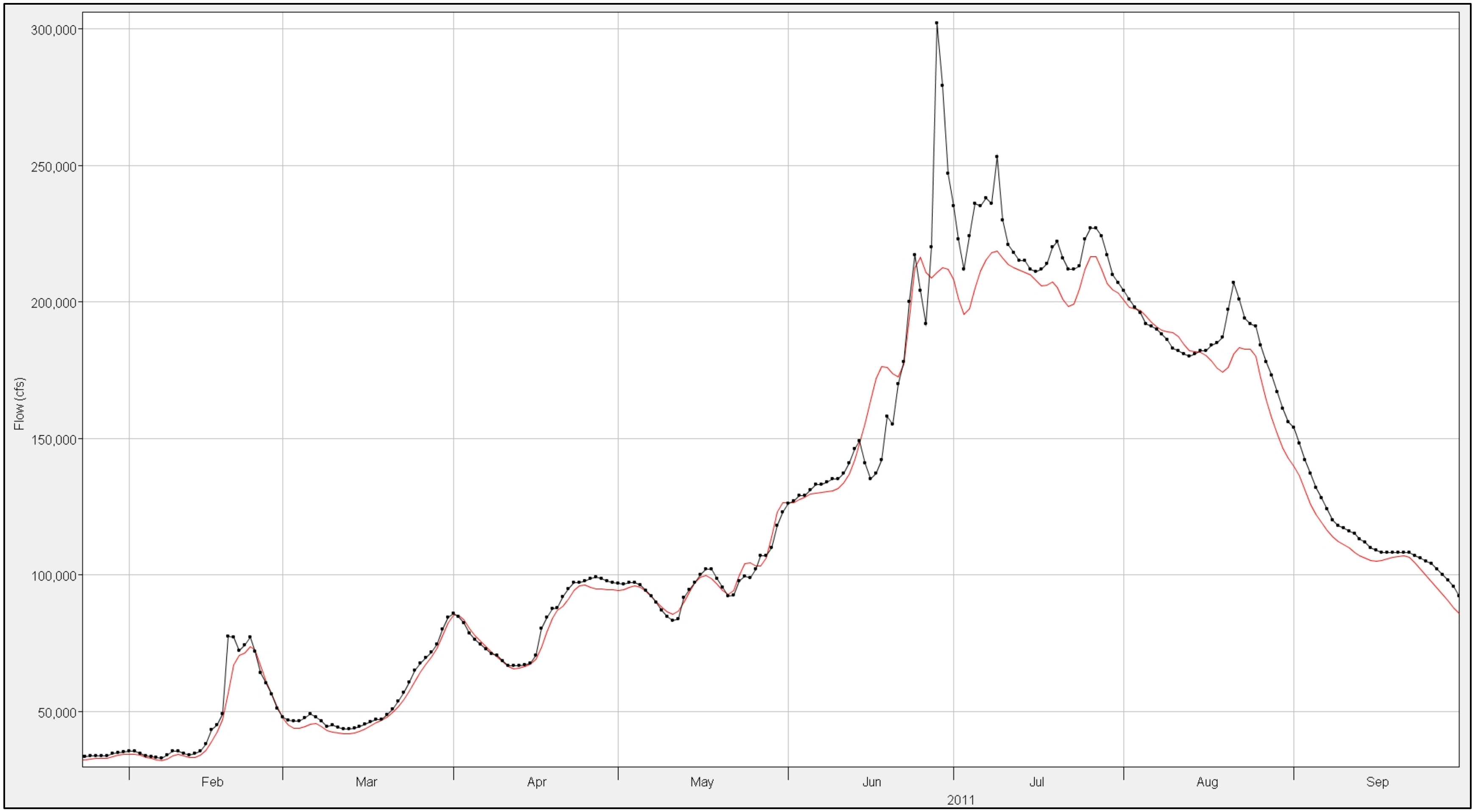


Figure B-2.13. NCNE-RUNE 2011

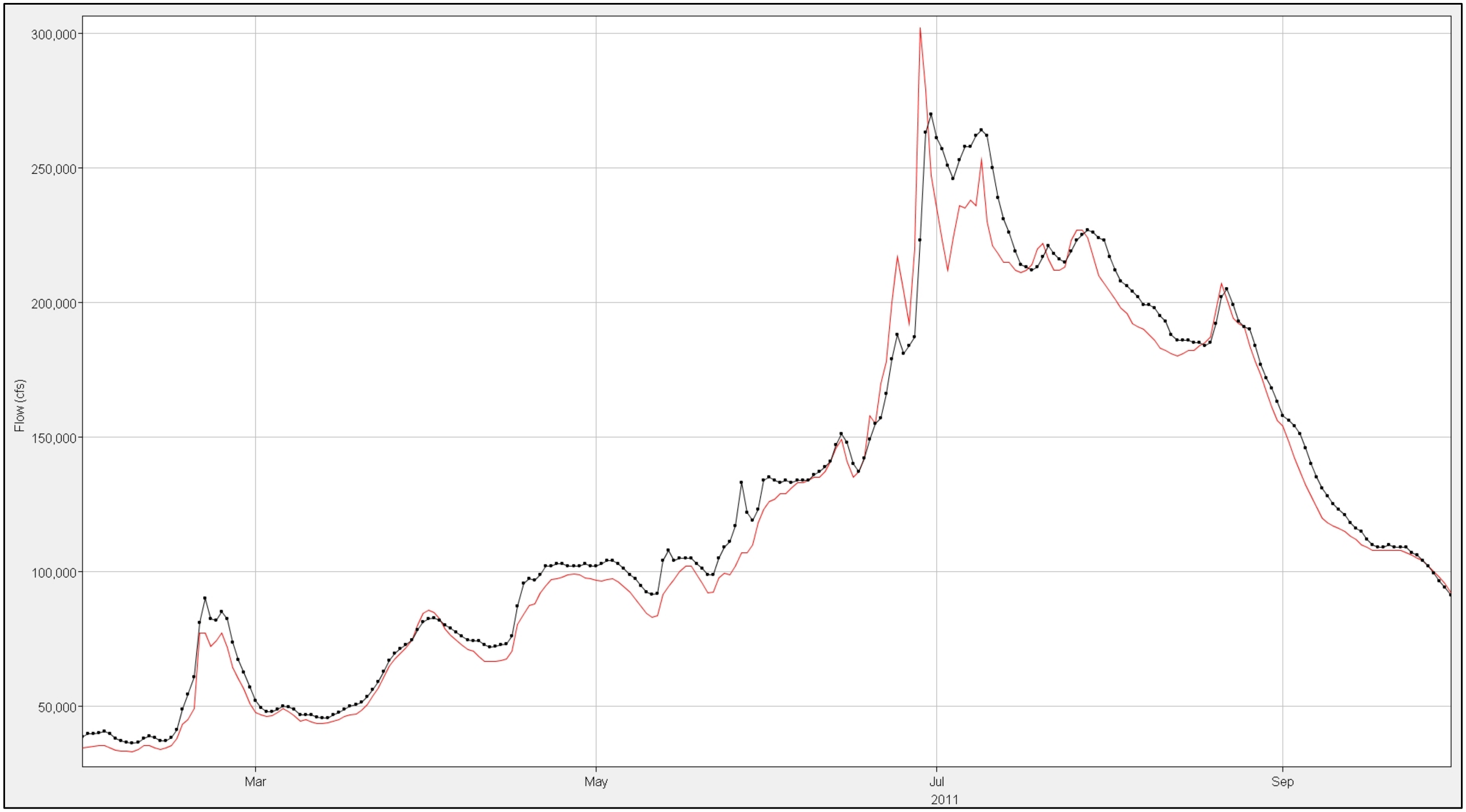


Figure B-2.14. RUNE-STJ 2011

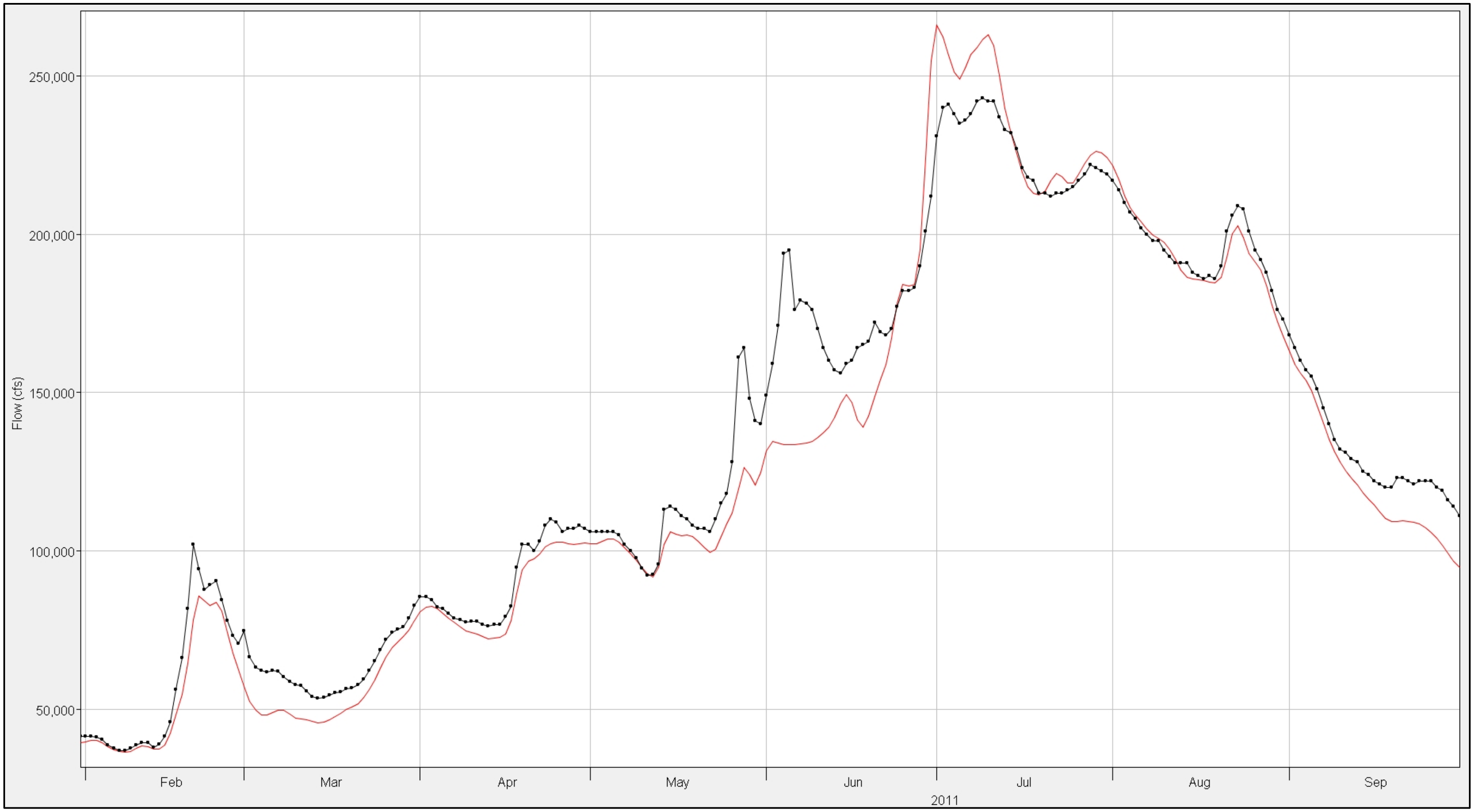


Figure B-2.15. STJ-MKC 2011

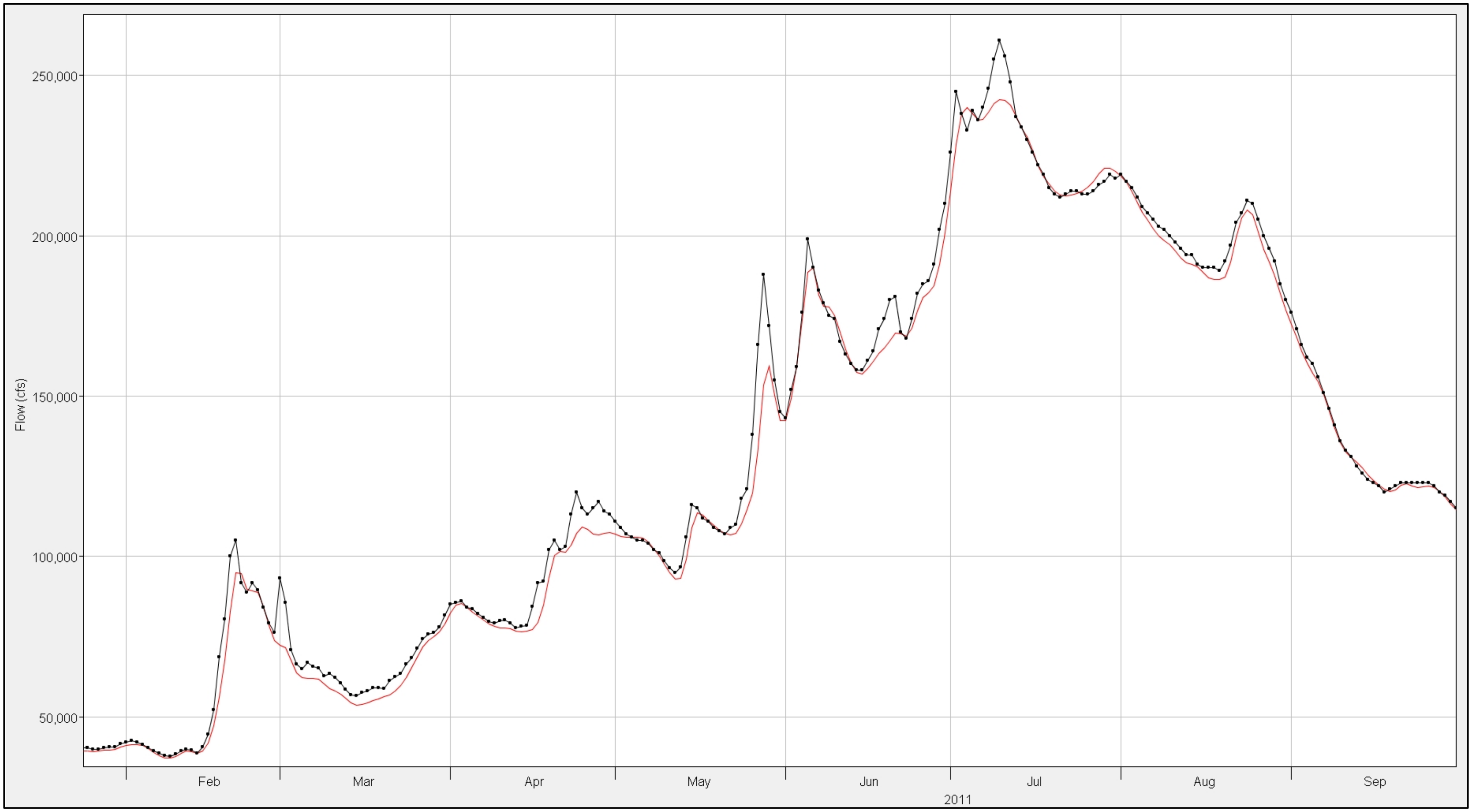


Figure B-2.16. MKC-WVMO 2011

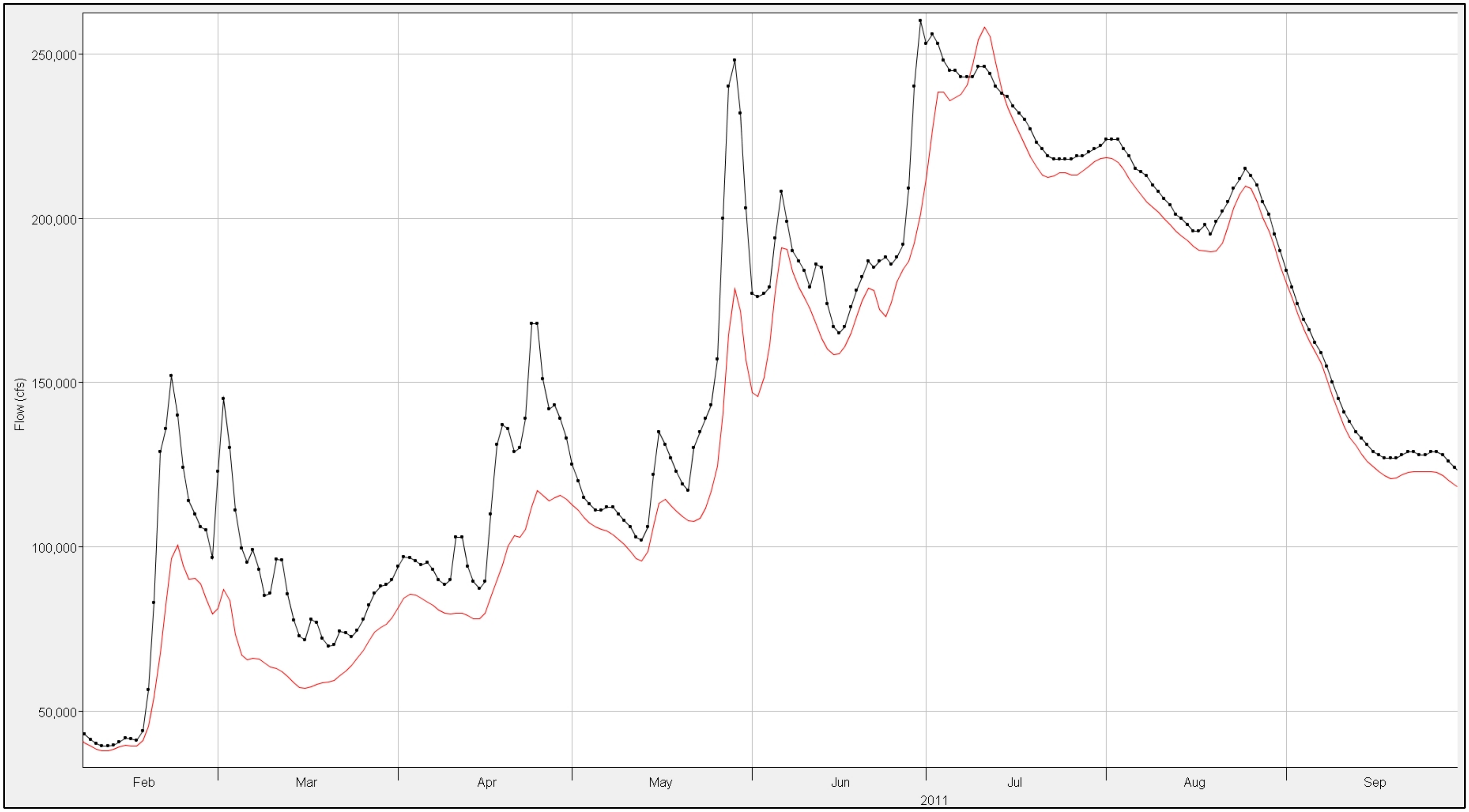


Figure B-2.17. WVMO-BNMO 2011

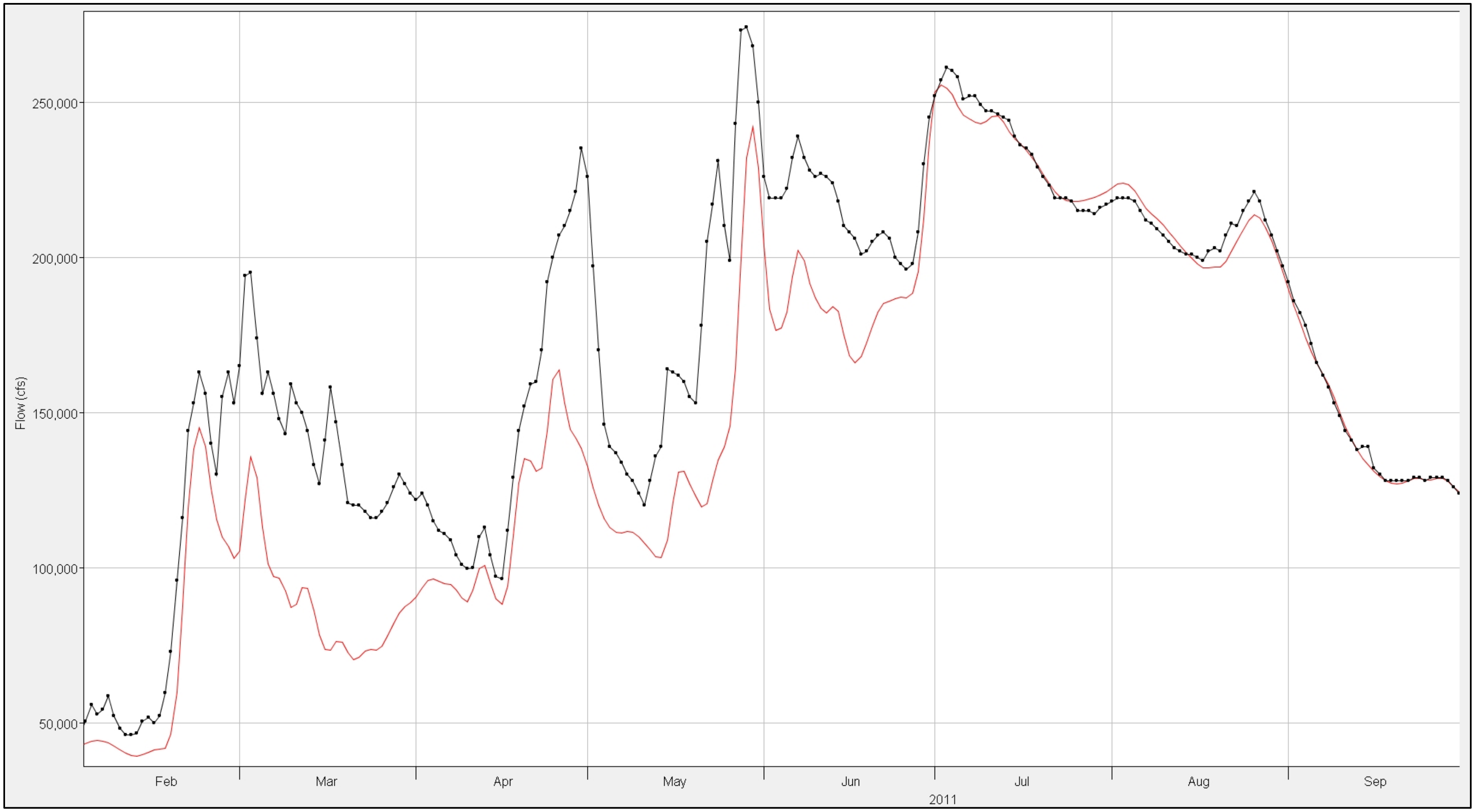


Figure B-2.18. BNMO-HEMO 2011

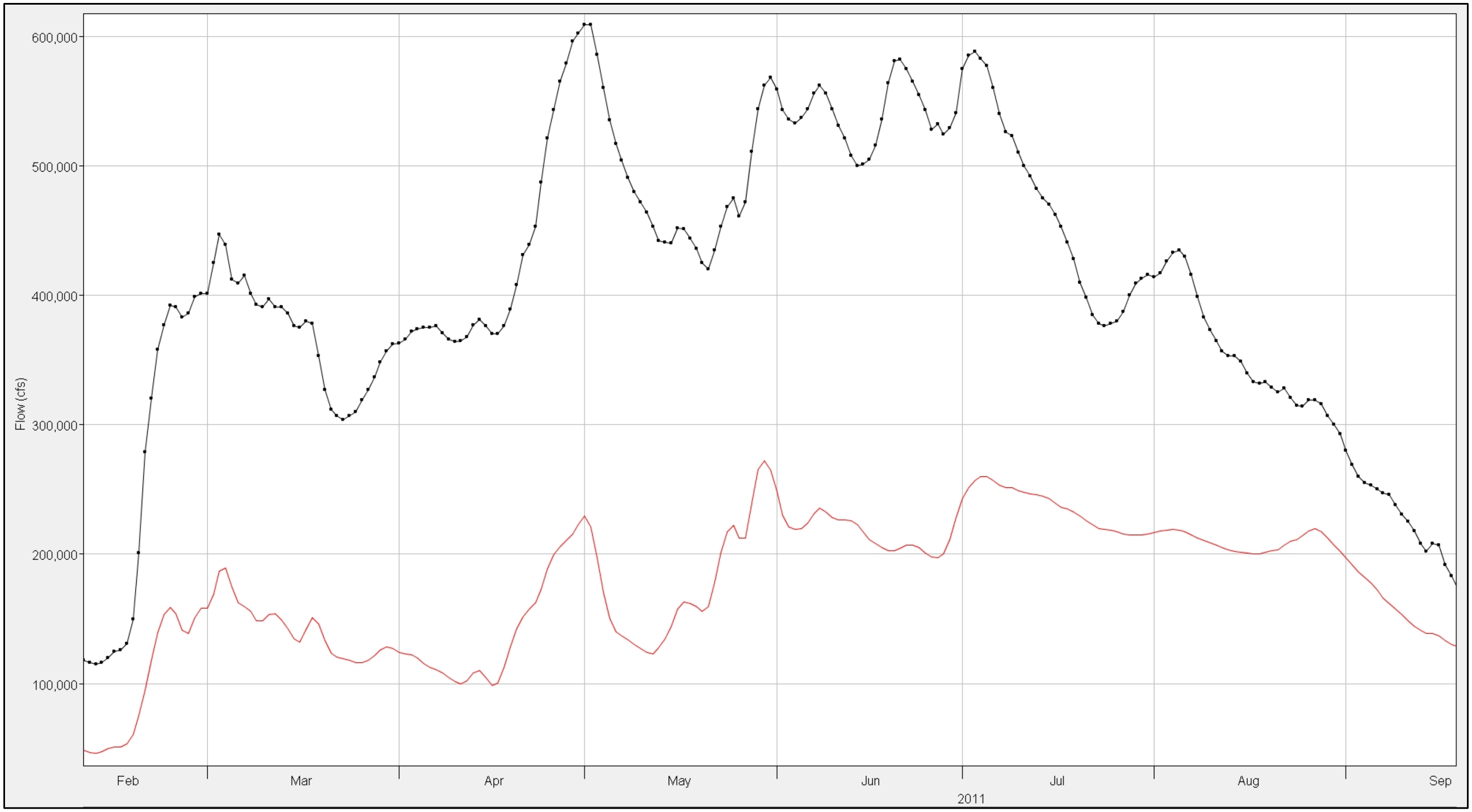


Figure B-2.19. HEMO-MISSISSIPPI RIVER 2011

Appendix B-3: Straddle-Stagger (Red) vs. Coefficient Routing (Blue) Results

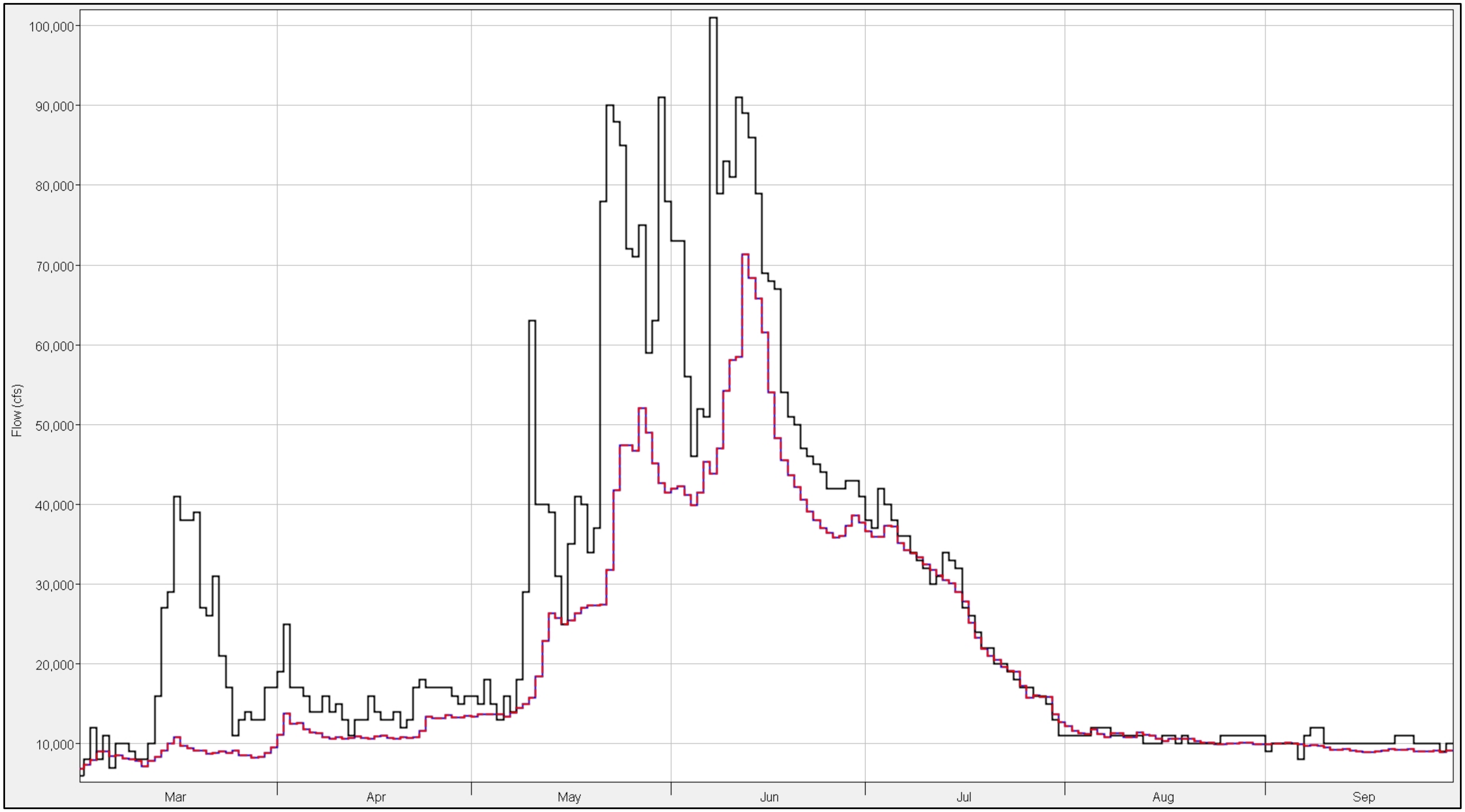


Figure B-3.1. RBMT-FTPK 2011

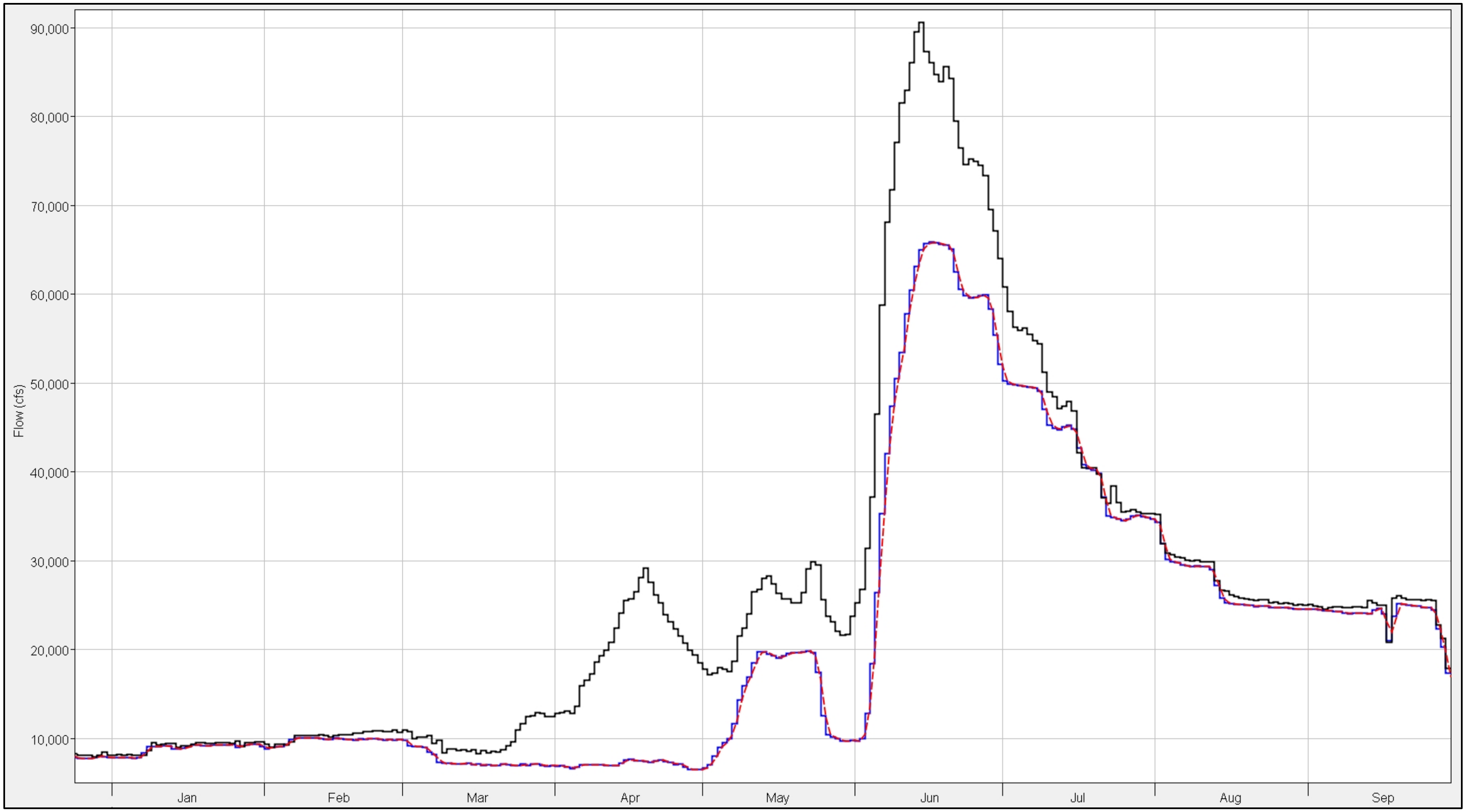


Figure B-3.2. FTPK-WPMT 2011

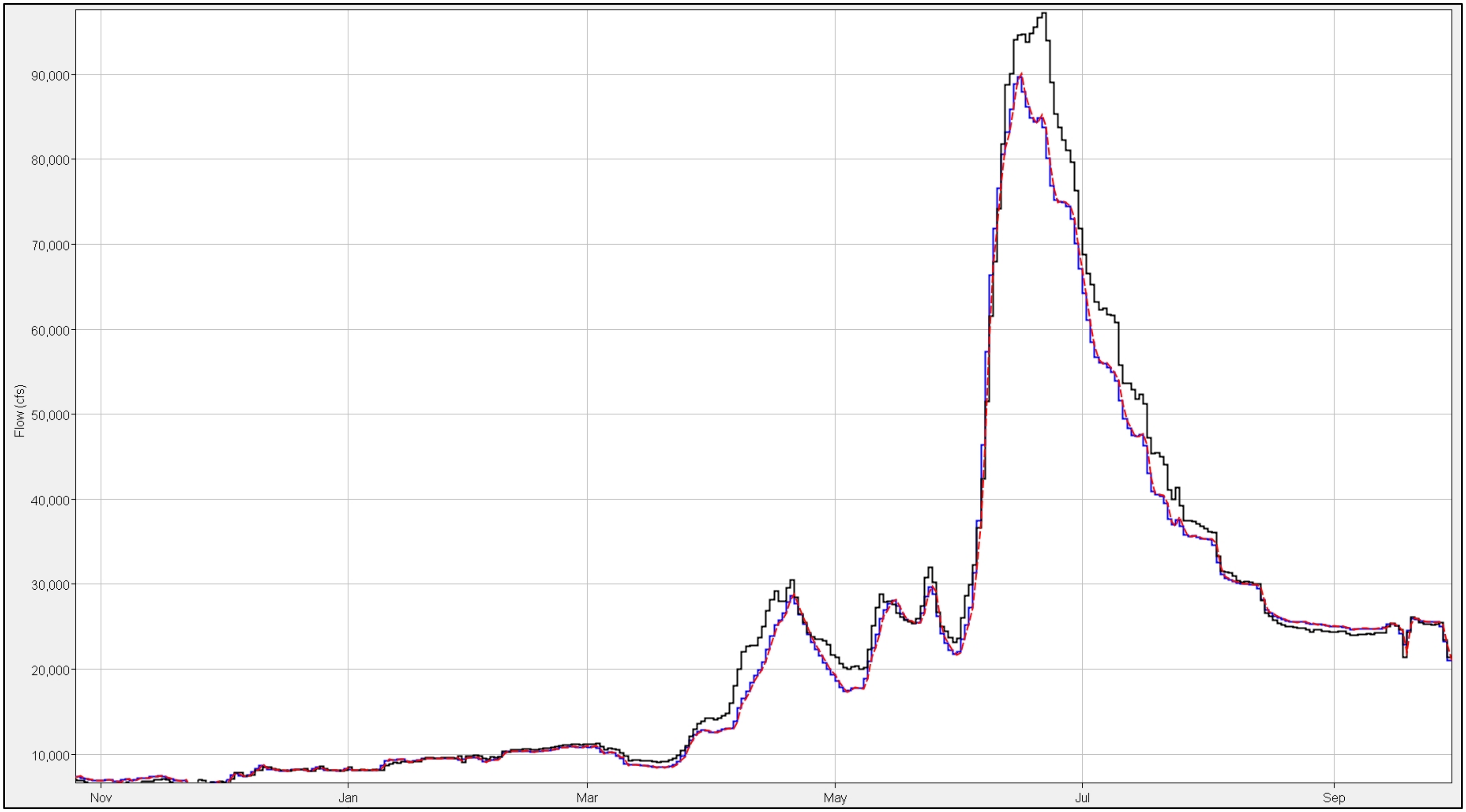


Figure B-3.3. WPMT-CLMT 2011

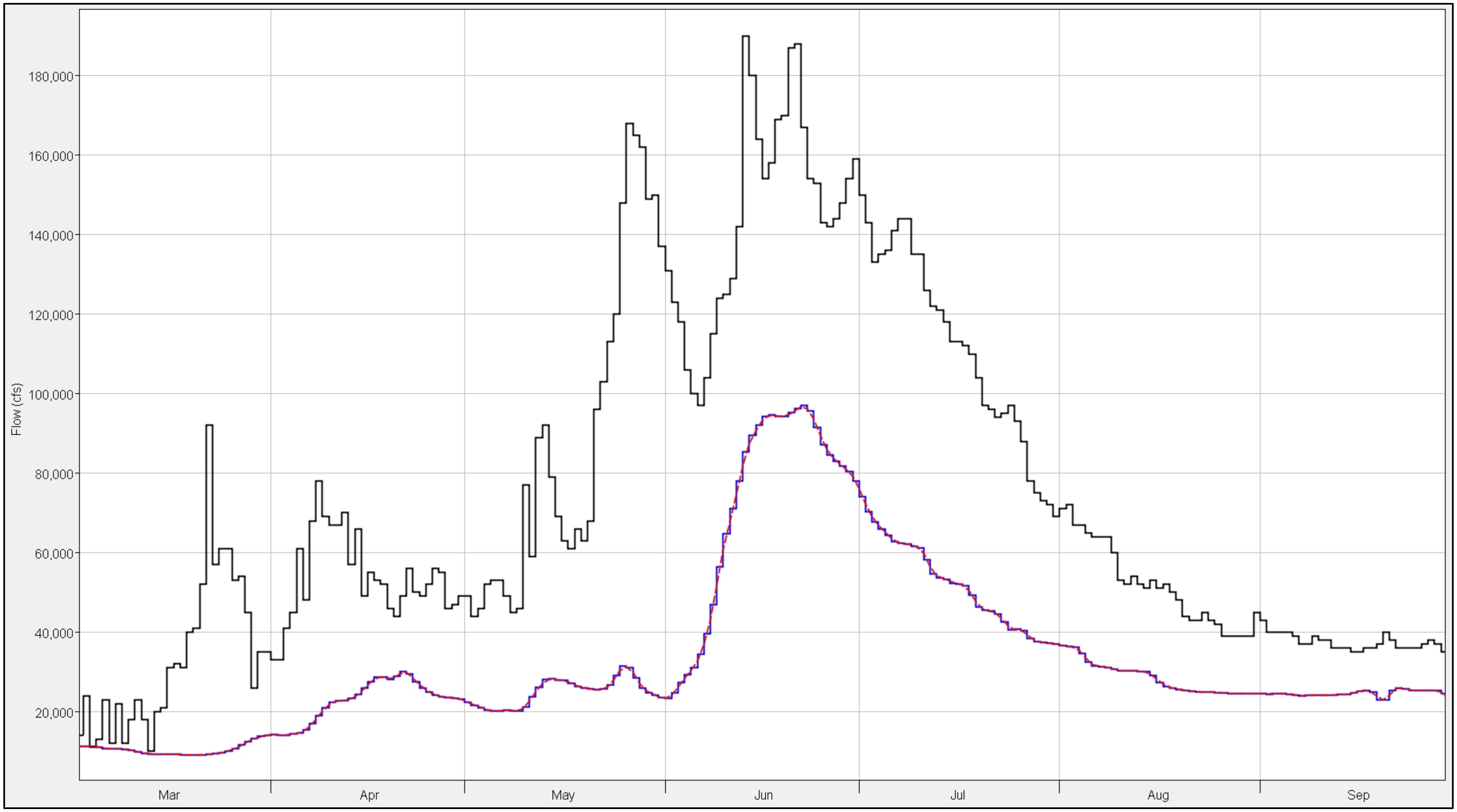


Figure B-3.4. CLMT-GARR 2011

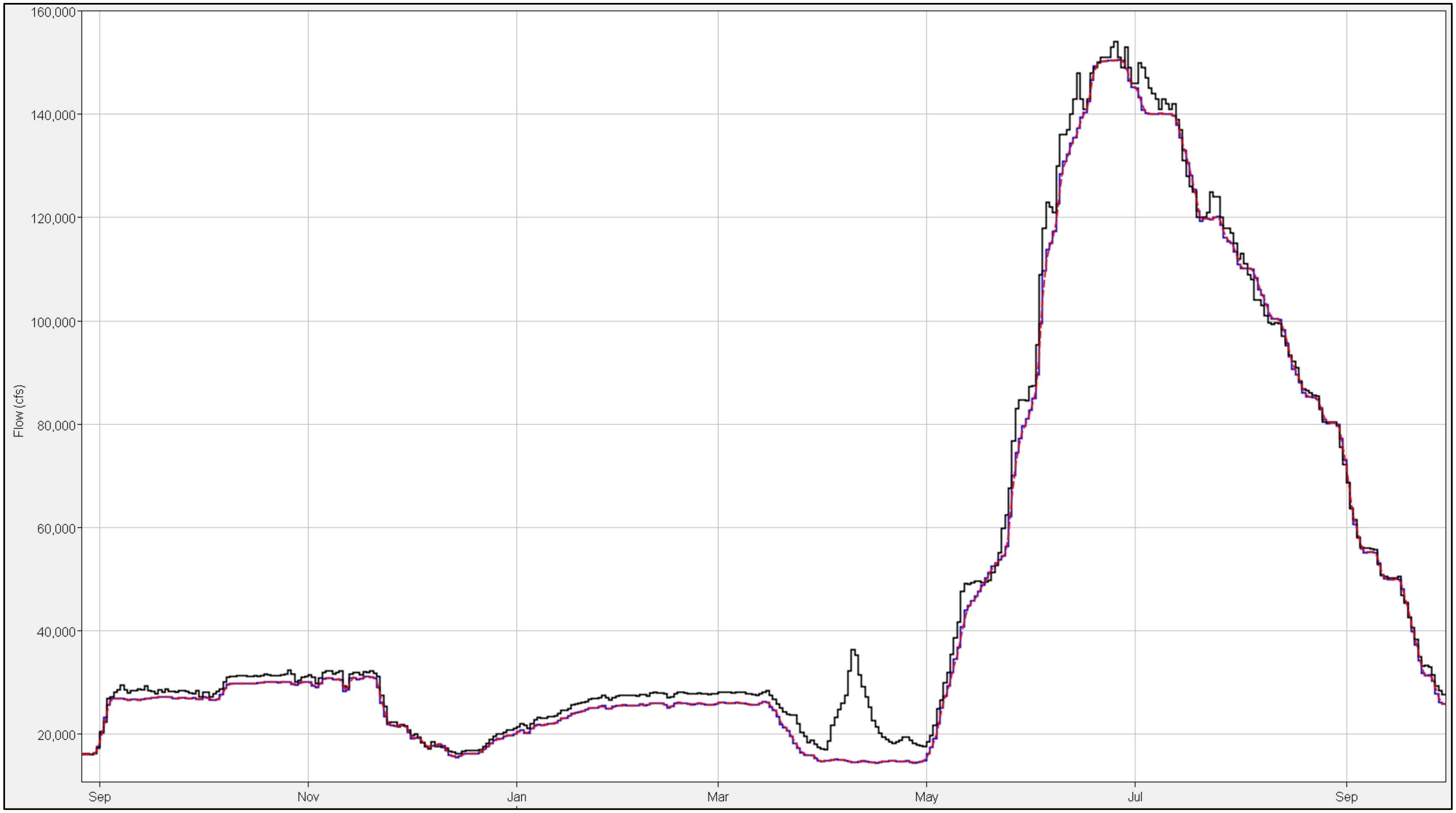


Figure B-3.5. GARR-BIS 2011

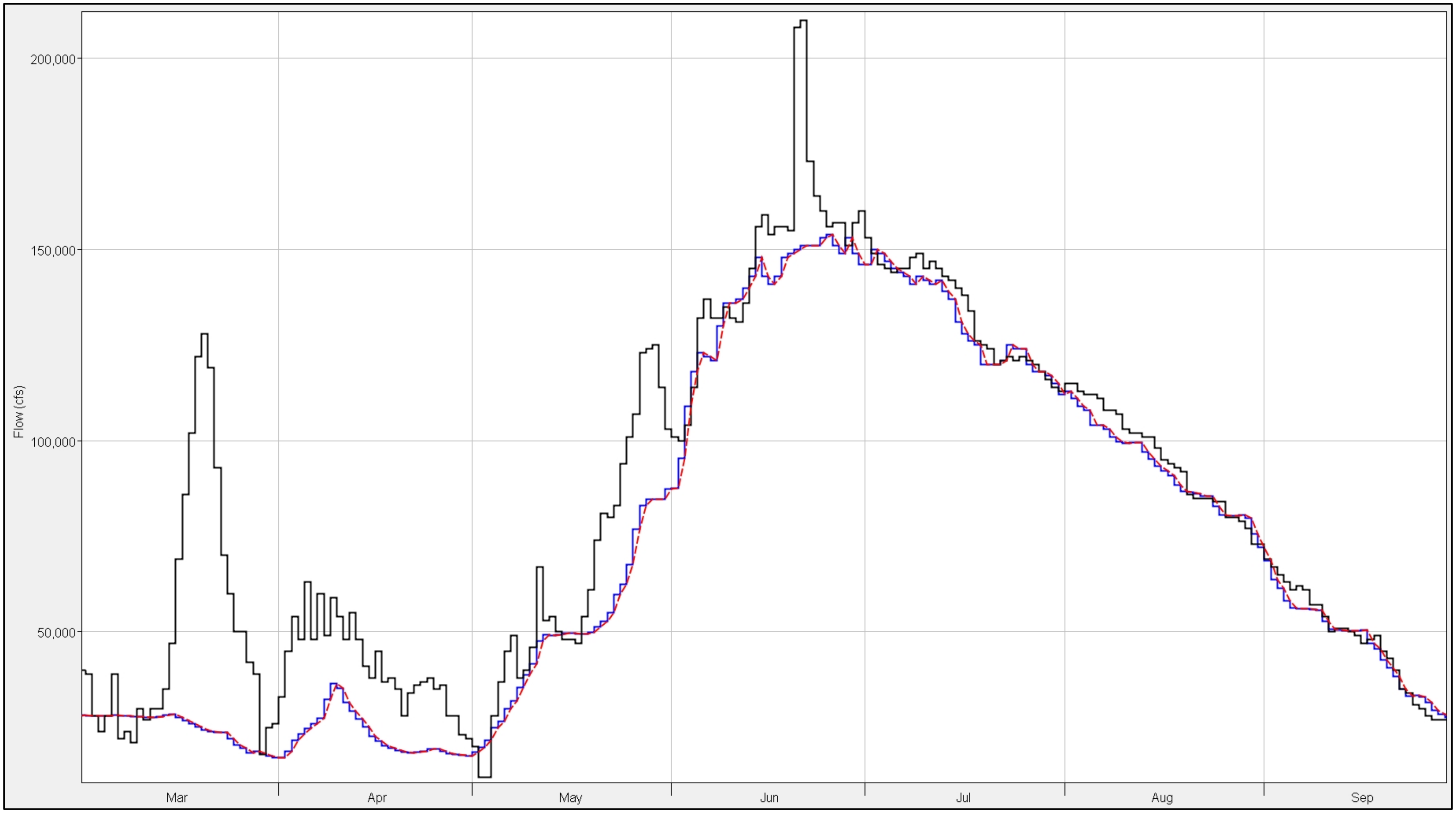


Figure B-3.6. BIS-OAHE 2011

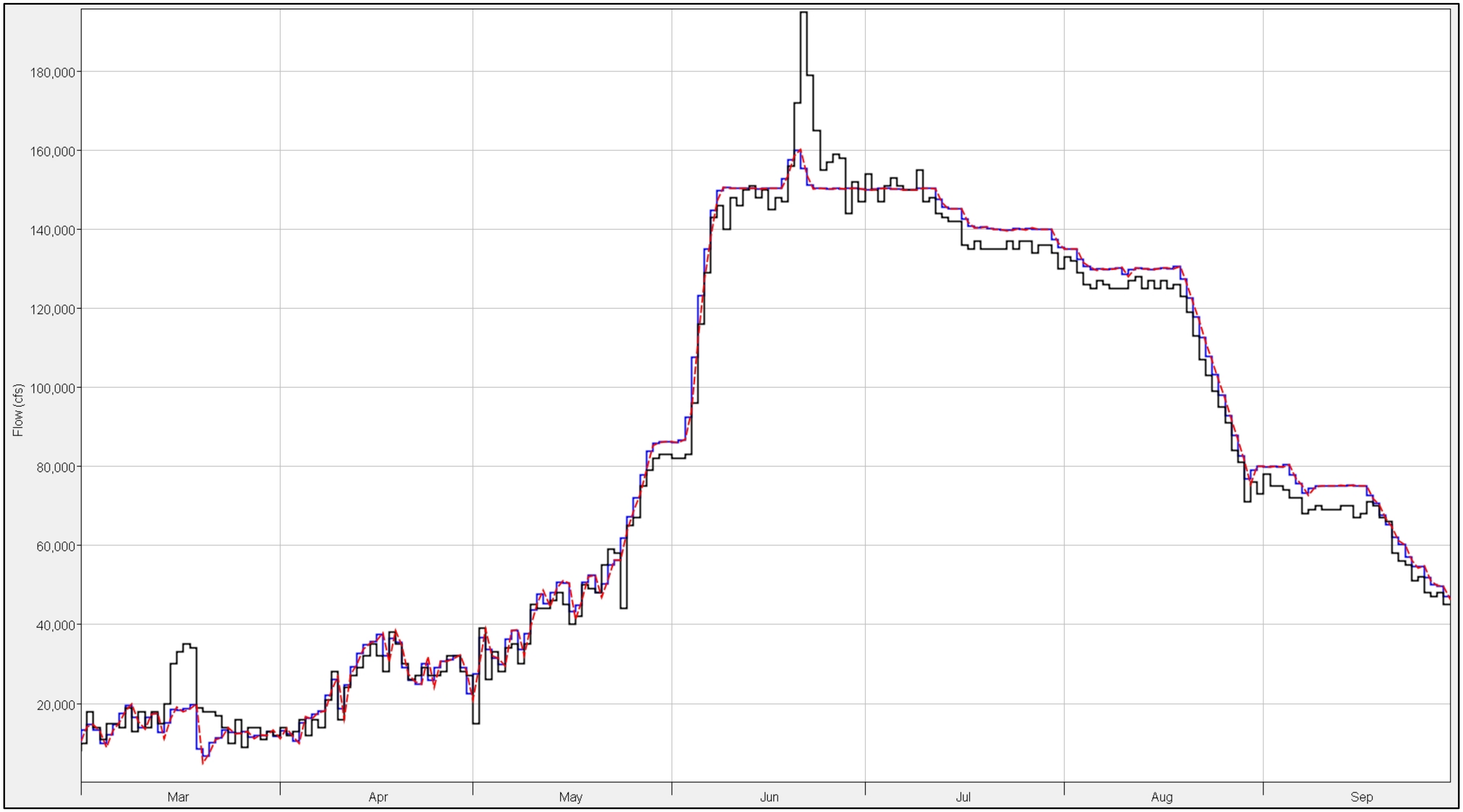


Figure B-3.7. OAHE-BEND 2011

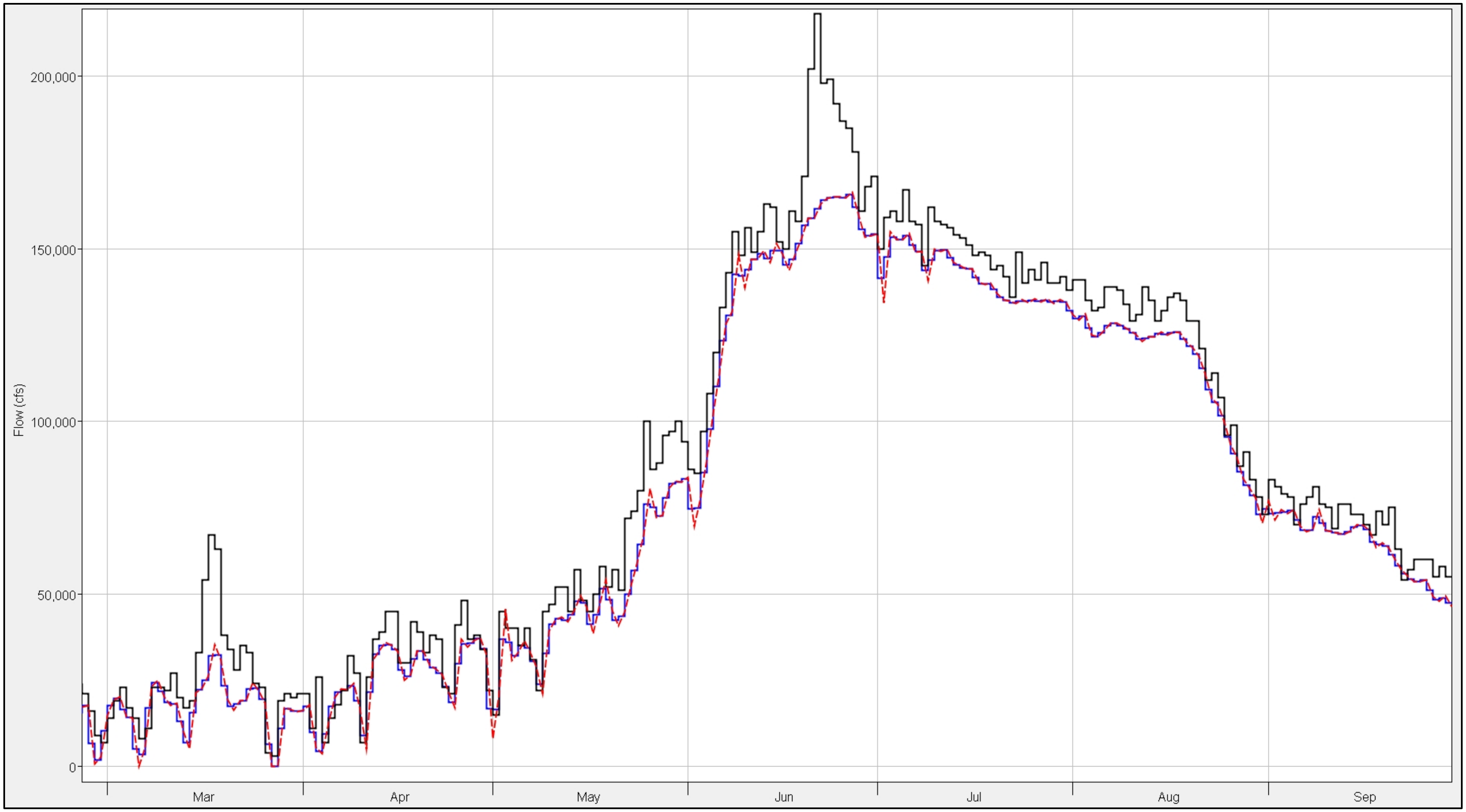


Figure B-3.8. BEND-FTRA 2011

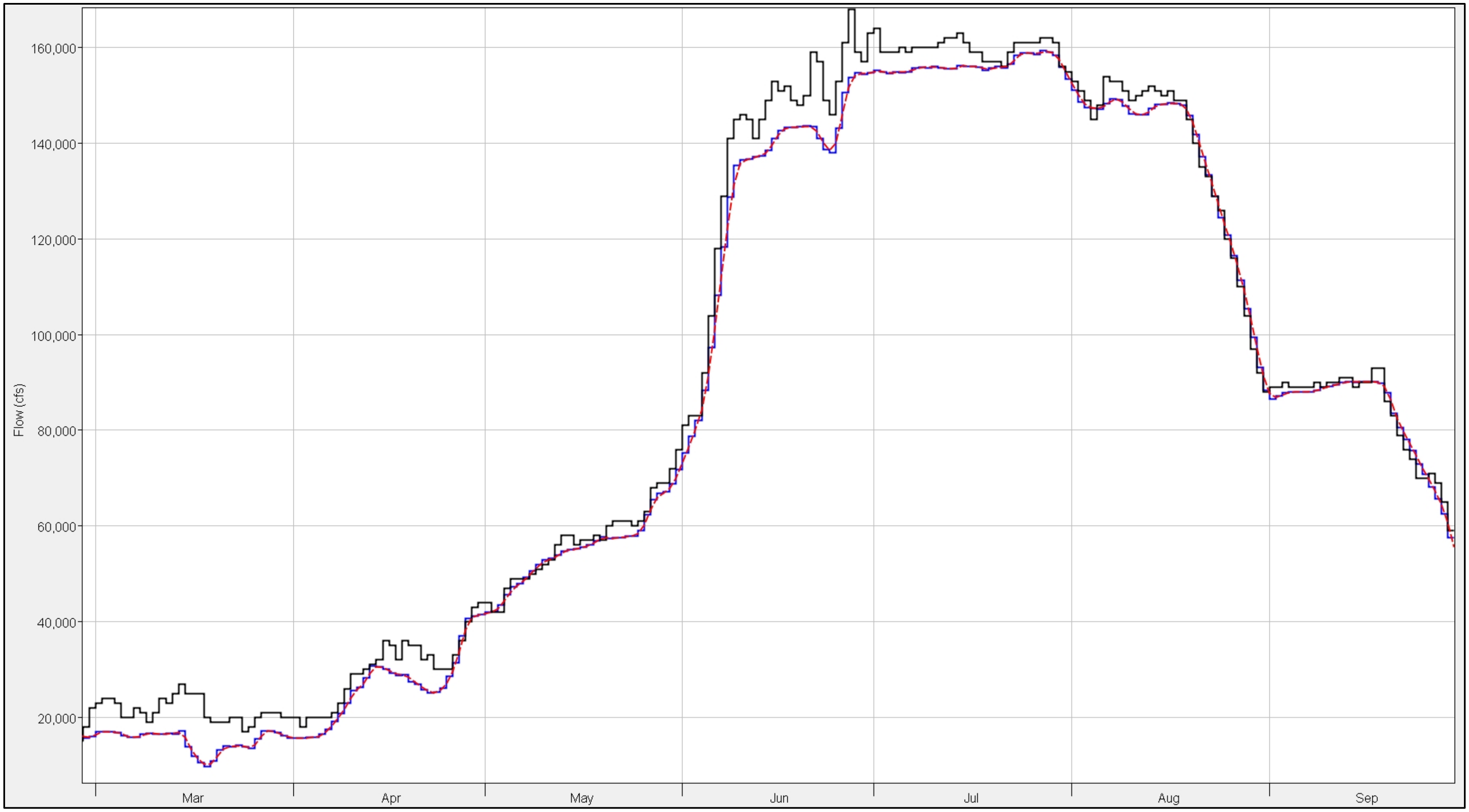


Figure B-3.9. FTRA-GAPT 2011

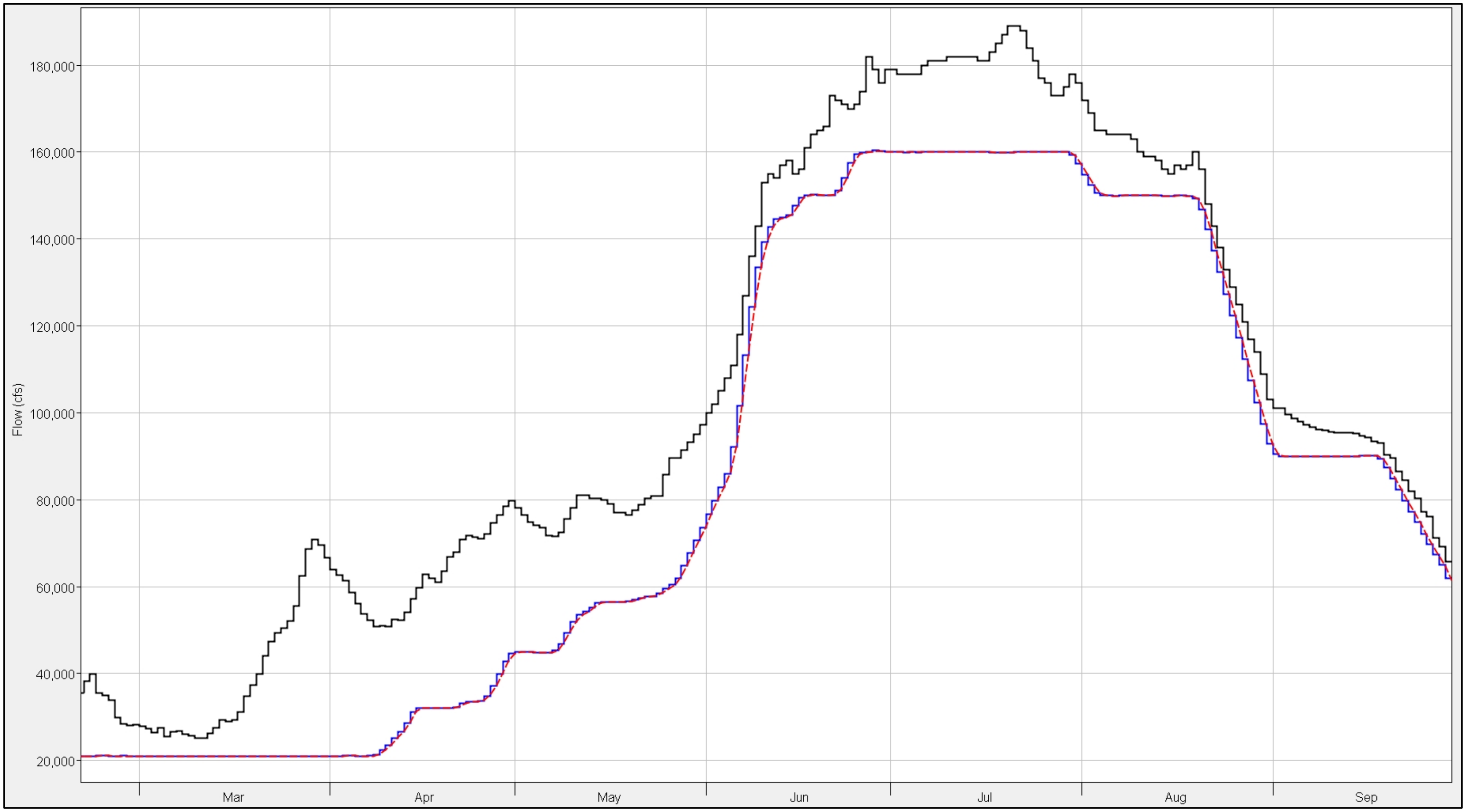


Figure B-3.10. GAPT-SUX 2011

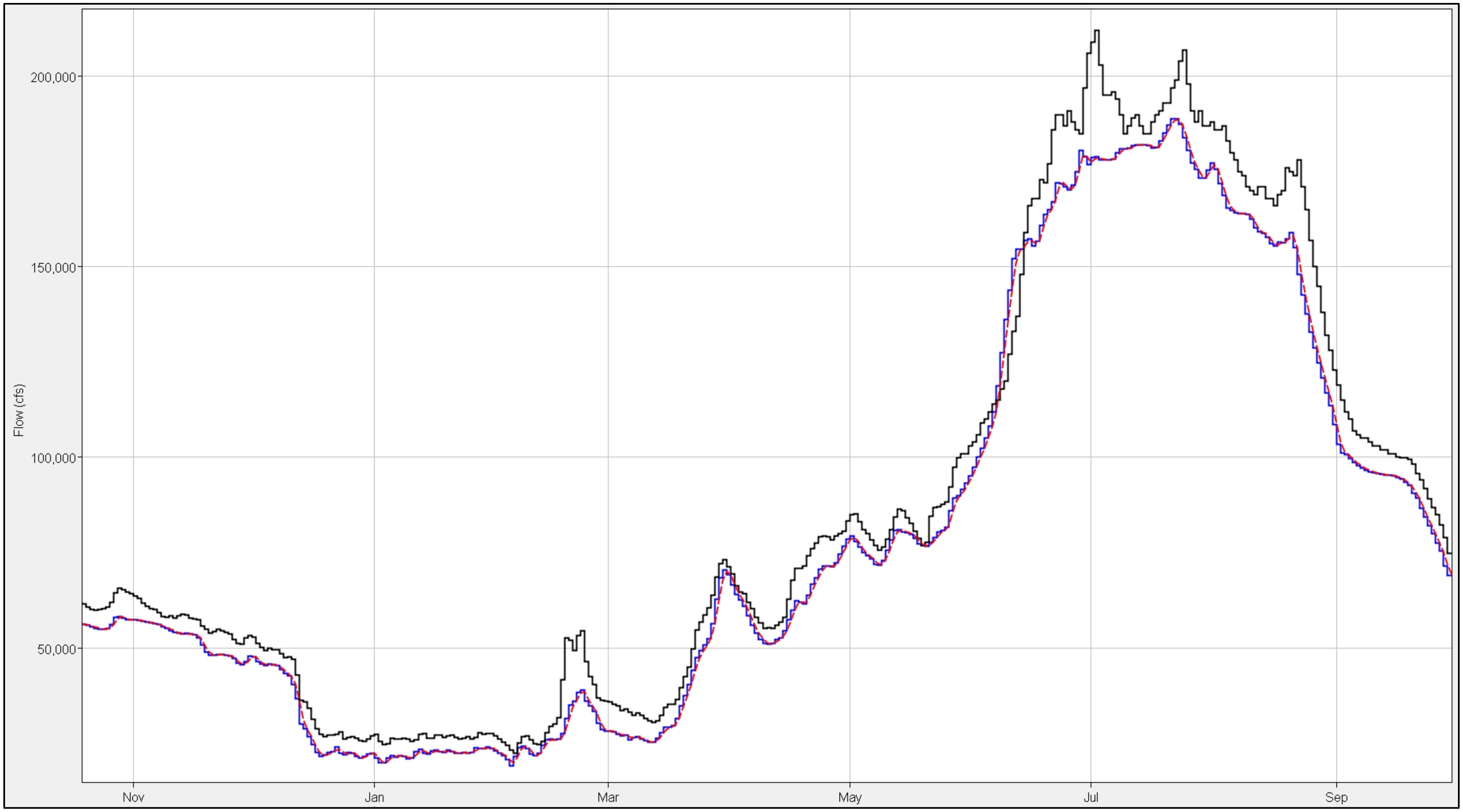


Figure B-3.11. SUX-OMA 2011

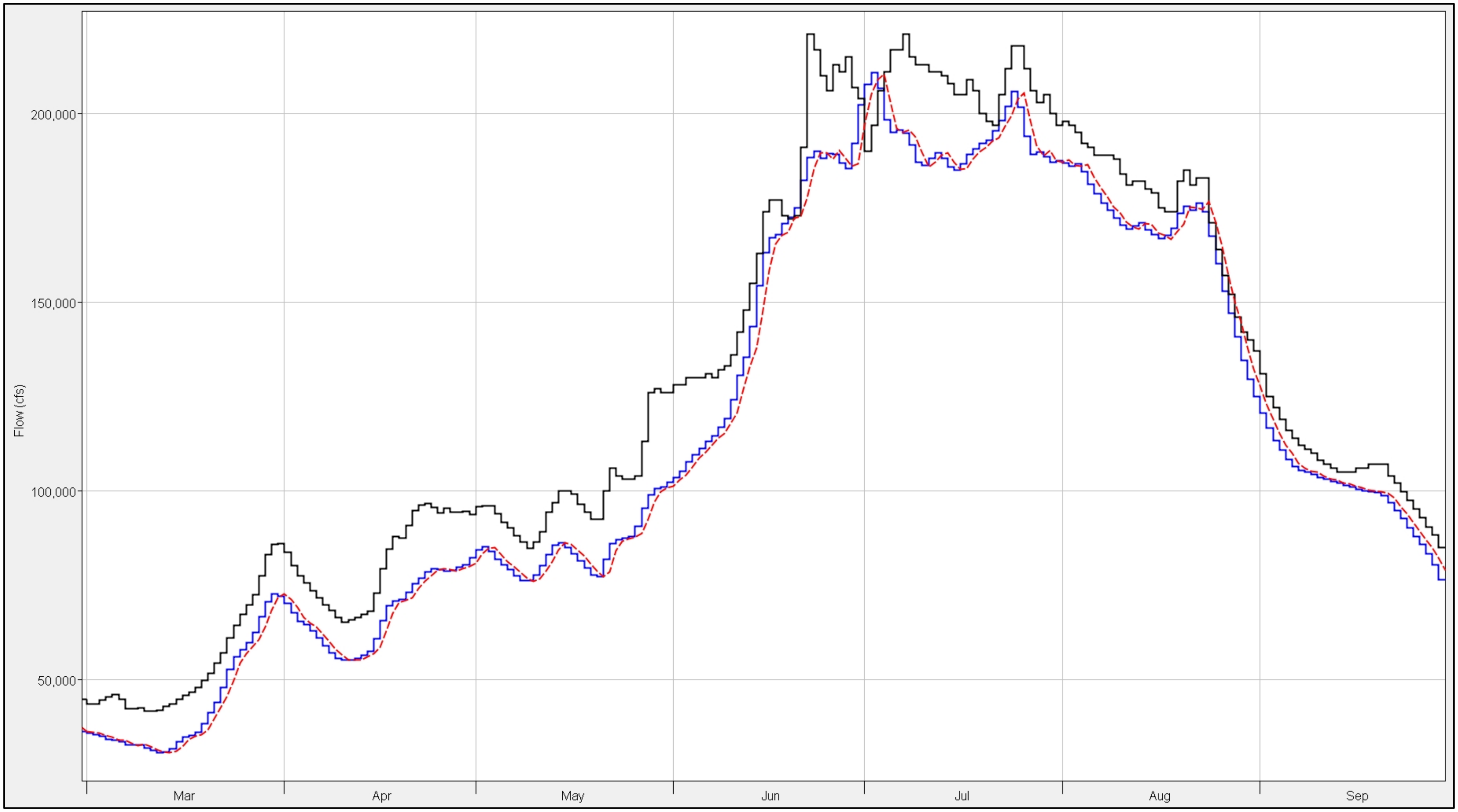


Figure B-3.12. OMA-NCNE 2011

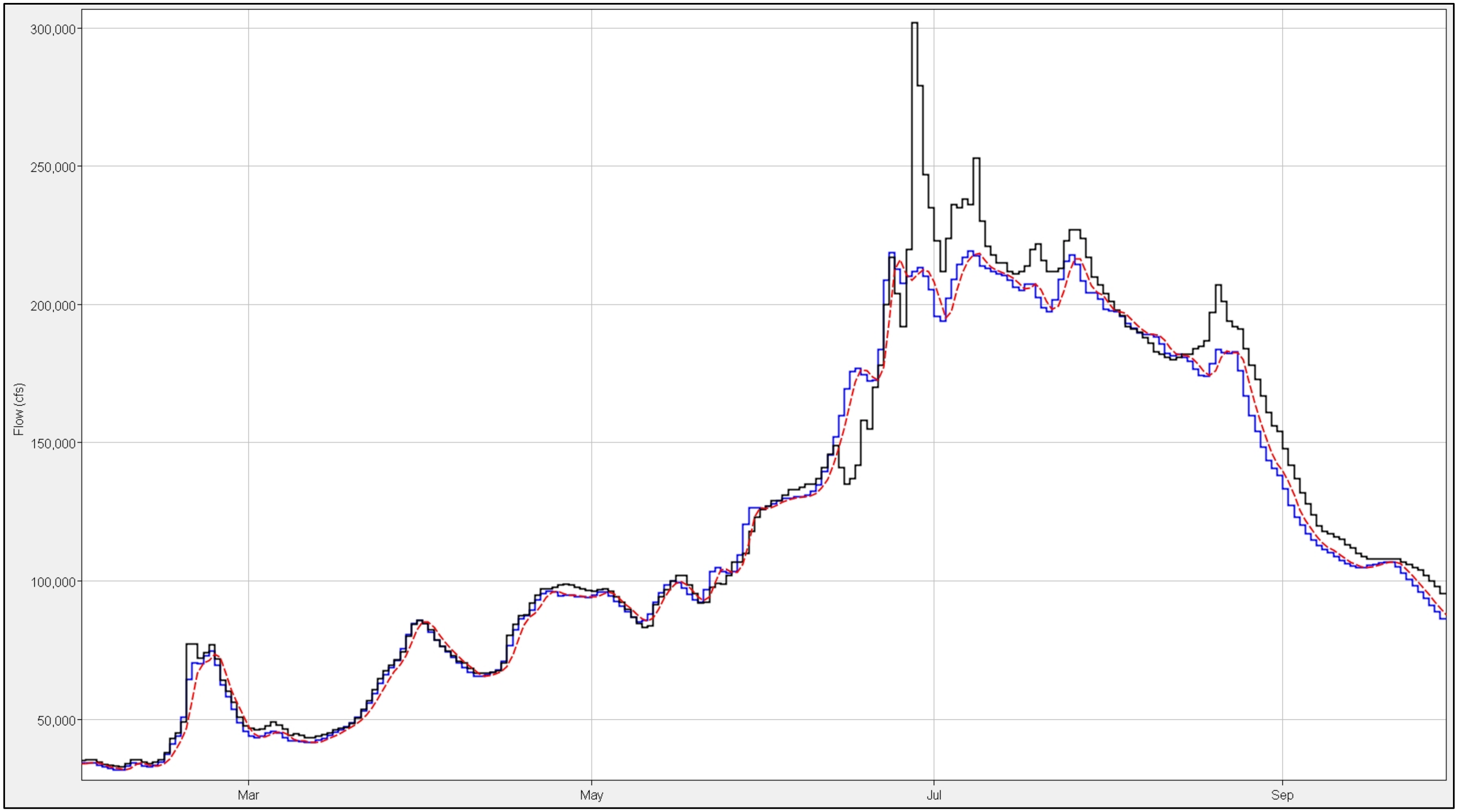


Figure B-3.13. NCNE-RUNE 2011

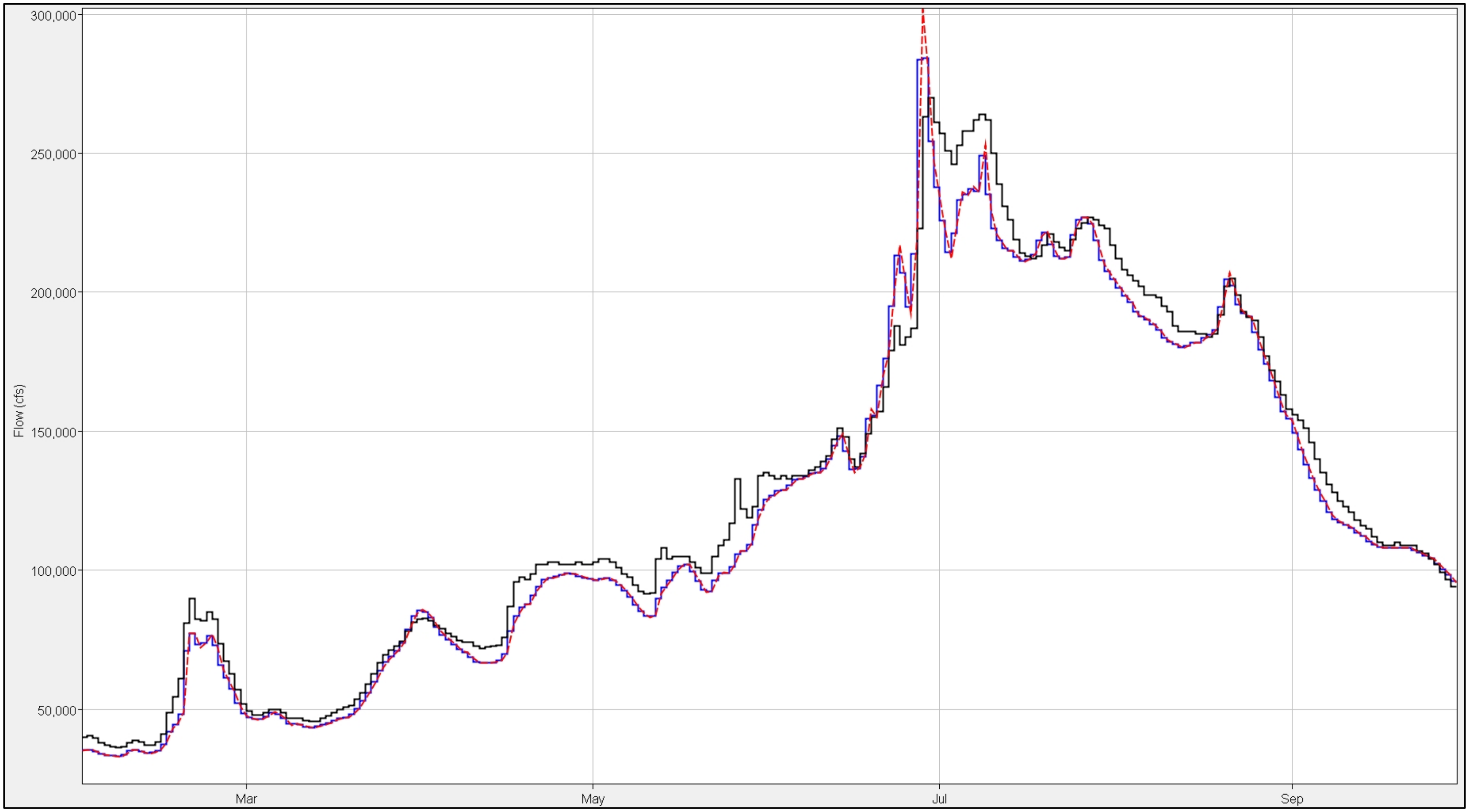


Figure B-3.14. RUNE-STJ 2011

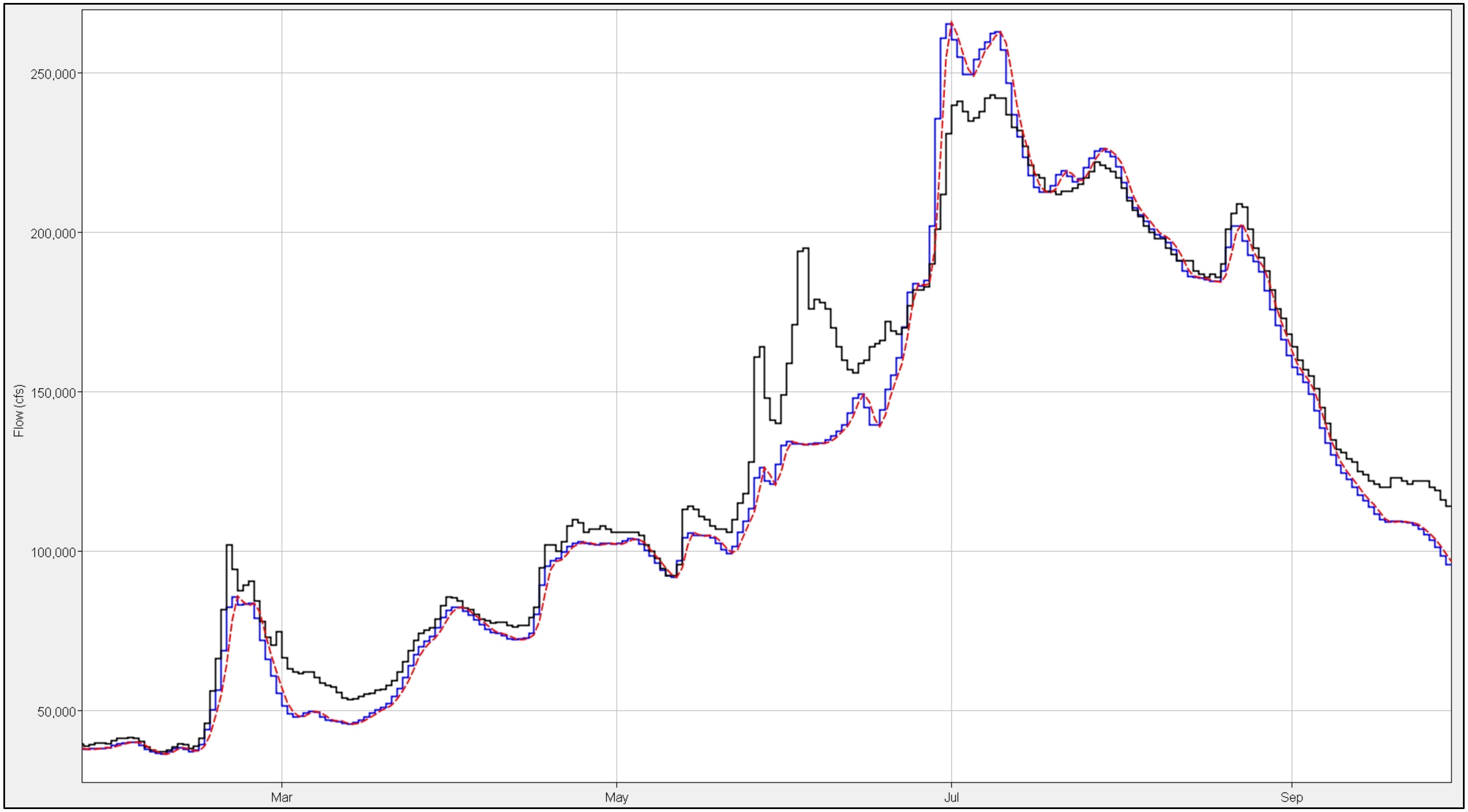


Figure B-3.15. STJ-MKC 2011

Figure B-3.16. MKC-WVMO 2011

Figure B-3.17. WVMO-BNMO 2011

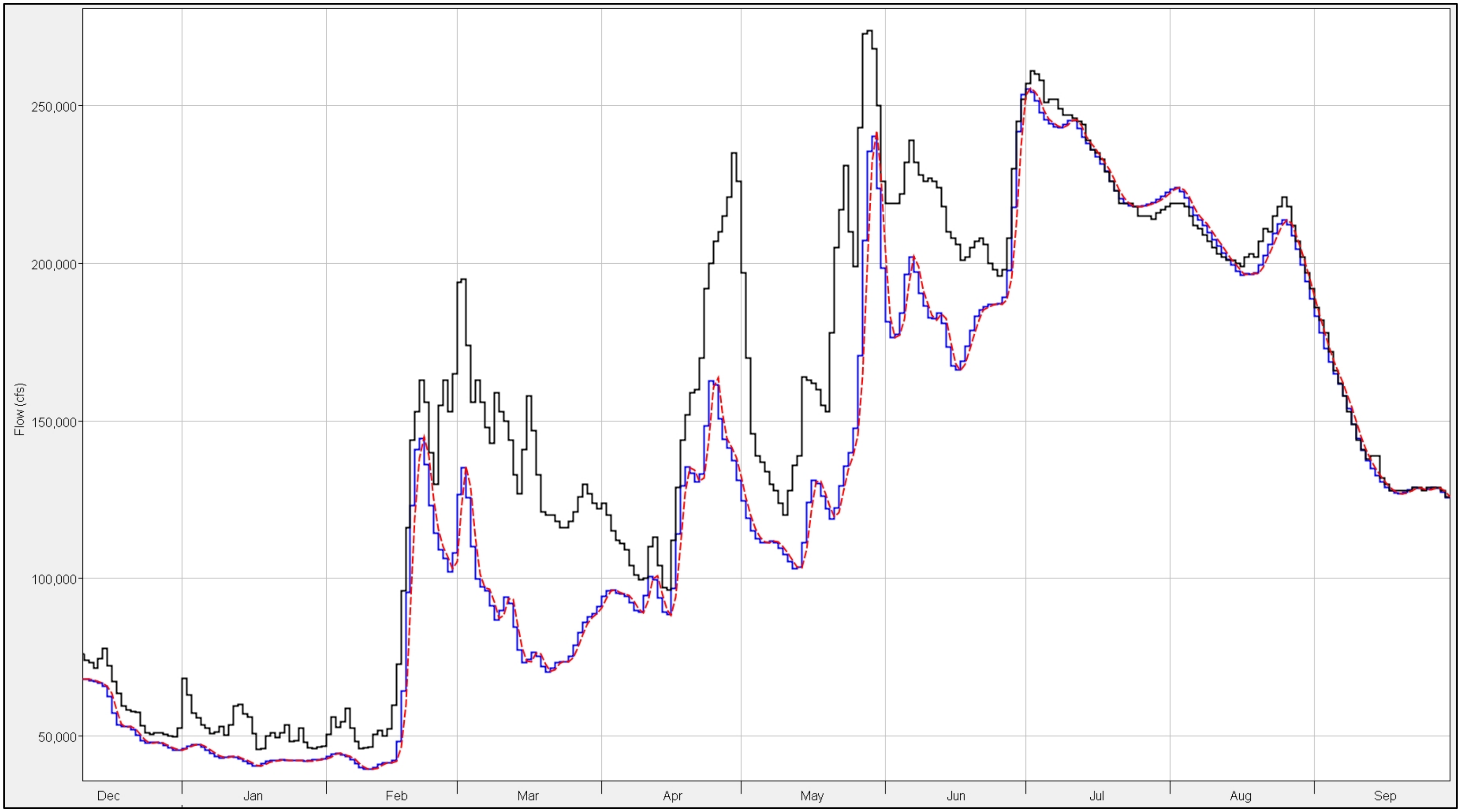


Figure B-3.18. BNMO-HEMO 2011

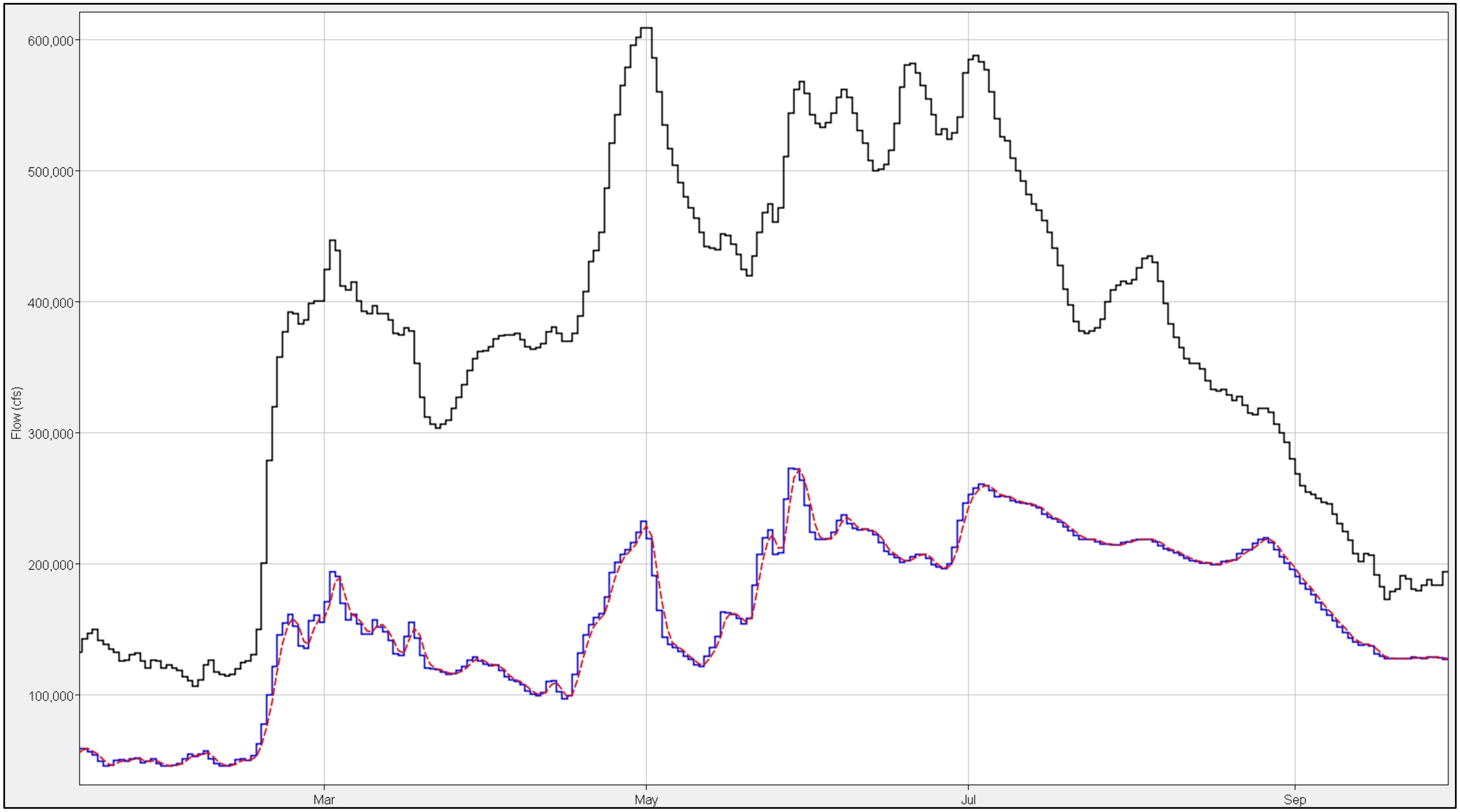


Figure B-3.19. HEMO-MISSISSIPPI RIVER 2011

11 APPENDIX B – UPPER MISSOURI AND YELLOWSTONE DATA DEVELOPMENT SUMMARY

This appendix summarizes the process to complete the period of record for stream and reservoir data. Summaries were only completed for gages used directly in HEC-ResSim. In some cases, additional gage records were extended to aid in the completion of the selected gage's data extension. Summaries for these gages were not developed, but similar methodology as described was used.

Upper Missouri

Tiber Dam Inflow/Outflow

1) Inflow – Linear regression using the adjusted USBR inflow values (to account for evaporation) and the extended Marias River near Shelby gage (shifted +1 day) was conducted. Use of the extended gage was required to get back to 1897 from 01 Oct 1955 when the USBR data began.
2) Outflow data were the same as inflow pre-dam.

Canyon Ferry Dam Inflow/Outflow

1) Linear regression using the USBR outflow values and the Holter gage was conducted. This methodology is appropriate here because the Holter data were extended using pre-dam regression analysis. Use of the extended gage was required to get back to 1897 from 28 Mar 1953 when the USBR data began.
2) A very small amount (31 days) of missing data for the USBR inflow record were also filled using a regression analysis between Toston and the USBR adjusted inflow (for evaporation). This was done because the Holter data could not be used post-dam.
3) Outflow data were the same as inflow data pre-dam.

Missouri River below Holter Dam near Wolf Creek, MT

1) From 01 Oct 1897 to 30 Sep 1922 and 01 Oct 1942 to 30 Sep 1945, regression values from Fort Benton (-1 day shift) and the extended Toston (+1 day shift) record were used.
2) From 01 Oct 1922 to 30 Sep 1942, regression values from Fort Benton (-1 day shift) and Hauser dam were used.
3) From 01 Oct 1945 on, actual Holter gage data were used.

Missouri River near Great Falls, MT

1) From 01 Oct 1897 to 30 Sep 1956, regression values from Fort Benton were used to estimate values at Great Falls. Also, a small amount of Great Falls data from 1953 were kept as it previously existed in the record.
2) From 01 Oct 1956 on, values from the Great Falls gage were used.

Missouri River at Fort Benton, MT

1) From 01 Oct 1897 to 31 Dec 2011, values from the Fort Benton gage were used with no missing data present.

Missouri River at Virgelle, MT

1) From 01 Oct 1897 to 28 Feb 1935, regression values from the Fort Benton gage were used.

2) From 01 Mar 1935 on, values from the Virgelle gage were used.

Missouri River near Landusky, MT

1) From 01 Oct 1897 to 28 Feb 1934, regression values from the Fort Benton gage were used.
2) From 01 Mar 1934 on, data from the Landusky gage were used.

Yellowstone

Buffalo Bill Dam

1) Inflow - From 01 Oct 1897 through 31 Dec 1909, the extended Shoshone River below Buffalo Bill Reservoir was used with 60 cfs/day subtracted off to represent local inflow from springs between the reservoir and the gage (USBR value for springs).
2) Inflow - From 01 Jan 1910 through 30 Sept 1915, daily average values for the extended Shoshone River below Buffalo Bill were used (average period 01 Oct 1897 to 31 Dec 1909 – adjusted for springs).
3) Inflow - From 24 Jan 1916 through 31 March 1952, utilized monthly USBR inflow estimates (adjusted for evaporation using daily average NWS & USBR values (average period 23 Mar 1952 through 31 Dec 2011)).
4) Inflow - From 01 Apr 1952 through 31 Dec 2011, utilized daily USBR inflow estimates (adjusted for evaporation using NWS & USBR daily evaporation data).
5) Outflow – From 01 Oct 1897 through 31 Dec 1909, the extended Shoshone River below Buffalo Bill Reservoir was used with 60 cfs/day subtracted off to represent local inflow from springs between the reservoir and the gage (USBR value for springs).
6) Outflow – From 01 Jan 1910 through 30 Sep 1942, the extended Shoshone River below Buffalo Bill Reservoir was used with 60 cfs/day subtracted off to represent local inflow from springs between the reservoir and the gage (USBR value for springs).
7) Outflow – From 01 Oct 1942 to 23 Mar 1952, the extended Shoshone River below Buffalo Bill Reservoir was used with 60 cfs/day subtracted off to represent local inflow from springs between the reservoir and the gage (USBR value for springs). Also, daily average Heart Mountain Canal discharges were added to the record. The canal discharges were obtained by taking the daily average value (01 Jan 1953-31 Dec 2011) and adjusting it by the actual monthly volume (actual daily values not available) to reflect releases made out of the dam for the canal.
8) Outflow – From 24 Mar 1952 through 31 Dec 2011, USBR daily average values were used.

Boysen Dam

1) Linear regression using the adjusted USBR inflow values (to account for evaporation) and the extended Wind River ab. Boysen Reservoir near Shoshoni gage was conducted. Use of the extended gage was required to get back to 1897 from 01 Mar 1952 when the USBR data began.
2) Outflow data were the same as inflow pre-dam.

Yellowtail Dam

1) From 01 Oct 1897 to 31 Oct 1965, multiple linear regression with the Lovell and Kane gage data were used.

2) From 01 Nov 1965 to 31 Dec 2011, actual USBR reservoir inflow values were used.
3) Outflow data were the same as inflow pre-dam.
4) Adjustments to the Yellowtail Dam inflow to account for incremental flow between Buffalo Bill and Yellowtail, as well as Boysen and Yellowtail, were completed.

Yellowstone River at Billings, MT

1) From 01 Oct 1897 to 30 Sep 1910, flows from the Yellowstone River at Glendive (-2 day shift) were used via a regression analysis with the Billings gage. Small amounts of the Glendive data were filled in using daily average data for that gage. Also, about two years of data (1904/05) did exist in the Billings record and these data were kept.
2) From 01 Oct 1910 to 31 Aug 1928, flows from a multiple linear regression using the Billings, Corwin Springs (+1 day shift), and Sidney (-3 day shift) gages were used.
3) After that time, data from the Billings gage were used.

Bighorn River above Tullock Creek near Bighorn, MT

1) From 01 Oct 1897 to 10 May 1945, a regression analysis with the Yellowtail inflow values (adjusted for evaporation) was used (+1 day shift).
2) From 11 May 1945 on, data from the Bighorn gage were used.

Yellowstone River at Miles City, MT

1) From 01 Oct 1897 to 30 Sep 1910, flows from the Yellowstone River at Glendive were used via a regression analysis with the Miles City gage. Small amounts of the Glendive data were filled in using daily average data for that gage.
2) From 01 Oct 1910 to 27 Aug 1928, flows from a multiple linear regression using the Miles City, Corwin Springs (+3 day shift), and Sidney (-1 day shift) gages were used. A small amount of data in 1922 and 1923 were already present in the Miles City gage data. These data were kept.
3) From 28 Aug 1928 on, gage data from Miles City were used.

Yellowstone River at Sidney, MT

1) From 01 Oct 1897 to 30 Sep 1910, flows from the Yellowstone River at Glendive (+1 day shift) were used via a regression analysis with the Sidney gage. Small amounts of the Glendive data were filled in using daily average data for that gage.
2) From 1 Oct 1910 on, the Sidney gage data were used with a few areas of missing data being filled in using the same regression as above. Additionally, a small amount of data at the end of the Sidney record were filled in using daily average values from that gage.

12 APPENDIX C – TECHNICAL MEMORANDUM FOR NWK UNREGULATED GAGE EXTENSIONS

Final Technical Memorandum

To: *Steve Spaulding, United States Army Corps of Engineers, Kansas City District*

From: *Matthew Scott*

Date: *December 21, 2012*

Subject: *Contract Number W912DQ-08-D-0048 – Task 1B.5 Spreadsheet Template Summary*

This memorandum summarizes work completed to develop a spreadsheet template which will be used by the CDM Smith Federal Programs (CDM Smith) project team to complete the gage extension analyses of Task 1B.5 of the ongoing Hydraulic Modeling and Design project. The memorandum is composed of the following sections:

- **Input Data** – a description of the input data required for the spreadsheet template;
- **Statistical Methods** – a summary of the statistical methods evaluated for the spreadsheet template development;
- **Analyses Completed** – a description of variations in the statistical methods that were evaluated to reduce prediction error and improve the accuracy of results;
- **Results** – a summary of the spreadsheet template results to extend the flow record of United States Geological Survey (USGS) Gage 06820500 - Platte River near Agency, Missouri;
- **Recommendations** – an outline of a recommended process for applying the spreadsheet template to the remaining gages with records to be extended;
- **Platte River Gage Record Extension** – a summary of the results of the recommendations as applied to the Platte River USGS gage to extend its daily average flow record.

Input Data

Input data to the spreadsheet consists of records of average daily stream flow recorded at USGS gage stations as well as the contributing drainage areas to each gage and straight-line distances between gages. The records of daily average flow include the record from the gage which is to have its record extended, referred to as the "missing-data gage" in this memorandum, as well as records from the gages to be analyzed using statistical analyses to extend the missing-data gage record, which are referred to as "surrogate gages".

A list of potential surrogate gages is created by identifying all gages within a 100 mile radius of the missing-data gage. Potential surrogate gages are not limited to the basin in which the missing-data gage was located. These gages are screened to find the ones most likely to accurately predict flows. Contributing drainage area and distances between the gages are used to screen and narrow the number of potential surrogate gages used in the Task 1B.5 gage record extension analyses. These two parameters help to identify the surrogate gages which are most similar to the missing-data gage.

Statistical Methods

Statistical methods used to extend the records of missing-data gages include linear regression and MOVE.1 analyses. Linear regression analyses are completed using logarithmically transformed flow records from missing-data and surrogate gages. The Microsoft Excel function LINEST is used to get regression output for both single and multiple surrogate gages. This data is then used to predict flows for the missing-data gage.

The procedure is calculated in the spreadsheet according to the general form of the linear regression and shown in Equation 1.
Equation **1**:**Equation 1**:

$$\hat{y}_i = a + b * x_i$$

where: $\hat{y}_i$ = logarithm of the predicted daily average flow

a = y-intercept

b = slope

x_i = i-th value of the logarithm of the flow recorded at the surrogate gage

Slope is calculated using Equation 2 (Levine, et. al. 2001) and y-intercept is calculated using Equation 3 (Levine, et. al. 2001):

Equation 2:

$$a = \frac{\sum_{i=1}^{n} x_i y_i - \frac{(\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{n}}{\sum_{i=1}^{n} {x_i}^2 - \frac{(\sum_{i=1}^{n} x_i)^2}{n}}$$

Equation 3:

$$b = \overline{y} - a * \overline{x}$$

where:

a	=	y-intercept of the linear regression equation
b	=	slope
x_i	=	logarithm of the i-th flow observation at the missing-data gage
y_i	=	logarithm of the i-th flow observation at the surrogate gage
n	=	the number of flow observations
$\overline{x}$	=	average of the logarithmically transformed observed missing-data gage flows
$\overline{y}$	=	average of the logarithmically transformed observed missing-data gage flows

The MOVE.1 procedure is calculated in the spreadsheet according to Equation 4 (Nielsen):

Equation 4:

$$\hat{y}_i = m_y + \frac{s_y}{s_x}(x_i - m_x)$$

where:

$\hat{y}_i$	=	logarithm of the predicted daily average flow
m_y	=	average of the logarithmically transformed missing-data gage flow record
s_y	=	standard deviation of the logarithmically transformed missing-data gage flow record
s_x	=	standard deviation of the logarithmically transformed surrogate gage flow record
x_i	=	logarithm of the flow recorded at the surrogate gage
m_x	=	average of the logarithmically transformed surrogate gage flow record

The spreadsheet also employs a modified MOVE.1 equation which allows it to predict flows based on records from multiple gages. The modified MOVE.1 equation is a weighted average of flows predicted by the original MOVE.1 equation for each of the individual surrogate gages, and takes the following form, shown in Equation 5:

Equation 5:

$$\hat{y}_i = \frac{\sum_{j=1}^{n}\left\{\beta_j\left[m_y + \frac{s_y}{s_{x,j}}\left(x_{i,j} - m_{x,j}\right)\right]\right\}}{\sum_{j=1}^{n}\beta_j}$$

where: $\hat{y}_i$ = logarithm of the predicted daily average flow

n = the number of surrogate gages

β_j = weighting factor for the j-th surrogate gage, as defined in Equation 6

m_y = average of the logarithmically transformed missing-data gage flow record

s_y = standard deviation of the logarithmically transformed missing-data gage flow record

$s_{x,j}$ = standard deviation of the logarithmically transformed surrogate gage flow record for the j-th surrogate gage

$x_{i,j}$ = logarithm of the flow recorded at the surrogate gage for the j-th surrogate gage

$m_{x,j}$ = average of the logarithmically transformed surrogate gage flow record for the j-th surrogate gage

The weighting factor β is dependent upon the area of the drainage area to the surrogate and missing-data gages and the straight-line distance from the surrogate gage to the missing-data gage, and is defined by Equation 6:

Equation 6:

$$\beta = \left[\left(1 - \frac{|A_g - A_s|}{A_g + A_s}\right) * \frac{1}{d}\right]$$

where:

where:	β	=	weighting factor
	A_g	=	the area of the drainage area to the missing-data gage
	A_s	=	the area of the drainage area to the surrogate gage
	d	=	the straight-line distance from the surrogate gage to the missing-data gage

The weighting factor is largest for surrogate gages which have drainage areas close to the size of the missing-data gage drainage area and are located close to the missing-data gage. As a result, the surrogate gages which are most similar to the missing-data gage are more highly weighted in the modified MOVE.1 equation.

Analyses Completed

The statistical methods were tested to find the best approach to extend gage records. To do this, a missing-data gage was chosen and the statistical methods were used to extend its gage record. The missing-data gage used was the USGS gage on the Platte River near Agency, Missouri (Site Number 06820500).

Surrogate gages were identified by first calculating the weighting factor for each gage within 100 miles of the missing-data gage using Equation 6. The gages were then sorted from largest weighting factor to smallest. Gages with the highest weighting factors which included daily flow records for the period of time to be extended at the missing-data gage were selected. A total of four surrogate gages were used for the test analysis, and Table 1 includes a list of gages used for extension of the USGS gage on the Platte River. Note that any days in which either the missing-data or surrogate gage had zero-values for daily flow were removed from the analyses, as the statistical methods use the logarithms of the daily flows. Also listed in Table 1 are the mean and standard deviation of the logarithmically transformed flow record for all gages.

Table 1. USGS Gages Used for Test Gage Record Extension

Site Number	Gage Name	Weighting Factor	Mean of Logarithmically Transformed Flow Record	Standard Deviation of Logarithmically Transformed Flow Record
Missing-Data Gage				
06820500	Platte River near Agency, MO	-	2.35	0.762
Surrogate Gages				
06897500	Grand River near Gallatin, MO	0.0201	2.40	0.765
06817000	Nodaway River at Clarinda, IA	0.0081	2.09	0.625
06809500	East Nishnabotna River at Red Oak, IA	0.0071	2.31	0.527
06898000	Thompson River at Davis City, IA	0.0070	1.93	0.772

Linear regression and MOVE.1 analyses were completed using the individual surrogate gages. In addition, these analyses were applied to four combinations of pairs of surrogate gages to predict Platte River flows, and an analysis which used three surrogate gages was also completed.

The accuracy of flows predicted by each analysis was evaluated using R-squared and error was measured using standard error. These are defined in Equation 7 and Equation 8 (Levine, et. al. 2001).

Equation 7:

$$R^2 = \frac{\sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

where:

$\hat{y}_i$ = logarithm of the predicted daily average flow

$\bar{y}$ = average of the logarithmically transformed observed flows

y_i = logarithm of i-th observed daily average flow

n = the number of surrogate gages

Equation 8:

$$\mathrm{StE} = \sqrt{\frac{\sum_{\mathrm{i}=1}^{\mathrm{n}}(\mathrm{y_i} - \hat{y}_i)^2}{\mathrm{n} - 2}}$$

where:

StE	=	standard error
y_i	=	logarithm of i-th observed daily average flow
$\hat{y}_i$	=	logarithm of the predicted daily average flow
n	=	the number of surrogate gages

Use of adjusted R-squared for multiple gage analyses of R-squared was evaluated. Adjusted R-squared, defined in Equation 9 (Levine, et. al. 2001), reflects both the number of explanatory variables and the sample size, and accounts for the tendency of R-squared to increase as the number of explanatory variables, which are surrogate gages for this analysis, increase.

Equation 9:

$$\mathrm{R}^2_{\mathrm{adj}} = 1 - \left[(1 - \mathrm{R}^2)\frac{\mathrm{p} - 1}{\mathrm{p} - \mathrm{k} - 1}\right]$$

where:

R^2_{adj}	=	adjusted R-squared
R^2	=	R-squared
p	=	number of daily average observed flows
k	=	number of surrogate gages used in multiple gage analysis

As shown in Equation 9, R-squared is reduced as the number of surrogate gages increase. However, given the large number of observations involved in the gage record extension analyses, the difference between R-squared and adjusted R-squared is not significant, as illustrated in Table 2. This table shows the percent change between R-squared and adjusted R-squared for an analysis with two surrogate gages and a series of assumed totals of data points. Two surrogate gages were assumed because R-squared and adjusted R-squared are equivalent for only one surrogate gage. For a minimum of one year of record, the largest difference between R-squared and adjusted R-squared is less than 1%. Therefore, it was concluded that use of R-squared is sufficient to evaluate correlation for multiple gage analyses.

Table 2. Adjusted R-squared Versus R-squared for Two Surrogate Gages

	R-squared:	0.9	0.8	0.7	0.6	0.5	0.4
	Number of Surrogate Gages:	2	2	2	2	2	2
Number of Data Points	Years of Data	Adjusted R-squared Percent Reduction Compared to R-squared					
365	1	0.06%	0.14%	0.24%	0.37%	0.55%	0.83%
730	2	0.03%	0.07%	0.12%	0.18%	0.28%	0.41%
1,095	3	0.02%	0.05%	0.08%	0.12%	0.18%	0.27%
1,460	4	0.02%	0.03%	0.06%	0.09%	0.14%	0.21%
1,825	5	0.01%	0.03%	0.05%	0.07%	0.11%	0.16%
2,190	6	0.01%	0.02%	0.04%	0.06%	0.09%	0.14%
2,555	7	0.01%	0.02%	0.03%	0.05%	0.08%	0.12%
2,920	8	0.01%	0.02%	0.03%	0.05%	0.07%	0.10%
3,285	9	0.01%	0.02%	0.03%	0.04%	0.06%	0.09%
3,650	10	0.01%	0.01%	0.02%	0.04%	0.05%	0.08%

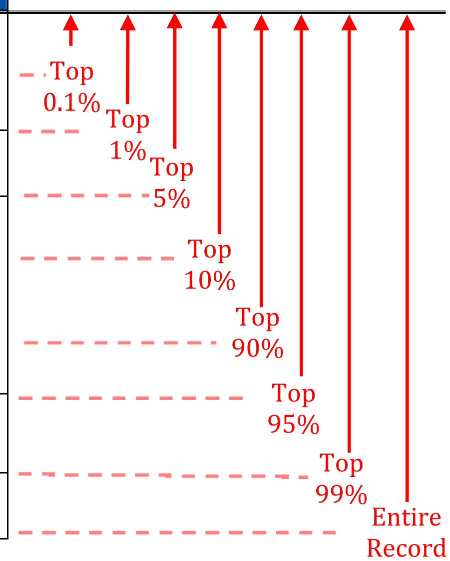
Two variations in the application of the statistical methods were also evaluated for their ability to decrease error and increase accuracy in the resulting predicted gage record. These two variations were completed for both statistical analyses using the East Nishnabotna River USGS gage record and included the following:

- **Variation 1**: Dividing the daily recorded flows at the surrogate gage by the drainage area to the 2/3 power.
- **Variation 2**: Splitting the missing-data gage flow record into seven regimes and completing linear regression and MOVE.1 procedures on each regime. To split the flow record into regimes, Platte River recorded flows were sorted from largest to smallest and assigned an exceedence probability based on a normal plotting position. Using these exceedence probabilities, flow regimes were first created by splitting the sorted record according to the seven regimes shown as Run 1 in Table 3.

  In addition, three runs were also completed in which only the flows at the highest and lowest limits of the sorted observed flow records were split into regimes. These runs are shown as Runs 2 through 4 in Table 3. The goal of these runs was to isolate the effect of extreme high and extreme low flows and to examine if linear regression or MOVE.1 analyses completed to predict these extreme flows would increase extreme flow prediction accuracy without significant loss of correlation or increase in prediction error, as measured using R-squared and standard error.

Table 3. Runs with Regimes at Highest and Lowest Limits of Sorted Observed Flow Record

<table>
<tr><th>Run 1</th><th>Run 2</th><th>Run 3</th><th>Run 4</th></tr>
<tr><td>Highest 0.1% of flows</td><td rowspan="2">Highest 1% of flows</td><td rowspan="3">Highest 5% of flows</td><td rowspan="2">Highest 1% of flows</td></tr>
<tr><td>Flows between the top 0.1% and top 1%</td></tr>
<tr><td>Flows between the top 5% and top 1%</td><td rowspan="5">Flows between the top 1% and top 99%</td><td>Flows between the top 1% and top 5%</td></tr>
<tr><td>Flows between the top 10% and top 5%</td><td rowspan="3">Flows between the top 5% and top 95%</td><td rowspan="3">Flows between the top 5% and top 95%</td></tr>
<tr><td>Flows between the top 90% and top 10%</td></tr>
<tr><td>Flows between the top 95% and top 90%</td></tr>
<tr><td rowspan="2">Flows lower than the top 95%</td><td rowspan="2">Flows lower than the top 95%</td><td>Flows between the top 95% and top 99%</td></tr>
<tr><td>Flows lower than the top 99%</td><td>Flows lower than the top 99%</td></tr>
</table>



Results

The results of the analyses were evaluated for both the accuracy and error of predicted flows by comparing observed flows at the missing-data gage against those predicted by the statistical methods. This comparison was done for the period in which data existed for the Platte River and surrogate gage records. Table 4 below shows the R-squared and standard error of the linear regression and MOVE.1 analyses.

Table 4. R-squared and Standard Error for Linear regression and MOVE.1 Analyses

Linear regression (Single Gage)			MOVE.1 (Single Gage)		
Gage	R-squared	Standard Error	Gage	R-squared	Standard Error
Grand River	0.862	0.283	Grand River	0.867	0.289
Thompson River	0.744	0.373	Thompson River	0.784	0.387
East Nishnabotna River	0.546	0.518	East Nishnabotna River	0.657	0.556
Nodaway River	0.657	0.450	Nodaway River	0.726	0.473

Table 4. R-squared and Standard Error for Linear regression and MOVE.1 Analyses (Continued)

	Linear regression (Multiple Gages)			MOVE.1 (Multiple Gage)		
	Gages	R-squared	Standard Error	Gages	R-squared	Standard Error
Two Surrogate Gage Analyses	Grand-Thompson	0.877	0.259	Grand-Thompson	0.884	0.260
	Grand-East Nishnabotna	0.884	0.262	Grand-East Nishnabotna	0.820	0.271
	Thompson-East Nishnabotna	0.751	0.368	Thompson-East Nishnabotna	0.744	0.407
	Nodaway-East Nishnabotna	0.657	0.450	Nodaway-East Nishnabotna	0.704	0.487
Three Surrogate Gage Analyses	East Nishnabotna-Thompson-Nodaway	0.759	0.362	East Nishnabotna-Thompson-Nodaway	0.749	0.405

The analyses with the highest R-squared and lowest standard error were the Grand-East Nishnabotna and Grand-Thompson multiple gage analyses, followed closely by the Grand River single gage analyses.

Using the Grand River record as the sole surrogate gage resulted in an R-squared value of between 0.86 and 0.87 and a standard error of between 0.28 and 0.29. The R-squared and standard error were not significantly increased when the Grand River record was used with the East Nishnabotna record and again with the Thompson River record. This would appear to indicate that use of a multiple gage analysis yields only incrementally more accurate predicted flows than an analysis using the single gage with the highest correlation and lowest error.

This conclusion is borne out in the remaining multiple gage analyses. Combined gage linear regression and MOVE.1 analyses were completed using the Thompson River and East Nishnabotna River records. Flows predicted by the Thompson River gage record alone had a higher R-squared and lower standard error compared to those predicted by the East Nishnabotna River alone, and their combined analyses did not yield more accurate predicted flows than the Thompson River single gage analyses.

Similarly, combined gage linear regression and MOVE.1 analyses were completed using the Nodaway River and East Nishnabotna River records. The Nodaway River single gage analysis had higher R-squared and lower standard error compared to the East Nishnabotna River, and their combined analysis did not yield more accurate predicted flows than the Nodaway River single gage analysis.

The three surrogate gage analysis also supported the conclusion that multiple gage analyses are only incrementally beneficial. The R-values of 0.759 and 0.749 for the linear regression and MOVE.1 East Nishnabotna-Thompson-Nodaway analyses were not higher than the R-values for the analyses using only the Thompson River, which had the highest single gage analysis R-values of the three surrogate gages. Standard error was not significantly reduced for the three gage analysis compared to the Thompson River single gage analysis.

Variation 1: Dividing Surrogate Record by Drainage Area to Power Less than One

Both the linear regression and MOVE.1 statistical methods were completed using the record from the gage on the East Nishnabotna River divided by the drainage area to the 2/3 power. The East Nishnabotna River gage was chosen because it had a low R-value and high standard error when used as the predictor of Platte River flows, as shown in Table 4, and increases in accuracy would be more apparent compared to a gage producing more highly accurate flow predictions.

Completion of the linear regression and MOVE.1 procedures using the East Nishnabotna River gage record divided by drainage area to the 2/3 power produced identical R-squared and standard errors to those same analyses applied to an unaltered East Nishnabotna River gage record. For the linear regression method, this result was caused by the slope of the linear regression remaining unchanged, while the y-intercept of the equation changed significantly, as shown in Table 5.

Table 5. East Nishnabotna River USGS Gage Record – Linear regression Method

Analysis Variation	Y-intercept	Slope
1A - Unaltered Record	-0.113	1.06
2A - Recorded Daily Flows Divided by Contributing Drainage Area to the 2/3 Power	1.98	1.06

The increase in y-intercept for Analysis 2A had the effect of offsetting the reductions in daily average flow caused by dividing by drainage area to the 2/3 power, and because the slope of the linear regression equation did not change, the flows predicted by the linear regression analysis were the same as in Analysis 1A. The linear regression model predicts flows based on variations in the surrogate gage daily record compared to the missing-data gage daily record, and because the surrogate gage daily flows were reduced by dividing by a single factor, these variations were proportionally preserved, and did not alter the flows predicted by the linear regression analysis.

A similar result was observed for the MOVE.1 procedure, as shown in Table 6. The mean of the logarithmically translated record decreased as a result of dividing the East Nishnabotna River flow record by drainage area to the 2/3 power for Analysis 2B. However, standard deviation of the logarithmically translated record did not change for Analysis 2B, resulting in predicted flows that were the same as those predicted by Analysis 1B.

Table 6. East Nishnabotna River USGS Gage Record - MOVE.1 Method

Analysis	East Nishnabotna River Mean of Logarithmically Translated Record	East Nishnabotna River Standard Deviation of Logarithmically Translated Record
1B - Unaltered Record	2.32	0.533
2B - Recorded Daily Flows Divided by Contributing Drainage Area to the 2/3 Power	0.352	0.533

Variation 2: Splitting Gage Record into Flow Regimes

The statistical methods were again applied to the USGS gage record at the East Nishnabotna River, and for this variation the flow record was split into the previously described flow regimes for Runs 1 through 4. The flow regimes were based on normal probability plotting positions assigned to the Platte River flows sorted from smallest to largest.

Run 1

Table 7 summarizes the linear regression analyses for each regime for Run 1.

Table 7. Daily Flows by Flow Regime

Flow Regime	Number of Data Points (Recorded Daily Flows)	Linear Regression Y-Intercept	Linear Regression Surrogate Gage (Nishnabotna River) Coefficient	R-squared	Standard Error
Top 0.1% of flows	28	4.49	0.020	0.022	0.081
Flows between the top 1% and top 0.1%	254	4.16	0.030	0.030	0.077
Flows between the top 5% and top 1%	1,127	3.73	0.050	0.031	0.135
Flows between the top 10% and top 5%	1,409	3.46	0.010	0.004	0.096
Flows between the top 90% and top 10%	22,546	0.77	0.680	0.369	0.396
Flows between the top 95% and top 90%	1,409	1.18	0.060	0.034	0.089
Flows lower than the top 95%	1,409	0.54	0.130	0.020	0.288

The LINEST Excel function was used to develop linear regression equations for each flow regime. The y-intercept and surrogate gage coefficients, as well as R-squared and standard error, for the linear regression equations for each regime are also shown in Table 7.

Because the flow regimes were created based on the Platte River record, and because there is not a direct way to determine which flow regime each daily flow would fall into for the portion of the Platte River record which is to be filled in by the analysis, methods for choosing which flow regime equation to use each day. To do this, the general linear regression and MOVE.1 equations based on the entire flow record which had been previously developed provided a general equation which could be used to sort daily flows into appropriate flow regimes. Once the appropriate flow regime was selected the flow regime-specific equations were then used to calculate the final predicted flow.

This process proved to be a significant obstacle to predicting accurate daily flows, and caused Run 1 to be less accurate than using a straightforward linear regression or MOVE.1 analysis. As shown in Table 8, use of the MOVE.1 equation with flow regimes resulted in the distribution of the predicted daily flows being skewed towards the lower flow regimes compared to the distribution of observed daily flows at the Platte River gage. Because of this, use of the MOVE.1 method for flow regimes was determined to be unusable.

The distribution of flows predicted by the linear regression analysis more closely followed the observed distribution of flows, although it tended to over-predict the number of flows in the 90 percent to 10 percent flow regime, with 92 percent of all predicted flows falling into that regime.

Table 8. Variation 2 - Run 1 Flow Regimes

Flow Regime	Number of Platte River Daily Flows	Percent of Flow Record	Number of Platte River Daily Flows Predicted by General Linear Regression Equation	Percent of Flow Record	Number of Platte River Daily Flows Predicted by General MOVE.1 Equation	Percent of Flow Record
Top 0.1% of flows	28	0.1%	7	0.02%	0	0.0%
Flows between the top 1% and top 0.1%	254	0.9%	39	0.1%	0	0.0%
Flows between the top 5% and top 1%	1,127	4.0%	316	1.1%	2	0.0%
Flows between the top 10% and top 5%	1,409	5.0%	835	3.0%	24	0.1%
Flows between the top 90% and top 10%	22,546	80%	25,922	92%	16,080	57%
Flows between the top 95% and top 90%	1,409	5.0%	988	3.5%	6,423	22.8%
Flows lower than the top 95%	1,409	5.0%	75	0.3%	5,653	20.1%

The R-squared for the linear regression analysis with Run 1 flow regimes was 0.553 and the standard error was 0.555, which does not represent an improvement in the accuracy of predicted flows compared to the results of the statistical analyses without flow regimes.

The Run 1 process was completed again using the same methodology except that flow regimes were selected based on East Nishnabotna River (surrogate gage) observed flows instead of Platte River (missing-data gage) observed flows. This resulted in an R-squared of 0.528 and standard error of 0.611 and did not represent an improvement in the accuracy of predicted flows compared to the results of the statistical analyses without flow regimes.

Runs 2, 3, and 4

Tables 9, 10 and 11 summarize the linear regression analyses for each regime for Runs 2, 3, and 4.

Table 9. Variation 2 - Run 2 Flow Regimes

Flow Regime	Number of Data Points (Daily Flows)	Linear Regression Y-Intercept	Linear Regression Surrogate Gage (Nishnabotna River) Coefficient	R-squared	Standard Error
Highest 1% of flows	282	4.08	0.0638	0.0541	0.118
Flows between the top 1% and top 99%	27,618	0.030	1.00	0.521	0.499
Flows lower than the top 99%	282	0.687	-0.286	0.0722	0.277

Table 10. Variation 2 - Run 3 Flow Regimes

Flow Regime	Number of Data Points (Daily Flows)	Linear Regression Y-Intercept	Linear Regression Surrogate Gage (Nishnabotna River) Coefficient	R-squared	Standard Error
Highest 5% of flows	1,409	3.55	0.137	0.0912	0.199
Flows between the top 5% and top 95%	25,364	0.419	0.834	0.443	0.447
Flows lower than the top 95%	1,409	0.537	0.136	0.019	0.295

Table 11. Variation 2 - Run 4 Flow Regimes

Flow Regime	Number of Data Points (Daily Flows)	Linear Regression Y-Intercept	Linear Regression Surrogate Gage (Nishnabotna River) Coefficient	R-squared	Standard Error
Highest 1% of flows	282	4.08	0.0638	0.0541	0.118
Flows between the top 1% and top 5%	1,127	3.73	0.0541	0.378	0.176
Flows between the top 5% and top 95%	25,364	0.419	0.834	0.443	0.447
Flows between the top 95% and top 99%	1,127	0.748	0.0170	0.367	0.205
Flows lower than the top 99%	282	0.687	-0.286	0.0722	0.277

Table 12 summarizes the R-squared and standard error values for each run. The East Nishnabotna observed flow record was used to choose the flow regime equation used to predict daily average flows. The flow regime equation used for each day was selected based on East Nishnabotna River flows for these runs.

Table 12. R-squared and Standard Error for All Linear Regression Flow Regime Runs

Run	R-squared	Standard Error
No Flow Regimes	0.546	0.518
Run 1	0.528	0.611
Run 2	0.511	0.519
Run 3	0.526	0.542
Run 4	0.520	0.539

The values for R-squared and standard error for the flow regime runs are comparable to those found using the general linear regression for all runs. Because Runs 2 through 4 were completed with the goal of increasing accuracy in prediction of extreme flows, the annual flow maxima predicted by each run were compared to annual flow maxima predicted by the linear regression equation without flow regimes and observed Platte River annual maxima. The annual maximum flows were assigned annual exceedence probabilities by ranking them using the normal plotting position. The results are shown in Figure 1.

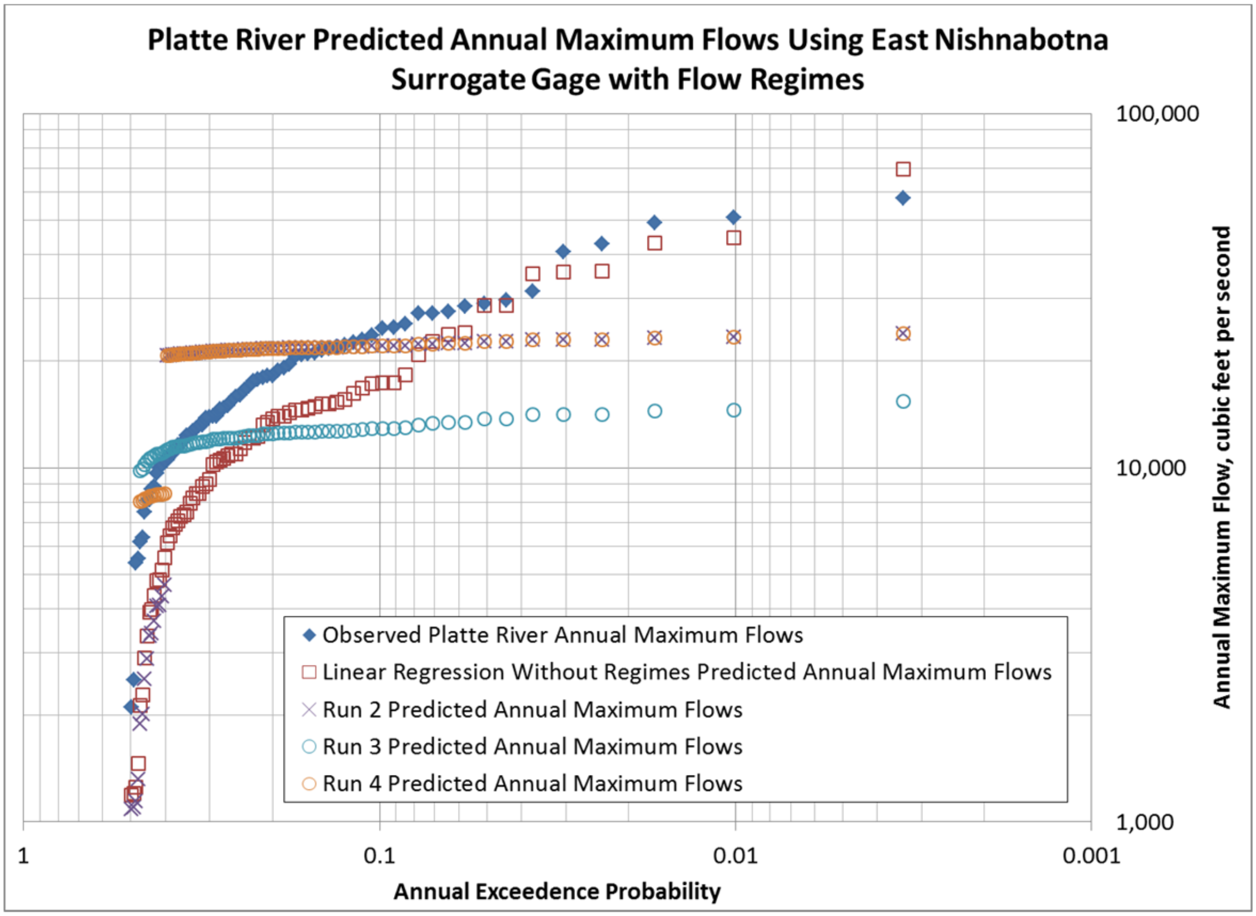


Figure 1. Lognormal Plot of Platte River Annual Flow Maxima – Observed and Runs 2, 3, and 4 Predicted Annual Maximum Flows

Note from ATR Reviewer: The labels state that they are lognormal (log-normal?) plots. They are actually log-log plots. The x axis should be recreated to represent a normal probability axis, not use a log axis. Those in the main body max out at an AEP of 0.5. This is highly unlikely for an 85 year record using a normal plotting position. Assuming "normal plotting position" means k/(n+1). I would expect the largest value to be around 0.99 as is seen in the plots in Attachment A. Additionally, all of these plots should use the same limits on the x axis to allow for easier comparison, as this is the purpose of these plots.

As shown in Figure 1, the flow regimes for Runs 2, 3, and 4 did not produce annual maximum flow results in line with observed values. This test analysis using Runs 2, 3, and 4 was completed using the East Nishnabotna linear regression analysis, which is not the most accurate compared to the other analyses completed and shown in Table 4. These runs were completed again using the most accurate analysis, the Grand-Thompson multiple gage MOVE.1 analysis, as described in Attachment B.

In addition to the Platte River gage extension analysis, Runs 2, 3, and 4 were also applied to two additional gage record extension analyses to provide additional data before conclusions were drawn with regards to their general application. These are also summarized in Attachment B.

Recommendations

Based on the previously described results, it is recommended to complete gage record extensions using single and multiple gage linear regression and MOVE.1 analyses without using either of the analysis variations. The following process, illustrated in Figure 2, is proposed to complete the remaining gage record extensions.

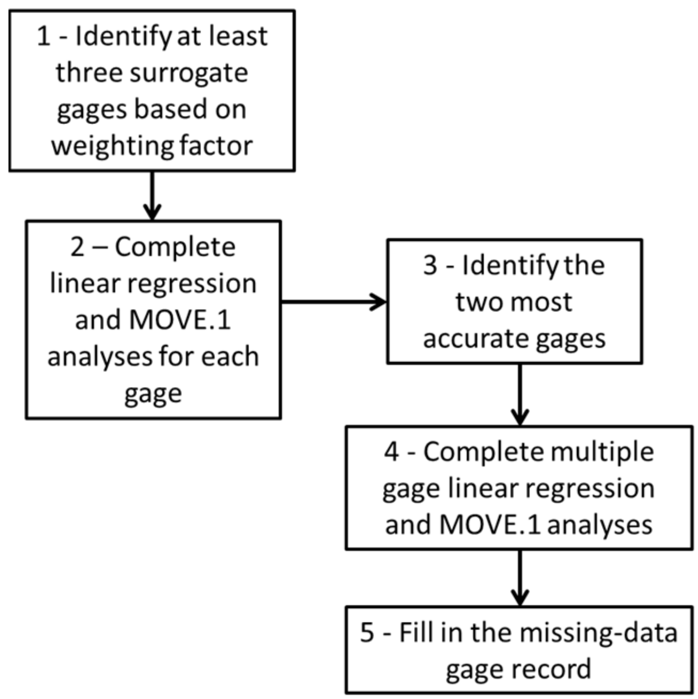


Figure 2. Proposed Gage Extension Process

- **Step 1: Identify surrogate gages**. This will be accomplished by creating a list of all USGS gages within 100 miles of the missing-data gage. Weighting factors will be calculated for each gage using Equation 3, and a total of three surrogate gages will be identified for use. These three gages will have the three highest weighting factors for gages which have an observed flow record for the dates which are to be filled in for the missing-data gage record.
- **Step 2: Complete linear regression and MOVE.1 analyses for each gage**. For each of the three surrogate gages identified in Step 1, linear regression and MOVE.1 analyses will be completed.
- **Step 3: Identify the two most accurate gages**. For each of the analyses completed in Step 2, R-squared and standard error will be calculated. The two analyses with the highest R-value and lowest standard error will be selected for Step 4.

- **Step 4: Complete multiple gage linear regression and MOVE.1 analyses**. Using the surrogate gages identified in Step 3, multiple gage analyses will be completed using linear regression and MOVE.1 procedures. These analyses will include use of the Runs 2, 3, and 4 flow regimes. R-squared and standard error will be calculated for all analyses.
- **Step 5: Fill in the missing-data gage record**. The most accurate analysis, as determined by comparing R-squared and standard error values from the analyses completed in Steps 2 and 4, will be used to fill in the missing-data gage record.

All assumptions and conclusions will be documented at all steps for each gage using a standard document, an example of which is included in Attachment A.

Platte River Gage Record Extension

All gages within 100 miles of the Platte River gage were identified and using the results report in Table 4, the Grand-Thompson MOVE.1 was chosen as the most accurate analysis. Table 13 summarizes the dates of availability of the USGS Platte River gage record and the Grand River and Thompson River surrogate gages are summarized in Table 13.

Table 13. USGS Gages Used to Extend Platte River Gage Record

Site Number	Gage Name	Range of Daily Average Flow Record Availability	Range of Daily Average Flow Record Used to Extend Platte River Record
Missing-Data Gage			
6820500	Platte River near Agency, MO	May 22, 1924 to August 10, 1930; May 12, 1932 to present	-
Surrogate Gages			
6897500	Grand River near Gallatin, MO	June 30, 1921 to present	June 30, 1921 to May 21, 1924; August 10, 1930 to May 11, 1932*
6898000	Thompson River at Davis City, IA	May 14, 1918 to present	May 14, 1918 to June 29, 1921

* - The Grand River record was used with the Thompson River record in a multiple gage MOVE.1 analysis to predict flows for these dates

Two different analyses were used to extend the Platte River gage record, as this allowed it to be extended further back in time. The Grand-Thompson multiple gage MOVE.1 analysis, which had the most accurate predicted flows of all analyses completed, was used to fill in as much of the Platte River record as possible, as shown in Table 13. The Thompson River gage record included daily average flows for back to 1918, whereas the Grand River gage record only extends back to 1921. The Thompson River single gage MOVE.1 analysis was therefore used to further extend the Platte River record backwards in time.

Monthly and Annual Volume Validation

To validate the results of the gage extension, the surrogate gage predicted records were used to calculate average monthly volumes which were then compared to average monthly volumes calculated from observed Platte River daily average flows. The period of time for this comparison included the range of daily average flow record availability for the Platte River gage record, shown in Table 13. Average monthly volume was calculated as the monthly sum of observed stream flow volume averaged over the number of months of observed Platte River flows. Table 14 summarizes the results of the comparison.

Table 14. Observed Versus Predicted Average Monthly Volumes

	Observed Platte River Flows	Predicted Platte River Flows					
Month	Average of Monthly Platte River Stream Flow Volume, ac-ft/1000	Average of Monthly Platte River Stream Flow Volume using Grand-Thompson MOVE.1 Analysis, ac-ft/1000	Difference in Volume from Observed	Percent Difference from Observed	Average of Monthly Platte River Stream Flow Volume using Thompson MOVE.1 Analysis, ac-ft/1000	Difference in Volume from Observed	Percent Difference from Observed
1	27.5	27.1	-0.4	-1.6%	26.9	-0.6	-2.2%
2	49.7	49.3	-0.4	-0.9%	48.5	-1.2	-2.5%
3	93.4	105.5	12.0	12.9%	103.6	10.1	10.9%
4	97.3	109.0	11.7	12.0%	111.5	14.2	14.6%
5	123.6	118.4	-5.2	-4.2%	123.4	-0.3	-0.2%
6	133.6	109.5	-24.1	-18.1%	117.3	-16.2	-12.2%
7	75.4	66.4	-9.0	-11.9%	70.1	-5.3	-7.0%
8	31.4	33.7	2.2	7.1%	25.8	-5.6	-17.9%
9	46.5	45.0	-1.5	-3.1%	40.3	-6.2	-13.3%
10	39.6	31.3	-8.3	-20.9%	35.3	-4.3	-10.8%
11	32.3	32.3	-0.1	-0.3%	32.3	0.0	-0.1%
12	26.6	26.6	0.0	-0.1%	28.7	2.1	8.0%
Totals:	777.1	754.0	-23.1	-	763.9	-13.3	-
Percent Difference from Observed:	-	-3.0%		-	-1.7%		-

Differences between predicted and observed monthly volumes were low for both analyses, and the Thompson MOVE.1 analysis predicted total average annual and monthly flows were found to be closest to observed values. The largest percent difference between the Thompson MOVE.1 and observed monthly volumes was -17.9% in August, and the smallest was -0.1% in November while the largest percent difference between the Grand-Thompson MOVE.1 and observed monthly volumes was -20.9% in October, and the smallest was -0.1% in December.

Differences between predicted and observed annual volumes were also low for both analyses. The percent difference between average annual flow volume observed at the Platte River gage and that predicted by the Grand-Thompson MOVE.1 analysis at 3.0%. The percent difference for the Thompson MOVE.1 analysis was 1.7%, indicating that the Thompson MOVE.1 analysis had monthly volumes closer to observed values than the Grand-Thompson MOVE.1 analysis.

The higher accuracy of predicted monthly and annual volumes by the Thompson MOVE.1 analysis compared to the Grand-Thompson MOVE.1 analysis is counterintuitive given that the Grand-Thompson MOVE.1 analysis had a higher R-squared and lower standard error. As described in Attachment B, Runs 2, 3, and 4 for Variation 2 were completed for the Grand-Thompson analysis, and these runs indicated that error in the Grand-Thompson analysis within the highest 5% of flows caused monthly volumes to be less accurate than those predicted by the Thompson River MOVE.1 analysis. This was because errors in predictions of the highest 5% of flows had a large effect on monthly volumes but did not have a correspondingly large effect on R-squared and standard error, as these parameters were calculated based on the logarithms of the predicted flows. This is illustrated in Table 15.

Table 15. Effect of Over-prediction of Logarithmically Transformed Daily Average Flows on Volume

Assumed Logarithm of Observed Daily Average Flow	Assumed Overestimated Logarithm of Predicted Daily Average Flow at 0.5	Observed Daily Flow Volume, acre-feet	Overestimated Daily Flow Volume, acre-feet	Increase in Daily Flow Volume Due to Error, acre-feet
0.5	1	6	20	14
1	1.5	20	63	43
1.5	2	63	198	136
2	2.5	198	627	429
2.5	3	627	1,983	1,356
3	3.5	1,983	6,272	4,289
3.5	4	6,272	19,835	13,562
4	4.5	19,835	62,723	42,888
4.5	5	62,723	198,347	135,624
5	5.5	198,347	627,229	428,882

The column furthest to the left in Table 15 has a series of assumed observed logarithms of daily average flows for a hypothetical stream gage. The column immediately to the right has a series of predicted logarithms of daily average flows which were assumed to have over-predicted by the observed logarithmically transformed flow by 0.5. As shown in Equations 4 and 5, the effect of this over-prediction is the same for the entire range of assumed flows. However, the amount of daily average flow which is over-predicted is not consistent for the entire range of assumed flows. Daily flow volume can be overestimated by 428,882 acre-feet when an observed logarithmically transformed flow of 5 is over-predicted by 0.5. Therefore, use of flow regimes for extreme flows can have a significant effect on monthly volume prediction accuracy.

As a result, Runs 2, 3, and 4 were completed for the Grand-Thompson MOVE.1 analysis, and Run 2 had an average annual predicted volume percent difference of 1.6% compared to average observed annual volume, which is more accurate than the Thompson MOVE.1 analysis. The effect of the Runs 2, 3, and 4 flow regimes on the Grand-Thompson MOVE.1 analysis are described further in Attachment B.

Annual Maximum Flow Distribution Validation

In addition to the monthly volume comparison, lognormal plots of observed and predicted annual maximum flow were compared. Annual flow maxima were assigned annual exceedence probabilities using normal plotting positions. As shown in Figure 3 below, Thompson-Grand MOVE.1 predicted annual maximum flows more closely follow the observed Platte River distribution and were more accurate compared to the Thompson River MOVE.1 predicted flows, which are generally higher than the observed flows.

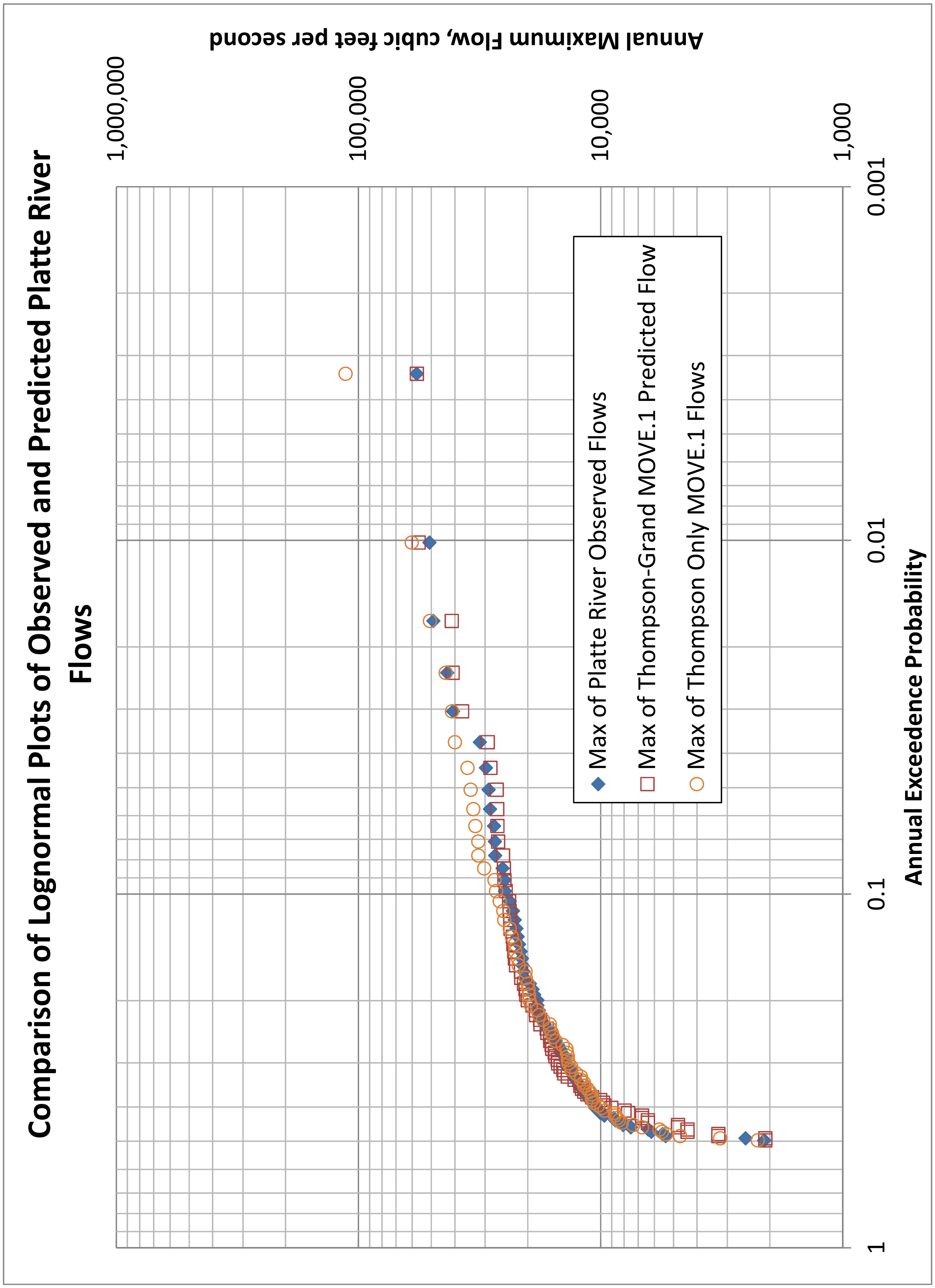


Figure 3. Lognormal Plot of Platte River Annual Flow Maxima – Observed Flows Versus Predicted Flows

Conclusions from Platte River Gage Extension Test Case

Based on the results of the Platter River gage extension test case, the recommendations were found to be feasible and able to produce accurate predictions which will meet the goals of the Missouri River model. In addition to the steps outlined in this technical memorandum, it is also recommended to complete comparisons of predicted annual volumes and annual flow maxima distributions against observed annual volumes and annual flow maxima distributions. This will provide a means to evaluate whether Runs 2, 3, or 4 should be used to produce more accurate monthly volumes and annual flow maxima.

References

Levine, David M., Ramsey, Patricia P., and Smidt, Robert K. (2001). “Applied Statistics for Engineers and Scientists”. Prentice Hall, Inc. Upper Saddle River, New Jersey.

Nielsen, Joseph P. “Record Extension and Stream flow Statistics for the Pleasant River, Maine”. *Report USGS*. <http://me.water.usgs.gov/reports/finalreport.pdf> (November 12, 2012)

Attachment A

Standard Gage Extension Analysis Documentation of Assumptions Form

Hydraulic Modeling and Design
Contract No. W912DQ-080D-0048
Task 1B.5
Extend Records of USGS Observed Daily Flow Data Back to 1898
Documentation of Assumptions

USGS Gage Record to be Extended: ____________________

Available Average Daily Flow Data: ____________ years

Dates to be Filled by Analysis: ____________________

Step 1: Identify Three Surrogate Gages

Name	ID	Weighting Factor	Data concurrent with missing gage
			years
			years
			years

Step 2: Complete Regression and MOVE.1 Analyses for each Gage

Regression	R-squared	Standard Error		MOVE.1	R-squared	Standard Error

Step 3: Identify the Two Most Accurate Gages

Step 4: Complete Multiple Gage Regression and MOVE.1 Analyses

Regression	R-squared	Standard Error		MOVE.1	R-squared	Standard Error

Step 5: Check Extreme Flow Regimes

Use XXXX Gage to check extreme flow regimes	Run	R-squared	Standard Error
	2: 1% Extreme Flow Regimes		
	3: 5% Extreme Flow Regimes		
	4: 5% with 1% Extreme Flow Regimes		

Step 6: Check Annual Flow Volumes and Annual Flow Maxima Distributions

-Most accurate annual flow volume predicted by XXXX -Most accurate annual maximum flow distribution predicted by XXXX	Run	Percent Difference
	MOVE.1	
	Run 2	
	Run 3	
	Run 4	

Step 7: Fill in Missing-Data Gage Record

Attachment B

Further Analysis of Runs 2, 3, and 4

The gage extension analysis process, as defined in the main body of the memorandum, was applied at two gages in addition to the USGS gage at the Platte River near Agency, Missouri. These included the gages at the Marais des Cygnes River near Reading, Kansas (Gage ID 06910800) and at the Chariton River near Chariton, Iowa (ID 06903400). The R-squared and standard error for all three analyses are included in the following Documentation of Assumptions forms, which were completed for each analysis. These include Runs 2, 3, and 4, which were completed using the analysis which had the highest R-squared and lowest standard error.

The goal of these additional analyses was to evaluate if one of the runs consistently produced more accurate results than the others. Accuracy was evaluated by comparing the average annual flow volumes and annual maximum flow distributions predicted by the analysis to observed values. Differences in average annual flow volumes were evaluated as a percent difference from observed volumes, and annual flow maxima distributions were evaluated using plots of the distributions. These plots are included in addition to the Documentation of Assumptions forms.

As shown in the Documentation of Assumptions forms and plots of annual flow maxima distributions,

- For the Platte River gage, the Run 4 analysis produced the most accurate average annual volumes while the annual flow maximum distribution was best predicted by the analysis without extreme flow regimes;
- For the Marais des Cygnes gage, the Run 3 analysis produced the most accurate average annual volumes while the annual flow maximum distribution was best predicted by the Run 2 analysis;
- And for the Chariton River gage, the analysis without flow regimes produced the most accurate average annual volumes while the annual flow maximum distribution was best predicted by the Run 2 analysis.

These results indicate that no single run would provide the most accurate results at each gage, and that all three runs should be completed and evaluated for each gage extension analysis. Where a single run analysis produced the most accurate annual flow volume and annual maximum flow distribution, it will be used to extend the gage record. Where different analyses produce the most accurate annual flow volume and annual maximum flow distribution, the analysis producing the most accurate annual flow volume will be used.

Hydraulic Modeling and Design
Contract No. W912DQ-080D-0048
Task 1B.5
Extend Records of USGS Observed Daily Flow Data Back to 1898
Documentation of Assumptions

USGS Gage Record to be Extended: Platte River near Agency, MO-06820500

Available Average Daily Flow Data: 5/22/1924-8/10/1930; 5/12/1932-present 85 years

Dates to be Filled by Analysis: 10/1/1919-5/11/1932

Step 1: Identify Three Surrogate Gages*

Name	ID	Weighting Factor	Data concurrent with missing gage
Grand River near Gallatin, MO	06897500	0.0201	
- Record includes 6/30/1921 to present			85 years
Nodaway River at Clarinda, IA	06817000	0.0081	
- Record includes 5/17/1918-present; missing 362 days b/w 1918 & 1921			85 years
East Nishnabotna River at Red Oak, IA	06809500	0.0071	
- Record includes 5/17/1918 to present			85 years
Thompson River at Davis City, IA	06898000	0.00703	
- Record includes 5/14/1918 to present			85 years

* - Four surrogate gages were used for this gage extension analysis because it was used as a test run to evaluate the gage extension process for all future analyses.

Step 2: Complete Regression and MOVE.1 Analyses for each Gage

Regression	R-squared	Standard Error		MOVE.1	R-squared	Standard Error
Grand River	0.862	0.283		Grand River	0.875	0.289
Nodaway River	0.657	0.45		Nodaway River	0.725	0.473
East Nishnabotna River	0.545	0.518		East Nishnabotna River	0.657	0.556
Thompson River	0.784	0.387		Thompson River	0.743	0.373

Step 3: Identify the Two Most Accurate Gages

Grand River near Gallatin, MO-06897500
Thompson River at Davis City, IA-06898000

Step 4: Complete Multiple Gage Regression and MOVE.1 Analyses

Regression	R-squared	Standard Error		MOVE.1	R-squared	Standard Error
Grand-Thompson	0.877	0.258		Grand-Thompson	0.884	0.26

Step 5: Check Extreme Flow Regimes

Use Grand-Thompson MOVE.1 to check extreme flow regimes

Run	R-squared	Standard Error
2: 1% Extreme Flow Regimes	0.883	0.261
3: 5% Extreme Flow Regimes	0.879	0.262
4: 5% with 1% Extreme Flow Regimes	0.881	0.261

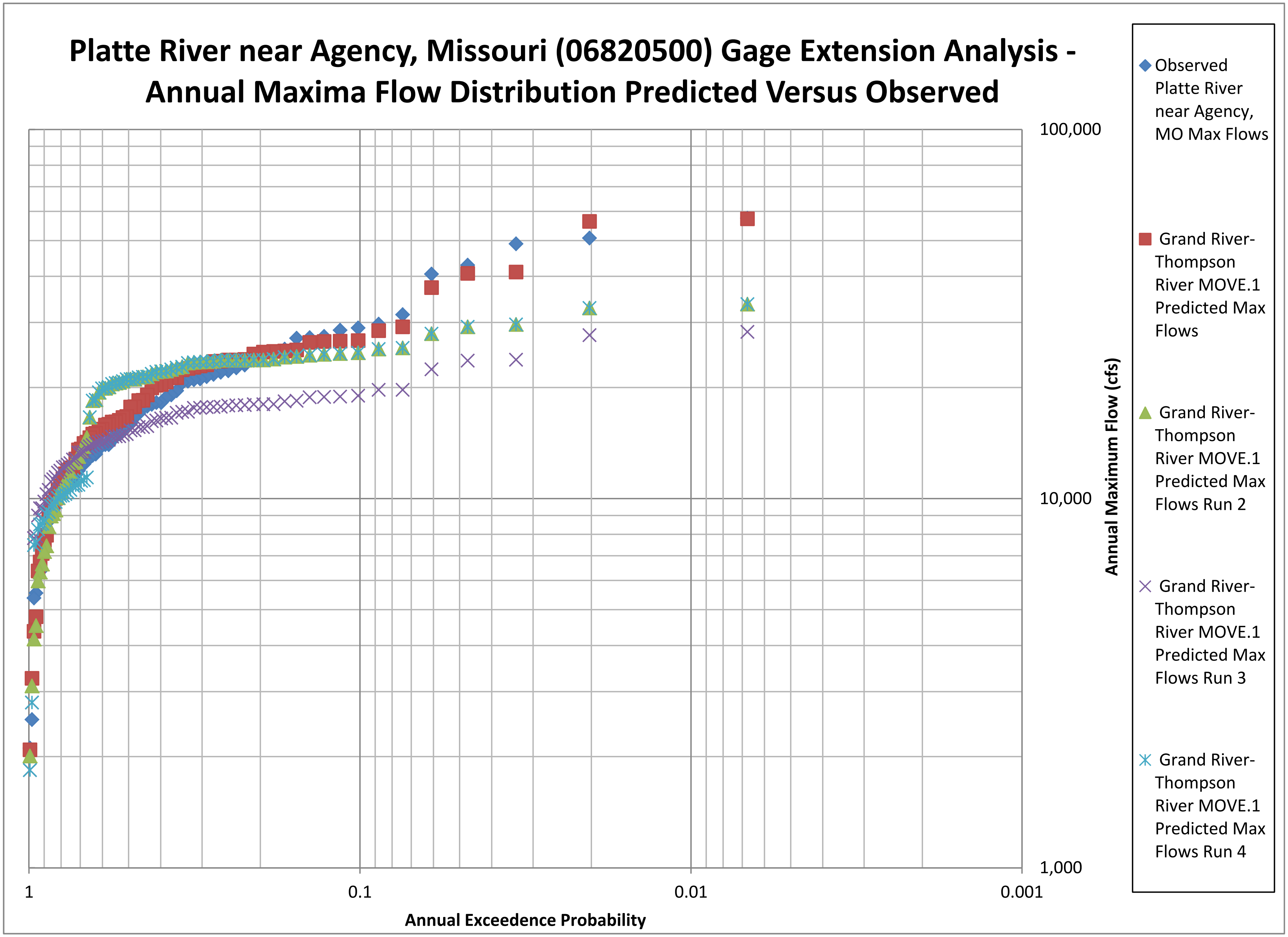
Step 6: Check Annual Flow Volumes and Annual Flow Maxima Distributions

-Most accurate annual flow volume predicted by Run 4 MOVE.1
-Most accurate annual maximum flow distribution predicted by MOVE.1

Run	Percent Difference
MOVE.1	-1.71%
Run 2	-3.00%
Run 3	-1.59%
Run 4	0.29%

Step 7: Fill in Missing-Data Gage Record

Use Grand-Thompson Regression to fill in record from 10/1/1919-5/22/1924. The Grand River was a good predictor, however period of record is not sufficient. Use Thompson River Regression to extend from 10/1/1919-5/22/1924.



Platte River near Agency, Missouri (06820500) Gage Extension Analysis - Annual Maxima Flow Distribution Predicted Versus Observed
100,000
10,000
1,000
Annual Maximum Flow (cfs)
1
0.1
0.01
0.001
Annual Exceedence Probability
Observed Platte River near Agency, MO Max Flows
Grand River-Thompson River MOVE.1 Predicted Max Flows
Grand River-Thompson River MOVE.1 Predicted Max Flows Run 2
Grand River-Thompson River MOVE.1 Predicted Max Flows Run 3
Grand River-Thompson River MOVE.1 Predicted Max Flows Run 4

USGS Gage Record to be Extended:	Marais des Cygnes River near Reading, KS-06910800	
Available Average Daily Flow Data:	5/15/1969-present	43 years
Dates to be Filled by Analysis:	10/1/1930-5/15/1969	

Step 1: Identify Three Surrogate Gages

Name	ID	Weighting Factor	Data concurrent with missing gage
Soldier Creek near Topeka, KS	06889500	0.0195	
- Record includes 5/3/1929-10/1/1932, 7/26/1935-present			43 years
Stranger Creek near Tonganoxie, KS	06892000	0.0095	
- Record includes 4/29/1929 - present			43 years
Little Arkansas River at Valley Center, KS	07144200	0.0025	
6/10/1922-present			43 years

Step 2: Complete Regression and MOVE.1 Analyses for each Gage

Regression	R-squared	Standard Error	MOVE.1	R-squared	Standard Error
Soldier Creek	0.561	0.675	Soldier Creek	0.666	0.722
Stranger Creek	0.543	0.689	Stranger Creek	0.655	0.739
L. Arkansas River	0.367	0.81	L. Arkansas River	0.56	0.905

Step 3: Identify the Two Most Accurate Gages

Soldier Creek near Topeka, KS-06889500
Stranger Creek near Tonganoxie, KS-06892000

Step 4: Complete Multiple Gage Regression and MOVE.1 Analyses

Regression	R-squared	Standard Error	MOVE.1	R-squared	Standard Error
Soldier-Stranger	0.596	0.647	Soldier-Stranger	0.679	0.68

Step 5: Check Extreme Flow Regimes

Use Soldier-Stranger Gage to check extreme flow regimes

Run	R-squared	Standard Error
2: 1% Extreme Flow Regimes	0.668	0.669
3: 5% Extreme Flow Regimes	0.632	0.663
4: 5% with 1% Extreme Flow Regimes	0.630	0.661

Step 6: Check Annual Flow Volumes and Annual Flow Maxima Distributions

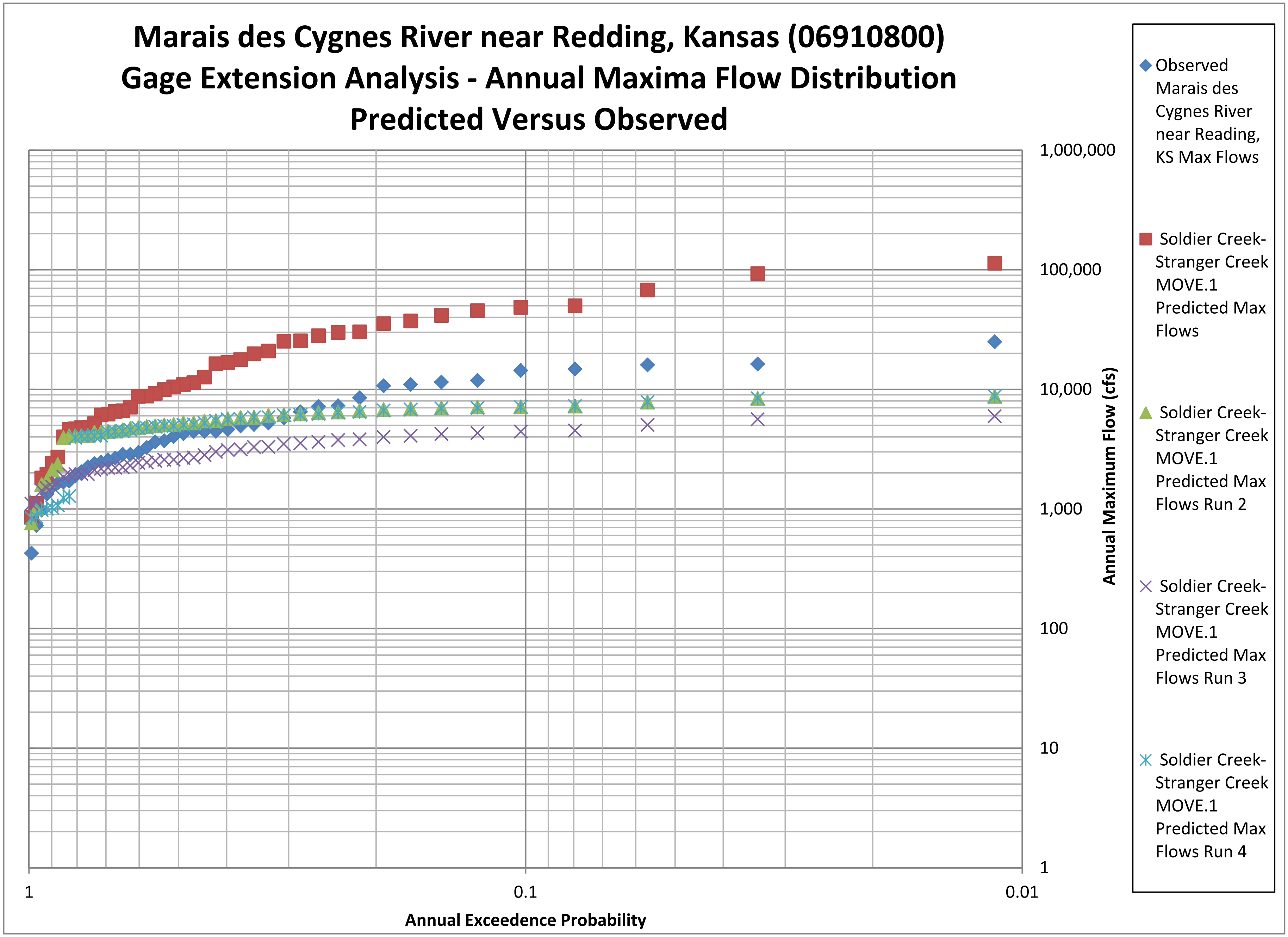
-Most accurate annual flow volume predicted by Run 3 MOVE.1

-Most accurate annual maximum flow distribution predicted by Run 2 MOVE.1

Run	Percent Difference
MOVE.1	129.33%
Run 2	41.93%
Run 3	8.61%
Run 4	19.25%

Step 7: Fill in Missing-Data Gage Record

Use Soldier-Stranger Run 3 MOVE.1 to fill in record from 10/1/1930-5/15/1969.


Marais des Cygnes River near Redding, Kansas (06910800)
Gage Extension Analysis - Annual Maxima Flow Distribution
Predicted Versus Observed
1,000,000
100,000
10,000
1,000
100
10
1
Annual Maximum Flow (cfs)
1
0.1
0.01
Annual Exceedence Probability
Observed Marais des Cygnes River near Reading, KS Max Flows
Soldier Creek-Stranger Creek MOVE.1 Predicted Max Flows
Soldier Creek-Stranger Creek MOVE.1 Predicted Max Flows Run 2
Soldier Creek-Stranger Creek MOVE.1 Predicted Max Flows Run 3
Soldier Creek-Stranger Creek MOVE.1 Predicted Max Flows Run 4

Hydraulic Modeling and Design
Contract No. W912DQ-080D-0048
Task 1B.5
Extend Records of USGS Observed Daily Flow Data Back to 1898
Documentation of Assumptions

USGS Gage Record to be Extended:	Chariton River near Chariton, Iowa-06903400	
Available Average Daily Flow Data:	10/1/1965 - 10/1/2012	47 years
Dates to be Filled by Analysis:	10/1/1930 - 10/1/1956	

Step 1: Identify Three Surrogate Gages

Name	ID	Weighting Factor	Data concurrent with missing gage
East Fork Big Creek near Bethany, MO	06897000	0.0113	
- Record includes 4/1/1934-10/1/1972; 10/1/1996-10/1/1999; 10/1/2000-10/1/2012			22 years
Locust Creek near Linneus, MO	06901500	0.0068	
- Record includes 4/1/1929-10/1/2012			47 years
Thompson River at Trenton, MO	06899500	0.00299	
- Record includes 8/1/1928-10/1/2012			47 years

Step 2: Complete Regression and MOVE.1 Analyses for each Gage

Regression	R-squared	Standard Error
East Fork Big Creek	0.630	0.617
Locust Creek	0.652	0.642
Thompson River	0.754	0.521

MOVE.1	R-squared	Standard Error
East Fork Big Creek	0.708	0.651
Locust Creek	0.722	0.676
Thompson River	0.791	0.54

Step 3: Identify the Two Most Accurate Gages

Locust Creek near Linneus, MO - 06901500
Thompson River at Trenton, MO - 06899500

Step 4: Complete Multiple Gage Regression and MOVE.1 Analyses

Regression	R-squared	Standard Error
Locust-Thompson	0.767	0.526

MOVE.1	R-squared	Standard Error
Locust-Thompson	0.762	0.592

Step 5: Check Extreme Flow Regimes

Use Locust Creek MOVE.1 to check extreme flow regimes - Thompson River MOVE.1 analysis had highest R-squared and lowest standard error but did not predict average annual volumes within 10% of observed volumes

Run	R-squared	Standard Error
2: 1% Extreme Flow Regimes	0.779	0.552
3: 5% Extreme Flow Regimes	0.760	0.540
4: 5% with 1% Extreme Flow Regimes	0.757	0.537

Step 6: Check Annual Flow Volumes and Annual Flow Maxima Distributions

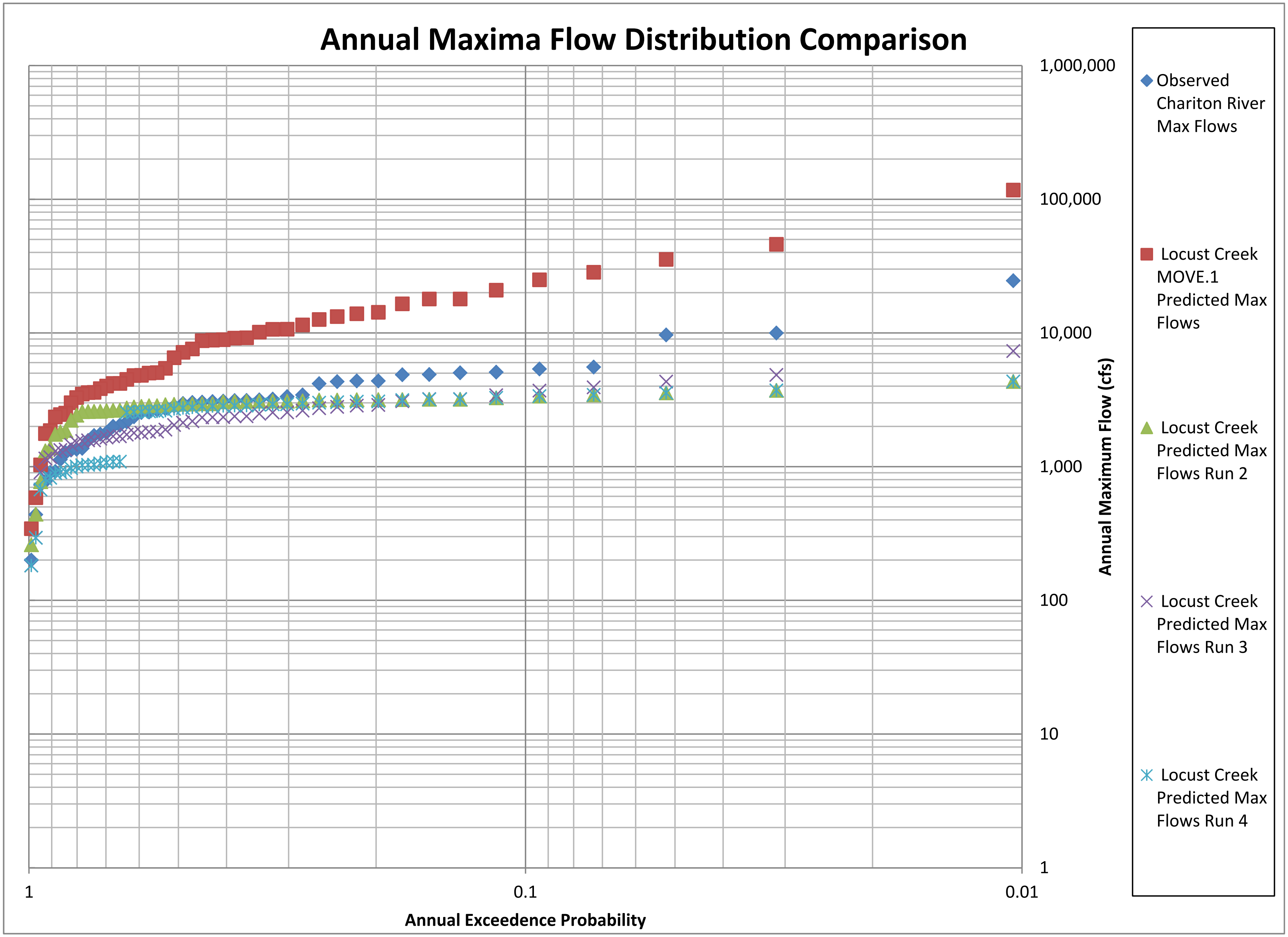
-Most accurate annual flow volume predicted by Thompson River MOVE.1

-Most accurate annual maximum flow distribution predicted by Run 3 MOVE.1

Run	Percent Difference
MOVE.1	110.76%
Run 2	14.19%
Run 3	-7.78%
Run 4	-15.59%

Step 7: Fill in Missing-Data Gage Record

Use Thompson River MOVE.1 Run 2 to fill in record from 10/1/1930 - 10/1/1956.


Annual Maxima Flow Distribution Comparison
1,000,000
100,000
10,000
1,000
100
10
1
Annual Maximum Flow (cfs)
1
0.1
0.01
Annual Exceedence Probability
Observed Chariton River Max Flows
Locust Creek MOVE.1 Predicted Max Flows
Locust Creek Predicted Max Flows Run 2
Locust Creek Predicted Max Flows Run 3
Locust Creek Predicted Max Flows Run 4